Guiding Principles on mixing in the management of radioactive wastes

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Preface

This report has been prepared by Eden NE under contract to the Nuclear Decommissioning Authority (NDA). The views expressed and conclusions drawn are those of the authors and do not necessarily represent those of NDA.

Conditions of publication

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Acronyms

BAT	Best Available Techniques
GDF	Geological Disposal Facility
HAW	Higher Activity Waste
HLW	High Level Waste
ILW	Intermediate Level waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository
NDA	Nuclear Decommissioning Authority
REPS	Radioactive Substances Regulation Environmental Principles
SAPS	Safety Assessment Principles
WAC	Waste Acceptance Criteria

Summary

This document describes guiding principles on mixing in the management of radioactive wastes. It seeks to establish acceptable practices based on industry experience to date benchmarked against current policy, regulatory and strategic drivers and constraints. The principles are illustrated with examples and considered through a series of case studies.

The guiding principles seek to provide a foundation for the development of consistent, acceptable radioactive waste mixing practices and provide an underlying basis for judgements. They provide a systematic and common framework to assist planning and ensure consistent decision making that aligns with optimised waste management plans and practices. They are designed to be consistent and align with relevant policy, strategy and regulation. The principles do not replace or remove the regulatory and legislative requirements on duty holders.

They have been developed using a consultative approach and building on a review and consideration of current practices within the UK nuclear industry. The project has also systematically reviewed the use of the terms “blending”, “mixing”, “dilution” and “averaging” in both UK and selected international regulatory, policy, strategy and guidance documents. Perceptions of these terms, and the impact that such perceptions have on waste management decisions, have been sought from nuclear sector representatives.

The following guiding principles are identified:

- PRINCIPLE 1: Government policy and strategy alignment

Radioactive wastes should only be mixed where this enables onward waste management and disposal consistent with government policy.

- PRINCIPLE 2: Ensuring an optimised approach

***Mixing* should only be undertaken where it is a necessary part of a waste management approach that is demonstrated to be optimised.**

Options involving waste *mixing* must consider the impacts through the waste lifecycle.

- PRINCIPLE 3: Regulatory compliance

***Mixing* of radioactive wastes must be in compliance with the regulations and consistent with relevant regulatory guidance.**

***Mixing* purely to achieve *dilution to* below Out of Scope or Exemption levels is prohibited, unless the activity has been authorised by the relevant environment agency.**

- PRINCIPLE 4: Compliance with waste acceptance criteria

***Mixing* of radioactive wastes should only be undertaken where this results in consignments that comply with the WAC of the receiving facility.**

The *average* activity concentration within a mixed waste consignment should be suitably representative of the waste.

The activity distribution across a mixed waste consignment must be consistent with any requirements on heterogeneity as specified in the WAC.

- PRINCIPLE 5: Physical and chemical compatibility of mixed wastes

Mixing of wastes that are physically and/or chemically incompatible should be avoided where this results in outcomes that are contrary to safe management and disposal.

- PRINCIPLE 6: Mixing and waste conditioning

Dilution is an acceptable consequence of waste conditioning, so long as the conditioning approach achieves a necessary safety outcome and the approach is optimised to ensure that conditioned waste volumes are minimised.

Each principle is illustrated with examples. The principles are also used to assess a number of illustrative case studies.

These guiding principles, together with the associated examples and case studies, are intended to promote increased confidence and consistency across the nuclear industry in activities, treatments and processes involving the mixing of radioactive waste. Through provision of these guiding principles, NDA seeks to enable opportunities for optimised waste management to be realised, both by waste producers and disposal site operators.

1. Introduction

1.1 Background

The Nuclear Decommissioning Authority (NDA) identified a need to develop a set of principles that can be applied to establish consistent, optimised and compliant approaches to the mixing of radioactive wastes. This aligns with NDA's mission "to deliver safe, sustainable solutions to the challenge of nuclear clean-up and waste management."

Radioactive waste streams are rarely homogenous, and often contain different levels of radioactivity across a given waste volume and/or the waste stream as a whole[1]. To illustrate this the outer layer of a surface contaminated item could be considered ILW if only the contaminated surface layer is considered (e.g. at the mm^3 scale) whilst the item in totality is LLW when the activity is averaged over its entire volume (scale of dm^3). Combining different radioactive wastes, and including non-radioactive materials, affects concentrations of radioactivity within the waste and should have the overall objective of managing radioactive wastes effectively, in ways that are safe and ensure protection of people and the environment.

There is an inevitable element of subjectivity to the acceptability of mixing during radioactive waste management. This is because policy, strategy, regulation and relevant waste acceptance criteria are, to varying degrees, often goal setting rather than prescriptive. These guiding principles are intended to help in making decisions and judgments over what is acceptable, whilst noting that some aspects may be contentious and require case-by-case consideration. The development of these principles responds to a perceived need to provide clarity and enable a more consistent approach across the NDA, their Site Licence Companies (SLCs) and non-NDA sites. Overall, it is intended to promote compliant and optimised outcomes for radioactive waste.

1.2 Aims

This document provides guiding principles on mixing[2] in the management of radioactive wastes. It seeks to identify acceptable practices based on industry practice to date benchmarked against current policy, regulatory and strategic drivers and constraints. The principles are illustrated with examples and considered through a series of case studies.

[1] Wastes that are managed and disposed in liquid or gaseous form are not considered further here as such aspects are considered routine. Mixing and immobilisation of liquid wastes to yield solid, conditioned waste products is within the scope of these principles.

[2] Mixing in this context also encompasses dilution, blending and averaging of radioactive waste, although each of these terms is defined separately within the report (Section 2).

The principles are intended to promote increased confidence and consistency across the nuclear industry surrounding activities, treatment and processes involving the mixing of radioactive waste. Through provision of guiding principles NDA seeks to enable opportunities for optimised waste management to be realised, both by waste producers and disposal site operators.

1.3 Scope and limitations

These guiding principles have been developed with inputs from UK nuclear industry representatives, including waste producers, disposal site operators and the NDA. Industry regulators[3] have been consulted in the course of this work and have commented on the guiding principles at the drafting stage.

The principles are intended to provide a systematic and common framework to help ensure optimised waste management plans and practices. They are provided as advice only. Clearly, they are not intended to remove or replace the onus on waste producers and waste disposal organisations to ensure regulatory compliance, including requirements to demonstrate optimised waste management and disposal on a case-by-case basis.

1.4 Development

The guiding principles have been developed using a consultative approach and building on a review and consideration of current practices within the UK nuclear industry. The work has also systematically reviewed the use of the terms “blending”, “mixing”, “dilution” and “averaging” in both UK and selected international regulatory, policy, strategy and guidance documents. Perceptions of these terms, and the impact that such perceptions have on waste management decisions, have been sought from nuclear sector representatives.

Consultation has involved a questionnaire approach with follow-up discussions. In particular, the project team has sought examples of both acceptable and unacceptable use of blending, mixing, dilution and averaging, with specific interest in examples that cause disagreement, either internally within organisations or between organisations.

A workshop with interested stakeholders was held to discuss the outcomes of the initial consultation and a number of case studies involving “blending”, “mixing”, “dilution” and “averaging” were developed. The guiding principles and case studies within this document were then drafted. A further workshop then sought agreement on the guiding principles, which were then revised, reviewed, finalised and issued.

The guiding principles reflect the current policy, strategy and regulatory landscape at the time of publication. They will require further consideration and updating in response to any relevant changes that would impact validity.

[3] The project team actively engaged with the Environment Agency and the Office for Nuclear Regulation in the course of this work. Representatives from these regulatory bodies participated in a project workshop in which the draft principles were considered.

1.5 Structure

This document provides the following:

- *Section 2: Definitions of key terms* – provides definitions of key terms that are used throughout.
- *Section 3: Guiding principles* – provides the guiding principles with supporting discussion of the basis of each and illustrative examples of acceptable and unacceptable practices.
- *Section 4: Industry practice* – an overview of relevant industry practices.
- *Section 5: Summary and next steps* – summarises the document and notes requirement to maintain and update.
- *Section 6: References* – provides a list of references, as quoted throughout.
- *Appendix 1: Relevant policy, strategy and regulation* - provides an overview of the most relevant policy, strategy and regulation.
- *Appendix 2: Case Studies* – provides cases studies that are discussed in the context of the guiding principles to exemplify how decisions on acceptability (or not) are reached against these exemplars, some of which are complex, marginal cases that have proved contentious.

2. Definition of key terms

The following definitions are consistent with the guiding principles outlined in Section 3. Where subsequently used each term is italicised to imply that a formal definition has been provided.

Averaging	An average can be defined as “a number expressing the central or typical value in a set of data, in particular the mode, median, or (most commonly) the mean, which is calculated by dividing the sum of the values in the set by their number” In the context of radioactive waste, averaging is the process of determining a suitable representative activity concentration for the waste, typically for comparison against a predefined waste acceptance criterion such as a limit on the specific activity concentration (e.g. Bq/g). In terms of radioactive waste management, averaging may involve: • Summing up the activity of a number of similar wastes (for example, drums or other discrete items), then dividing by the total mass or volume of all of these wastes to obtain a representative activity concentration for these wastes as a single consignment (or sentencing volume). • Applying a derived fingerprint to a population of wastes. The fingerprint being based on average isotopic ratios and radionuclide distributions for the component waste streams as a whole. • Deriving an activity concentration for wastes based on an assumed or derived penetration depth of the radioactive contamination into the waste. Depending on the situation, some of these methods will be more accurate and effective than others.
Blending	Blending is a type of mixing, where the mixing process is irreversible. Blending is physically mixing two or more compatible wastes to create a product with a relatively uniform chemical or physical property that aligns with a target value or range. The desired properties may be, for example, an activity concentration or chemical composition that ensures compatibility with onward management or disposal routes.
Co-disposal	Co-disposal is combining different waste streams or an assemblage of discrete solid items in a disposal consignment.

	This results in a mixed waste consignment, although the component wastes may or may not be fully mixed within it.
Conditioning	Conditioning of radioactive wastes refers to the operation that transforms radioactive waste into a safe form for transport, storage and/or disposal. Steps in conditioning may include some or all of the following stages: waste pretreatments (such as drying), the conversion of the waste to a solid wasteform and enclosure of the waste in containers. The package may also be overpacked, if necessary.
Co-processing	Co-processing involves different waste streams being processed in combination for a treatment or conditioning process. Mixing may occur during co-processing.
Dilution	For the purposes of this project, dilution is the act of combining non-radioactive or radioactive waste or materials of different activity concentrations such that the activity concentration of the combined waste or material product is less than the maximum activity concentration of the initial inputs assuming the activity concentrations of the inputs and the outputs are calculated over the same representative volume or mass. Any activity, treatment or process that combines wastes of different activity concentrations or adds non-radioactive material or waste to radioactive waste will result in dilution. Dilution may occur as a result of packaging, blending, mixing, immobilisation in an encapsulating medium, co-processing or co-disposal.
Mixing	Radioactive waste or materials shall be considered to have been mixed if they have been combined with — (a) different radioactive materials or waste; (b) non-radiologically contaminated materials or waste; or (c) any other substance or material. Mixing may occur at various times during the waste lifecycle, including during accumulation and upon retrieval. Mixing may be such as to ensure complete homogeneity, as in a fully mixed liquid that is homogeneous at the molecular scale, or may result in a heterogeneous product, such as an assemblage of discrete solid items. The extent of

	heterogeneity in a mixed waste may be a specific consideration in waste acceptance criteria.
Waste segregation	An activity in which different types of waste within a mixed waste are separated or are kept separate during accumulation on the basis of radiological, chemical and/or physical properties. This is undertaken to facilitate the optimised waste management and disposal of the separated components of a mixture. Selectively separating out components of a mixed waste stream (i.e. segregation) essentially unmixes parts of the waste.
Waste streams	A collection of waste items at a particular site, usually in a particular facility or from particular processes or operations. It is often distinguishable by its radionuclide content and in many cases also by common physical and chemical characteristics.

3. Guiding principles

The following principles are a foundation for the development of consistent, acceptable radioactive waste mixing practices and provide an underlying basis for judgements. They provide a systematic and common framework to assist planning and ensure consistent decision making that aligns with optimised waste management plans and practices. They are designed to be consistent with, and ensure alignment with relevant policy, strategy and regulation (Appendix 1)

Examples of acceptable and unacceptable practices are provided to illustrate the concepts. More detailed case studies (Appendix 2) are considered in the context of the guiding principles to illustrate the relevant considerations.

1.6 PRINCIPLE 1: Government policy and strategy alignment

Radioactive wastes should only be mixed where this enables onward waste management and disposal consistent with government policy.

Mixing of radioactive waste should only be undertaken where this enables outcomes that are consistent with the relevant government radioactive waste management policy at that time[4] (see Appendix 1: Relevant policy, strategy and regulation). Aspects of current policy that are most relevant to mixing include:

- management of wastes using a lifecycle approach, which will help identify the most appropriate waste management route determined by the risk posed by the waste;
- risk-informed management of waste through to disposal using routes that are specified in policy statements and which align with waste categories;
- the intent to ensure minimisation of waste arisings.

Relevant considerations include:

- It is important to evaluate whether the wastes (prior to *mixing*) would be more appropriately managed and disposed individually via separate routes to ensure consistency with policy. For example, it is appropriate to route LLW consignments to the LLWR, but not so for those consignments that include substantial quantities of waste containing long-lived radionuclides that would not be deemed suitable for disposal in near surface facilities.
- In some cases it may be necessary to consider wider policy drivers and to seek to balance these. For example, the policy presumption towards early solutions to waste management may be enabled by allowing small quantities of HAW to an overall LLW waste consignment in order to facilitate early disposal, where this is acceptable within an overall consignment and particularly so for wastes at the LLW / ILW boundary. This may be considered appropriate where the outcome is compliant with other requirements (such as the disposal facility *WAC* and the supporting facility

[4] Relevant policy statements issued by UK Government and Devolved Administrations.

safety case) and where this can be shown to facilitate an optimised and risk-informed approach overall[5]. Early dialogue between consignor and consignee is recommended to establish if this is an acceptable approach in specific cases.

Acceptable example: Segregation of a mixed waste stream

A mixed radioactive waste stream is segregated on site (in England) in a suitably designed waste sorting and segregation facility. Low level wastes are disposed to the LLWR or via appropriate LLW diversion routes, including metals sent for recycling and combustible wastes sent for incineration. Higher activity waste components are separated, conditioned and stored pending geological disposal. This is consistent with routes specified in relevant policy statements.

Unacceptable example: ILW purposefully consigned with LLW

Waste items arise in routine operations as segregated ILW that are stored on nuclear sites in England. Following conditioning for disposal, their levels of radioactivity remain significantly in excess of LLW activity criteria (for disposal to LLWR), i.e. they are not borderline wastes. There are secure storage facilities for the ILW items on the sites at which they arise. These ILW items could be mixed with lower activity LLW for co-disposal at LLWR in consignments that meet LLWR specific activity limits overall. However, this is contrary to the current long-term management policy of the UK government, which is to package and hold HAW[6] in secure interim storage until they can be transferred to a GDF.

[5] UK Government and Devolved Administrations, UK Strategy for the Management of Solid Low Level Waste from the Nuclear Industry: Strategic Environmental Assessment Post-Adoption Statement, published in 2016 states that, *"The Government notes the potential benefit of moving towards a waste management approach of risk based disposability assessment, rather than through classification; and will work with Regulators, the NDA and waste producers to determine the practicalities and feasibility of adopting such an approach … The Government is supportive of the work being undertaken by the industry and Regulators to identify how waste at the LLW / ILW boundary could be managed more flexibly, according to risk assessment."*

[6] Note that the GDF disposal concept is for HAW and this includes, "*A small amount of Low Level Waste (LLW) which can't be safely disposed of in existing surface disposal facilities*".

1.2 PRINCIPLE 2: Ensuring an optimised approach

***Mixing* should only be undertaken where it is a necessary part of a waste management approach that is demonstrated to be optimised.**

Options involving waste *mixing* must consider the impacts through the waste lifecycle.

Optimisation has a specific regulatory and legislative meaning when applied to the consideration of radiological risks to people, and requires that radiation exposures are as low as reasonably practicable/achievable (ALARP/ALARA[7]), taking into account economic and societal factors. The ALARA principle is recommended by the International Commission on Radiological Protection (ICRP) and incorporated into UK legislation.

An optimised approach is typically demonstrated through production of a Best Available Techniques (BAT), Best Practicable Means (BPM) and/or ALARP case. Such cases provide relevant claims, arguments and evidence demonstrating that the proposed approach is optimal. When identifying an optimised waste management approach, a range of options should be considered and any selected option demonstrably shown to be optimal.

Relevant considerations include:

- Mixing of radioactive waste should only be undertaken where this is part of an optimised approach to waste management considering the whole lifecycle. Identification of any optimal approach requires a proportionate consideration and assessment of alternative options. Relevant factors to be considered and the approach to making optimisation arguments are outlined in the NDA Value Framework [1].
- Waste mixing that enables components of the mixture to be managed with a lower level of long-term isolation[8] must be demonstrated as being acceptable (e.g. where ILW that would otherwise be disposed to a GDF is mixed with LLW to enable disposal to the LLWR). When identifying an optimised approach any resultant benefits, such as greater utilisation of the radiological capacity of the facility, must be considered against the associated detriments, such as an associated increase in the radiological impact imposed on that facility. Such benefits and detriments are not easily quantified and early dialogue between the consignee and consignor is recommended to identify acceptable approaches.
- It is important to note that an optimisation study may be inconclusive, in that no single approach may be regarded as unequivocally optimal. In such cases an element of judgement is required and decisions need to take account of uncertainties within the assessment.

[7] The Basic Safety Standards Directive (BSSD) defines the optimisation principle such that all exposures to ionising radiation are kept as low as reasonably achievable (ALARA).
[8] Deep geological disposal provides a greater degree of isolation over the long-term than near surface disposal.

- Optimisation should seek to ensure balance across the lifecycle, which necessitates consideration of factors impacting both waste consignor and consignee through all steps to final disposal. For example, if an option that involves waste mixing enables benefits for the waste producer but deleteriously impacts the consignee (e.g. via a challenge to the disposal facility safety case) this option may not be optimal overall. A consultative approach that seeks to ensure a balanced outcome should be adopted.

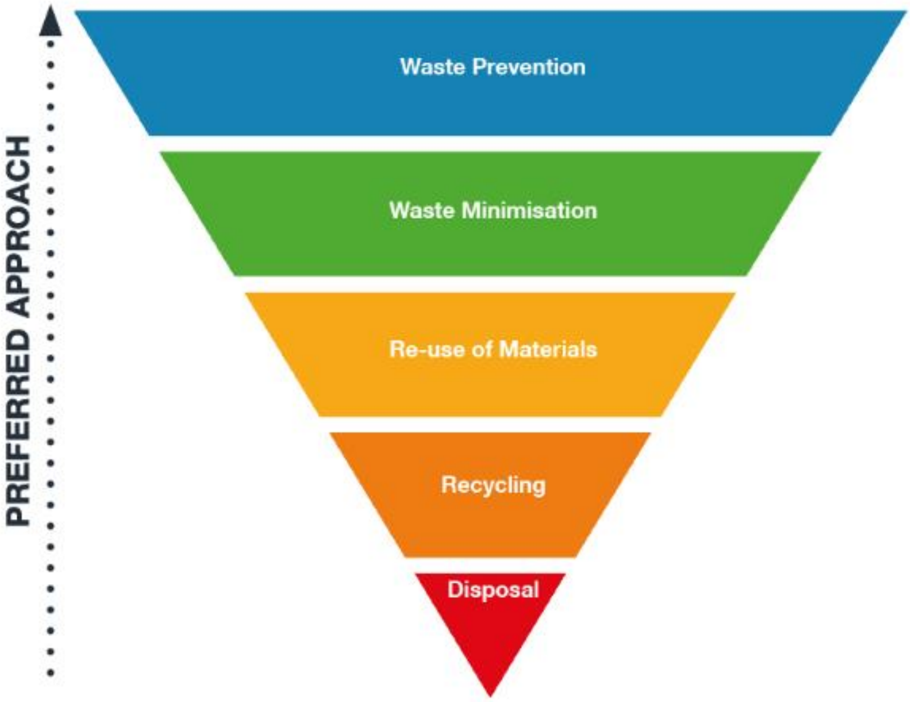


Figure 1 Waste Management Hierarchy

- An optimised approach will apply the Waste Management Hierarchy (Figure 1), seeking firstly to prevent waste arisings. Unavoidable waste arisings should be minimised, both with respect to volume and activity. Reuse and recycling options are pursued, where practicable. Final disposal is only pursued as a least preferred approach.
- Consideration of the waste lifecycle is particularly relevant when considering the possibility of segregating wastes. The design of new waste management facilities is likely to require arrangements for segregation to be developed at the design stage and hence to enable appropriate segregation at the outset. Waste segregation is unlikely to be necessary when the end treatment or disposal point of the segregated wastes are the same. However, segregation will often be the optimal waste management approach when it is practicable and allows for diversion of wastes away from disposal facilities for higher-hazard waste. The extent to which segregation is to be pursued for mixed wastes should be determined as part of optimisation studies to determine how best to manage the wastes. Operational risk reduction and hazard reduction may be important considerations for some wastes.

Acceptable example: Consolidated waste consignments making best use of disposal capacity.

A commercial waste management company receives LLW from various nuclear sites and combines these to produce mixed consignments of waste for disposal to the LLWR. A variety of waste conditioning processes are deployed, including size reduction, metal decontamination, drying, super-compaction, cement encapsulation, or a combination thereof, as appropriate, and as selected by appropriate assessments to identify optimised approaches. One of the primary aims is to minimise the volume of waste for disposal, whilst ensuring that the consignment complies with the conditions for acceptance for disposal at LLWR. Overall this brokering approach enables consolidated waste consignments that make best use of LLWR disposal capacity by effectively mixing compatible wastes that in combination seek to ensure the highest acceptable radioactivity loading per consignment, hence making best use of LLWR radiological capacity. This practice also avoids unfilled containers potentially being consigned to LLWR because of insufficient arisings at a single site to enable container filling within the package certification period. The associated case aligns well with relevant national strategic BAT cases and represents an option that is well-received both by regulators and stakeholders.

Unacceptable example: Waste dilution using other wastes that could be better managed by alternative approaches.

A proposed consignment of radioactive waste from a site in England contains some waste with an average activity concentration that substantially exceeds the activity concentration limits set out in the LLWR WAC. There would be spare disposal volume within the half-height ISO container. A consignor BAT study concludes that it is acceptable to fill the remaining disposal volume with very low activity radioactively contaminated soil, on the grounds that the overall consignment activity concentration would then comply with the WAC and this would utilise the disposal capacity more efficiently.

On review of the proposed consignment, the consignee observes that:

- the bulk of the consignment has an average activity concentration that exceeds the activity limits set out in the LLWR WAC. On that basis storage pending disposal to the GDF is more aligned with current policy;
- the very low activity radioactively contaminated soil should be managed and disposed by appropriate routes (such as by landfill or in-situ disposal, where appropriate), rather than being used as a diluent; and,
- the presence of soil would prevent effective grouting of the container to an extent that the required performance in the disposal environment could be compromised.

As such the consignment is rejected as a suboptimal solution that is unsuitable for disposal.

In this case, what was argued to be BAT for the consignor was not deemed BAT for the consignee, and thus not an optimised outcome overall.

1.3 PRINCIPLE 3: Regulatory compliance

***Mixing* of radioactive wastes must be in compliance with the regulations and consistent with relevant regulatory guidance.**

***Mixing* purely to achieve *dilution to* below Out of Scope or Exemption levels is prohibited, unless the activity has been authorised by the relevant environment agency.**

The requirement to ensure regulatory compliance is fundamental. Of particular note are the specific details of environmental permits, which may be prescriptive to align with details of the safety case for the receiving site (such as details of acceptable *averaging* of activity across a consignment accepted for disposal). It is important to ensure that the details specified in consignor and consignee permits are reviewed and complied with. Consistency with relevant regulatory guidance will also help to ensure compliance.

Suitably specified WAC and checks on conformity will ensure compliance with disposal permits. Generic aspects, such as ensuring sufficient characterisation to demonstrate compatibility with proposed management and disposal routes and the need to demonstrate optimisation, are not discussed further.

Relevant considerations include:

- There are relatively few formal regulatory requirements that directly relate to mixing and dilution (Appendix 1). Most notably, within environmental permits, typically there are clauses relating to dilution and mixing, and permits always require an optimised approach to be applied. This is consistent with the need to demonstrate that BAT (or BPM) is being used in all waste management activities relevant to a disposal endpoint, including mixing. Regulatory guidance, most notably the Radioactive Substances Regulation Environmental Principles (REPS[9]) which are applicable in England and Wales (Appendix 1), offer specific advice on what is acceptable. To summarise, mixing that provides net benefits in terms of health, safety and environment is not precluded. However, dilution solely for the purposes of re-categorisation to a lower category should be avoided.
- Mixing of different categories of radioactive wastes is not prohibited by legislation and hence there is no fundamental regulatory requirement preventing, for example, the mixing of LLW and ILW. However, any such mixing should be shown to provide an optimised outcome when relevant factors and impacts are considered from both the waste producer and disposal facility operator perspectives.
- Mixing of wastes of similar activity level (e.g. LAW with LAW) is considered broadly acceptable, routine practice.

[9] See, in particular, “Principle RSMDP8 – Segregation of Wastes” in: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/296388/geho0709bqsb-e-e.pdf

- Mixing of wastes of different activity category (e.g. small quantities of HAW mixed with LAW) is also current practice, although less widespread and potentially more contentious. Arguments to support such practices are typically based around a consignment meeting the facility WAC based on overall consignment activity averaging, the need to fully use waste container volumes and drivers to enable early hazard reduction or where it is not ALARP to segregate (e.g. prompt disposal of small quantities of HAW that would otherwise require storage prior to the availability of a dedicated HAW disposal route, such as a GDF). Dialogue between the consignee and consignor is strongly advised prior to any such mixing.
- Mixing of large quantities of very low activity LLW in consignments dominated (in radioactivity terms) by a small HAW component is generally considered unacceptable. Such practices would need to be considered in detail against any "heterogeneity" requirements in the facility WAC (if defined), noting that these may be judgement based. Cases where any very low activity LLW "diluent" could be practicably disposed via other disposal routes with greater capacity (such as by in-situ disposal or to a permitted landfill, with or without treatment, as appropriate) are unlikely to be considered optimal.
- Direct, purposeful mixing of radioactive and non-radioactive wastes for disposal is not pursued and would result in increased disposal volumes. However, such mixing may be incidental to some waste treatment routes, such as a continuous feed of different waste types from several consignors in incinerator operations and the unavoidable inclusion of clean soil during excavation of contaminated soils.
- Deliberate dilution of radioactive wastes to below Out of Scope or Exemption levels is prohibited (except where such an activity has been authorised by the relevant environment agency). Indeed, where dilution has been undertaken with the intention of releasing the waste from regulatory control, the waste automatically becomes in-scope of the legislation.

Acceptable example: Consignment of a compliant mixed waste.
Waste soil, concrete and rubble from different waste streams are loaded into a single disposal container and consigned to the LLWR as a mixed consignment of waste. The individual wastes within the consignment have varying activity levels but all are below LLW activity limits based on suitably robust characterisation data. The whole consignment is compliant with the disposal facility WAC. The waste disposal routing is consistent with the national strategic BAT for such wastes and also with the operator's specific BAT case for these wastes.

Unacceptable example: Consignment of HAW with LLW resulting in a highly heterogeneous mixed waste.
A large HAW item is consigned to LLWR in a container with a larger volume of lightly contaminated sand and rubble (low activity-LLW) added to fill the available volume. The HAW item comprises over 90% of the combined activity in the consignment, yet occupies less than 10% of the waste volume. The consignment as a whole is compliant with the activity limits of 4 GBq t^{-1} for all alpha-emitting radionuclides and 12 GBq t^{-1} for all other radionuclides.

This is deemed unacceptable for the following reasons:

- The practice is not consistent with BAT because:
  - The consignment contains large volumes of low activity LLW that could be disposed through other, better aligned routes which would not use valuable disposal capacity at the LLWR.
  - Disposal of HAW to a route designed for LLW is not consistent with extant Government policy.
- Arguably, the consignment does not comply with the heterogeneity requirements of the LLWR WAC, although this is a judgement-based aspect as per, "*The total Specific Activity of a Waste Consignment must be a reasonable reflection of the Activity of the waste across the volume of the waste*".

On this basis, consignment of the waste to LLWR would breach permit conditions relating to the use of BAT and those requiring compliance with consignee WAC.

1.4 PRINCIPLE 4: Compliance with waste acceptance criteria

***Mixing* of radioactive wastes should only be undertaken where this results in consignments that comply with the WAC of the receiving facility.**

The *average* activity concentration within a mixed waste consignment should be suitably representative of the waste.

The activity distribution across a mixed waste consignment must be consistent with any requirements on heterogeneity as specified in the WAC.

Waste consignors must ensure that they comply with the WAC of treatment or disposal providers as per standard requirements of environmental permits. Such compliance will mean that the waste consignors should know the properties of each waste package or waste stream with sufficient detail and accuracy to demonstrate WAC compliance. WAC should be suitably defined and prescriptive as to ensure that waste consignors understand the requirements and to ensure consignors are suitably informed as to how to comply. If WAC do not exist, such as in the case of a conceptual disposal facility, then disposability should be established via appropriate assessments (such as the Disposability Assessment process for proposed disposals to a future GDF).

Relevant considerations include:

- WAC should reflect the safety requirements of the disposal facility to enable risk-informed disposability. WAC should include sufficient detail to enable consistent judgments on waste acceptability, including criteria of relevance to mixing.
- Wastes must be sufficiently characterised to ensure conformance with the WAC of the receiving facility. There may be a challenge to ensure that WAC requirements are achievable and do not place undue disproportionate or impracticable characterisation burdens on consignors.
- The extent of mixing within a mixed waste consignment will have a significant influence on the heterogeneity in activity distribution across the consignment. Wastes having different activity concentrations that are combined but not intimately mixed will retain their individual activity concentrations at the relevant scale (e.g. drums of different wastes that are placed within a disposal container). If volumes of a consignment are expected to exceed activity limits over appreciable volumes then the consignor should notify the consignee and seek a view on acceptability.
- The average activity concentration within a mixed waste consignment should be suitably representative of the wastes (Figure 2). Obtaining the correct average activity concentration (as measured in either mass or volume based terms) for a mixed waste product is of fundamental importance. It is important that any averaging within a waste consignment is consistent with the receiving facility WAC. Acceptable averaging masses, volumes or areas, should be consistent with any assumptions made in the derivation of the radionuclide concentration limits. Ideally WAC should clearly specify the acceptable

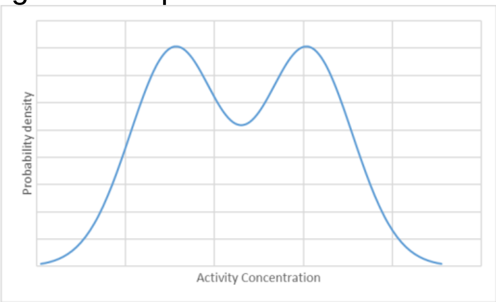
approach to activity averaging, including quantitative criteria that are consistent with the assessments in the supporting safety cases.

- There should be clear specification of acceptable levels of heterogeneity in activity distribution across a consignment that are consistent with the supporting safety cases. Ideally such criteria should be quantitative, as in the case of several landfill WAC and the discrete item limits in the LLWR WAC [4]. Ideally, WAC should define the mass (or volumetric) scale at which any activity concentration limit applies (e.g. the average activity concentration within a defined mass of waste must not exceed the specified activity limit). Such limits should be derived from the facility safety case.
- If acceptable levels of heterogeneity in activity distribution across a consignment are not specified in the WAC then advice should be sought from the facility operator in the first instance. If such advice is not forthcoming a reasonable generic averaging mass of 300 kg[10] is suggested for wastes consigned to disposal facilities, based on IAEA recommendations [2] relating to clearance and exemption of waste. This mass is broadly consistent with assumptions made in the scenarios used in the radiological assessments to derive clearance values.
- Consignees should make it clear if there is flexibility in WAC, or the possibility for a variation, and establish a process to enable this. In cases where there is flexibility or scope for variation, early engagement with treatment or disposal providers is critical to enable decisions on mixing (and the potential outcomes of dilution and concentration) to be made early in the process; mitigating against the potential for re-work and double handling of waste or the generation of problematic wastes.
- Further, for unique radioactive wastes, where there is no precedent for their management, collaboration and communication between consignors and consignees will be essential to ensure WAC compliance and successful waste management. This engagement will also help future waste management because on longer timescales, additional underpinning of ESC arguments or modifications to disposal practices (for example, use of a different container type) may allow WAC to be modified.
- Consignors and consignees should share good practice regarding compliance with Waste Acceptance Criteria, which may include examples of non-conformance. From a consignor's perspective, compliance with another facility's WAC is required for compliance with their own environmental permit.

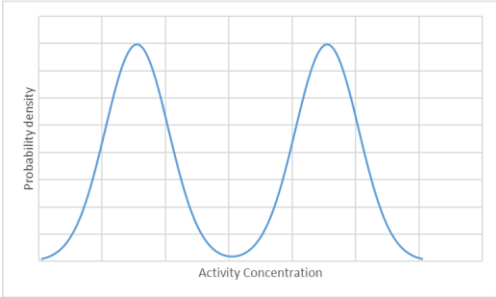
[10] *"an averaging mass of several hundred kilograms would be considered reasonable. This would be in accordance with the assumptions made in the scenarios used for the derivation of the values",* (see Section 2.2.5 in [2]).

Any use of a generic averaging mass needs to be mindful that other averaging criteria may be applicable in other parts of the waste lifecycle (e.g. such as those associated with transport regulations, as outlined in Appendix A1.5).

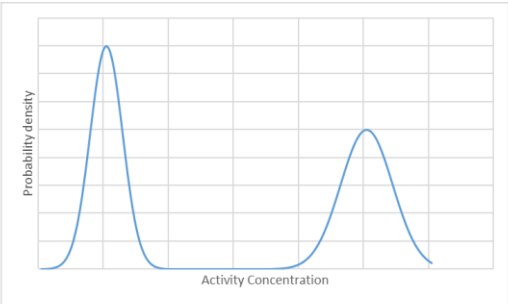
Figure 2: Representativeness of mean for multimodal distributions



(a) Mean likely to be representative of activity concentration of mixed wastes



(b) Mean unlikely to be representative of activity concentration of mixed wastes. Antimode significantly less frequent than major modes.



(c) Mean unlikely to be representative of activity concentration of mixed wastes. Distance between major modes significant.

Explanatory note (to Figure 2):

In an inhomogeneous mixed waste there will be local volumes of differing activity concentration. For example, the average activity considered at a volume scale of 1 litre may vary significantly within an overall waste volume of 1 cubic metre. When expressed as a histogram (plotting the number of such volumes versus the associated activity concentration of that local volume) this may appear as a series of peaks (or modes) reflecting the presence of discreet populations. These modes are the local concentrations that appear most often at that local volume scale within the waste consignment as a whole.

In the illustrative diagrams above there are two modes reflecting contributions from two separate wastes that have been mixed. In some cases the overall average (mean) activity concentration of the waste as a whole may be a reasonable representation of the modal activity concentrations where the modes overlap significantly (a). Where the modes are symmetrical and do not overlap significantly the dip between the peaks (the antimode) corresponds with the mean activity for the waste as a whole but is not representative of the activity of the two modes (b) and more so when the modes are unsymmetrical and significantly separated (c).

In complex mixed wastes there may be multiple modes. The extent of mixing will influence the modality. If wastes are fully mixed (at all scales) then such modes would not exist (i.e. the waste would be homogeneous) however, in reality, a narrow peak (mode) would be expected even for homogenous wastes.

Acceptable example: Appropriate volume averaging.
Contaminated concrete slabs have a range of activity concentrations between 4 Bq g^{-1} and 1000 Bq g^{-1}. These are placed together into a container for disposal to a landfill site that is permitted to dispose of radioactive waste The average activity concentration of the consignment is less than 200 Bq g^{-1}, the consignment is compliant with both disposal and transport surface dose rate criteria, and the slabs meet the disposal facility WAC with respect to discrete items and heterogeneity in activity concentration.

This proposal is acceptable on the basis that radiological risks from disposal of the consignment are kept as low as reasonably achievable and disposal facility WAC are met.

Unacceptable example: Unacceptable heterogeneity.
Mixed fuel element debris (FED) waste from a reactor vault largely comprises LLW sludge, together with a small component of more highly activated nimonic springs. The latter are made from corrosion resistant nickel-chromium alloy and contain appreciable Co-60 activities at levels far exceeding 12 GBq t^{-1}. These metallic items individually breach the activity limits for discrete items as per the LLWR WAC. Packages containing bulk sludge and small quantities of nimonic springs would meet the overall LLWR activity limits when averaged over the disposal container volume.

Such mixed waste consignments are unacceptable for disposal to LLWR for several reasons:

- the WAC is not met because the springs do not comply with the activity limits for discrete items as defined, even though the consignment as a whole meets the LLWR activity limits when averaged over the disposal container volume;
- the nimonic springs are HAW that are readily separated and can be managed by alternative approaches (decay storage followed by disposal via other routes); and.
- the nimonic springs are identified by the LLWR as discrete items and are described as *"Items made from corrosion resistant nickel-chromium alloy and of interesting (pocketable) form."* Published guidance states that nimonic springs *"must be segregated from FED, or other wastes".*

1.5 PRINCIPLE 5: Physical and chemical compatibility of mixed wastes

Mixing of wastes that are physically and/or chemically incompatible should be avoided where this results in outcomes that are contrary to safe management and disposal.

Although *mixing* can provide benefits, it should be avoided where physical and/or chemical incompatibilities would result in deleterious interactions that are contrary to safe management and disposal. Generally speaking, there should be a net safety, health or environmental benefit from the mixing of the wastes, and, in all cases, no net safety, health or environmental detriment**.**

Relevant considerations include:

- Sufficient knowledge of both the wastes and the mixed product may be required to judge compatibility. Compatibility both in the short term and in the long term should be considered. Consultation may be required for a consignor to gain such knowledge (for example, the effect the mixed product may have on the long-term performance of a disposal facility). Where there are significant uncertainties and concerns it can be prudent to perform controlled mixing trials prior to full scale deployment.
- Consignors, disposal operators, waste service and transport providers should work together to ensure that they have a common understanding of what is compatible and incompatible. Any significant learning from experience should be shared.
- Incompatibilities may include:
  - chemical reactions that yield chemotoxic reaction products or have deleterious effects on the waste product, such as those leading to breaches in required containment (e.g. internally driven corrosion of packaging);
  - production of significant quantities of gases that may be flammable, explosive or toxic;
  - creation of a waste that does not meet transport requirements;
  - creation of a waste that evolves less favorably in the disposal environment;
  - creation of a waste product that separates into different phases shortly after mixing and where these separate phases may be incompatible with onward management and disposal steps (e.g. evolution of free liquids).
- It is important to consider the timescales over which deleterious evolution of waste may occur due to incompatibilities, as not all incompatibilities may be immediately apparent (e.g. slow reactions that might occur over extended timescales).
- Mixing can be acceptable as part of an optimised waste management approach where:
  - no incompatibilities exist (for example, consignment of multiple, mutually unreactive waste streams in a single disposal container);

- a more stable product can be created from two separate wastes (for example, calcining an acidic, liquid waste and melting the resultant calcine with glass frit to create a vitrified waste product);
- one constituent of the mixture is a waste and the other an encapsulating medium that effectively immobilises the waste to yield a stable product (for example, cementation of sludges).

Acceptable example: Mixing that produces a safe and passive waste form.
Liquid and slurry wastes, including effluent treatment flocs and pond sludges, are homogenised for co-processing. The mixed slurry is metered into drums containing a sacrificial mixing paddle, and mixed with specially blended cement powders in a process referred to as in-drum mixing. Product trials were used to demonstrate waste compatibility and to demonstrate no adverse reaction between the waste and encapsulant. The process yields a solid monolithic product that is suitable for long term storage, transport and disposal.

Unacceptable example: Mixing that results in a potentially explosive reaction product.
Sludge wastes are mixed with an organic absorbent material to remove free liquids. The sludge is then stored in sealed drums together with miscellaneous solid wastes, including some containing nitrate salts, pending disposal by incineration. During storage the organic adsorbent and the nitrate salts react forming a reactive product and an exothermic reaction rapidly releases gases leading to pressurization and rupture of the drums, with spread of contamination.

1.6 PRINCIPLE 6: Mixing and waste conditioning

Dilution is an acceptable consequence of waste conditioning, so long as the conditioning approach achieves a necessary safety outcome and the approach is optimised to ensure that conditioned waste volumes are minimised.

Waste conditioning may involve *mixing* and *dilution* by addition of an encapsulating medium, such as cement-based grout, and a waste container. It may be acceptable to account for the container materials as part of the total mass when calculating the activity of a conditioned waste package overall, depending on any specific requirements of the WAC for the receiving facility. In such cases, both the encapsulant and the container materials effectively dilute the overall activity concentration when activity concentrations are averaged over the waste package as a whole.

Relevant considerations include:

- In many cases, mixing of wastes either with each other, or with non-radioactive materials, to immobilise, encapsulate or otherwise condition waste is good practice where this demonstrably provides a necessary safety benefit. The quantity of materials added during waste conditioning should be the minimum amount required to provide the desired benefit. Addition of excess conditioning materials purely to dilute waste is not acceptable.
- Inevitably, waste conditioning can lead to dilution[11] of activity. Any dilution occurring as a result of waste conditioning should be incidental, and such practices are generally acceptable so long as they do not involve unnecessary dilution by addition of excess conditioning materials to what is required to achieve the safety outcome. In some cases, conditioning may reduce averaged activity concentrations across waste categories (e.g. ILW becomes LLW following conditioning) and thus enable management and disposal through current routes for LAW. Deliberate, unnecessary conditioning purely to achieve dilution and recategorisation is not acceptable.

[11] It is acknowledged that conditioning can also lead to concentration of activity. However, such conditioning would result in a waste product that would require treatment or disposal to higher-hazard facilities to adequately manage the radiological risk.

Acceptable example: A conditioned waste product with a suitable waste to encapsulant ratio.
Wastes from a reactor cooling pond are stored as a slurry. The slurry is combined with cement grout, which immobilises the waste and removes any free liquid. The waste encapsulation process is optimised such that the slurry to cement ratio gives the required waste product performance whilst ensuring that conditioned waste volumes are minimised. The resultant conditioned waste product is suitable for safe transport and disposal in compliance with the LLWR disposal WAC.

Unacceptable example: A waste product with a less than optimal waste loading.
A waste package is produced containing a waste loading far lower than the encapsulant can safely accommodate for onward management, transport and disposal. The waste inventory is not limiting (i.e. there is more waste requiring conditioning). This is not acceptable as it represents dilution of the waste and the overall conditioned waste volume for the waste stream as a whole will be greater than is necessary. This is not an optimised outcome and is counter to ensuring application of the waste management hierarchy.

4. Industry practice

Industry practice regarding the mixing, blending, averaging and dilution of wastes has evolved significantly over the years to reflect changes in site custodianship, the introduction of LLW diversion routes, and changes in relevant legislation.

The policy, legislative, regulatory, and strategic landscape is complex, and there can be a need to balance competing aims. In this section we review industry practice based on a sample of published waste management arrangements, and provide a brief overview of established practices and relevant codes of practice.

4.1 Waste acceptance criteria

Treatment or disposal route providers are required to assess the safety and environmental impacts of treatment or disposal of radioactive waste to their facilities, and to demonstrate that they are adequately controlling these impacts, or in the case of radiological risks, reducing them as far as is reasonably practicable.

Waste acceptance criteria (WAC) provide the qualitative and quantitative criteria, that must be complied with for solid radioactive waste to be accepted at a treatment or disposal facility. WAC are specified by the operator of the facility and are typically founded on an underlying safety case. WAC conditions ensure compliance with safety cases and implement the relevant aspects of the site permits and any other regulatory requirements, such as those relating to waste transport and requirements under the nuclear site licence (where applicable).

Several observations are made below, based on a review of the published WAC. This draws heavily on the Low Level Waste Disposal WAC as a comprehensive exemplar [12].

Guidance produced by RWM Ltd has also been reviewed in relation to disposal to a future Geological Disposal Facility (GDF) and the associated generic specifications [3]. Averaging is mentioned in relation to aspects of the transport regulations (described in below) and package heat outputs [12]. Mixing is discussed in relation to "in-drum mixing". The terms blending and dilution do not appear in the specifications.

4.1.1 Blending

The term blending (as defined in this report) does not appear in any of the WAC that have been reviewed. Blending appears to be more widely used in relation to the waste management steps that precede disposal.

4.1.2 Mixing

There are few instances of the terms "Mixing" or "Mix" being explicitly used in WAC. Discussion of "mixed radionuclides" in some WAC reflects the isotopic mixture associated with wastes, rather than implying a mixture of wastes.

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[12] screening levels are based on averaged package heat outputs but these do not preclude packages with higher heat outputs being acceptable based on detailed assessment

The Low Level Waste Disposal WAC [12], prohibit mixing solely to achieve WAC compliance and state (L3.2.3) that waste, *"must not be mixed with other wastes solely for the purpose of re-categorisation of the waste as acceptable for disposal at the Low Level Waste Repository"*. This is discussed further in Section 4.1.4.

4.1.3 Dilution

Direct dilution of waste is only permitted where this is part of an optimised waste management scheme. Dilution purely to enable recategorisation for alignment with waste management routes is prohibited by standard permit conditions; which is routinely reflected in disposal facility WAC.

The Low Level Waste Disposal WAC [12], for example, very clearly prohibits dilution solely to achieve WAC compliance. Notably, L2.4 Non-Waste Materials states, *"Where materials must be added to the waste, the customer shall use reasonably practicable means to limit the quantity of non-waste materials present in a Waste Consignment. It is not acceptable to purposely dilute waste or add materials for shielding purposes or otherwise for the sole purpose of achieving compliance with the requirements of this Waste Acceptance Criteria."*

This recognises that addition of non-waste materials may be acceptable, if required, and it is subject to minimisation and optimisation arguments. As an example, paragraph L3.2.4 Low-activity Sources, reflects on the potential inability to practicably remove all *"extraneous packaging and shielding"* (which could be considered a diluent) and requires pre-conditioning as the WAC require encapsulation of sources in a can.

4.1.4 Averaging

The Low Level Waste Disposal WAC [29] very clearly stipulate (L3.2.2) that the total specific activity of any waste consignment for disposal as Low Level Waste must not exceed 4 GBq t^{-1} for all alpha-emitting radionuclides and 12 GBq t^{-1} for all other radionuclides. It is also clearly stated that "Only immediate packaging required to safely manage the waste, which includes the Disposal Container, can be included in the calculation of Specific Activity." This is entirely consistent with the permit, which requires averaging over a consignment and is clear that immediate "packaging" is a legitimate part of any average.

Activity heterogeneity is addressed further in the WAC (L3.2.3, "Activity Heterogeneity and Discrete Items"). This clearly states that, *"A waste consignment may include volumes of wastes or Discrete Items for which the Specific Activities exceed the maximum total Specific Activities for a Waste Consignment given in L3.2.2; however, the total Specific Activities averaged over the Waste Consignment must not exceed the maximum Specific Activities given in L3.2.2, waste must be managed in accordance with regulatory guidance, and the Activity of Discrete Items within a Waste Consignment must be limited.*

While the Specific Activity may vary across a Waste Consignment, and in some volumes, or Discrete Items may exceed the maximum Specific Activities for a Waste Consignment given in L3.2.2, waste volumes or Discrete Items that are known to exceed the maximum Specific Activities given in L3.2.2 must not be mixed with other *wastes solely for the purpose of re-categorisation of the waste as acceptable for disposal at the Low Level Waste Repository."*

This condition implies that waste volumes within a given waste must not be mixed with other wastes solely to achieve recategorisation as LLW for disposal. It does not preclude waste volumes within a given waste exceeding the specific activity limits for a consignment as a whole.

The LLW Disposal WAC also includes the follow statement, *"The total Specific Activity of a Waste Consignment must be a reasonable reflection of the Activity of the waste across the volume of the waste."* The terminology "reasonable reflection" is open to interpretation. Presumably, a small volume of very highly active waste in an otherwise lightly radioactively contaminated waste would be questionable and probably challenged by LLWR.

Other WAC include some quantitative criteria in relation to acceptable variations in specific activity within a consignment [4]. For disposals to Clifton Marsh or at the East Northant Resource Management Facility (ENRMF), the maximum activity concentration in wastes must not exceed 1000 Bq/g and the average activity concentration must not exceed 200 Bq/g. For Clifton Marsh, the average activity concentration limit applies to a consignment, whereas for ENRMF the average activity concentration limit applies over a consignment or for every successive 10 tonnes, whichever has the lowest total mass.

4.1.5 Variations to WAC

WAC that are relevant to the mixing, blending, averaging and dilution of wastes include:

- activity limits on the total quantity of radionuclides that can be disposed of at the facility, which would often feed into an allocated capacity for consignors and be controlled on a Sum of Fractions basis;
- activity concentration limits on consignments, whether on individual radionuclides or the sum from all radionuclides;
- requirements on heterogeneity of items;
- limits on activity or activity concentrations for particles, discrete items, or single items
- requirements on leachability of encapsulated or conditioned wastes;
- dose rate limits.

Such WAC are usually derived from Safety Case documentation based on assumptions about the physical and chemical properties of the expected wastes, and the expected treatment or evolution of the wastes at the facility. Consequently, if the expected wastes have materially different physical or chemical characteristics to that assumed in the Safety Case documentation then these requirements may change, either becoming more stringent or more relaxed. In such cases, treatment or disposal facility operators may vary the WAC to allow for the safe treatment or disposal of the radioactive waste in question.

4.2 Routine practices

This section very briefly reviews common practices in the nuclear sector and highlights those aspects that align with the terminology adopted in this report.

4.2.1 Waste conditioning

Waste conditioning involves treating and transforming radioactive waste into a form suitable for safe handling, transportation, storage and disposal [34]. This may include the conversion of the waste to a solid wasteform and enclosure of the waste in containers. Provision of an overpack may be necessary where a conditioned waste package does not provide an adequate safety function, for example, overpacking may enable safe transport or the overpack may form an additional engineered barrier in a disposal environment. The addition of "clean" materials to waste during conditioning could be interpreted as dilution for a specific purpose to improve overall waste management. The added materials have a functional, beneficial purpose and any associated dilution is incidental to this and such dilution should be minimised. Waste conditioning is therefore very different to deliberate dilution purely to enable recategorisation of waste.

The terms "conditioning volume" and "packaging volume" are also used in relation to the UK radioactive waste inventory [5]. The conditioned volume is the volume of the 'wasteform' (waste plus immobilising medium; also called the 'container payload') within the package.

The conditioned volume will generally exceed raw waste volumes but will vary significantly depending on the nature of the waste, any pretreatments (such as super compaction or thermal treatment) and the acceptable/tolerable loading in the encapsulant. Thermal treatment of waste can significantly reduce waste volumes (e.g. incineration resulting in small quantities of ash from a much larger volume of waste feed).

Historical UK inventory information provides some relevant information, as follows [6]:

- conditioned ILW at Sellafield varies between about 50% and 80% encapsulating material by mass, and the waste: encapsulant ratio is governed by the nature of the waste;
- a number of LLW sludge and ion exchange resin streams, from Berkeley, Harwell and MoD sites, were immobilised in cement-based matrices for disposal at the LLWR. The proportion of cement that makes up the conditioned products varied between about 40% and 80% by mass depending on the particular waste; and,
- the vitrified HLW product at Sellafield comprises approximately 25% calcined waste oxide (produced by heating the liquid high activity waste) and 75% glass by mass.

The packaged volume is the total volume taken up by the waste, the immobilising medium and the waste container. Typically, the packaged volume is between 20% and 50% greater than the conditioned volume, depending on the type of container.

Therefore, waste conditioning increases waste volume to varying degrees. In extreme cases waste conditioning may more than double the waste volume relative to that of the raw waste.

In the case of wastes at the ILW/LLW boundary, conditioning may result in ILW becoming LLW when the activity is averaged over the total conditioned waste mass (i.e. mass of waste plus encapsulant plus container combined). In terms of disposal to LLWR, as described above, it is notable that the encapsulating grout added by LLW Repository Ltd is not considered a valid component of any average activity definition, as per the relevant permit requirement and as reflected in the WAC.

In the absence of disposal facilities for HAW, designing waste management practices, including mixing processes, to enable activity concentrations near the LLW limits can maximise the activity within a given LLWR disposal volume. Such practices are commonplace, for instance, as part of the management of liquid effluents during production and conditioning to create a waste product suitable for disposal to the LLWR. However, practices that involve diluting higher activity wastes with lower activity wastes are currently contentious, irrespective of drivers to maximise use of the radiological capacity of the LLWR.

As per regulatory expectations and requirements any decisions on waste conditioning and ensuring an optimised waste product need to be suitably underpinned via BAT, BPM/BPEO and ALARP arguments, as appropriate.

4.2.2 Waste blending

In the UK nuclear sector, the term blending has been used to imply controlled, intimate mixing of wastes to achieve a desired property. The wastes that are to be blended may have been accumulated separately (e.g. in separate tanks) but are amendable to management through a common plant or process.

As an example, high level waste (HLW) raffinates from oxide fuel and Magnox fuel reprocessing are blended prior to vitrification. This ensures an appropriate feed chemistry to yield a suitable glass composition in the vitrified product [7]. Ultimately, this practice reduces the volume of the vitrified residues produced and avoids the need to add further inactive glass formers. As was noted above, typically the vitrified product is approximately 25% waste oxides (by mass). Blending can also ensure that the product remains within the commercially agreed product envelope to enable eventual waste substitution and return (as per reprocessing contracts in the case of vitrified wastes).

4.2.3 Waste mixing

A waste stream is a collection of waste items at a particular site, usually in a particular facility or from particular processes or operations. It is often distinguishable by its radionuclide content and in many cases also by its physical and chemical characteristics*.* Waste streams as a whole (rather than individual consignments from a given waste stream) are generally considered in strategic-, planning- and optimisation-level considerations.

Mixing of different waste streams is established practice (e.g. mixing of different liquid waste feeds in waste vitrification, mixed consignments of different wastes in a single disposal container to ensure that the full disposal capacity is utilised).

Selective sorting and segregation of specific waste items or waste volumes within a given waste stream can be used to yield a mixed waste with specific characteristics. For example, ILW items or volumes could be segregated from a largely LLW waste stream for management as HAW. Selective sorting of waste could also be used to produce a waste that falls just within a given classification (e.g. “high end” LLW). Any such approaches require suitably precise waste characterisation. The practicability of sorting and segregation must be considered to ensure that a net benefit is obtained (e.g. aspects such as additional dose uptake and cost are relevant factors).

Some examples of typical mixing practices and the supporting rationale are outlined below:

- *Mixing* of waste types in a consignment for disposal may include combinations of ILW and LLW from the same facility in a consignment to enable optimised disposal where it is demonstrably impractical to segregate the waste categories (e.g. mixing of waste ion exchange resins of different activity loadings to yield a mixture that meets LLW limits). The overall consignment is LLW to align with the disposal route and, hence, suitable for disposal to the LLWR as a conditioned waste product. However, specific items within a heterogeneous consignment may exceed LLW activity concentration limits if considered in isolation. *Mixing* ILW and LLW in this case can avoid costly detailed segregation and associated worker dose impacts, and could be argued to make best use of the available volumetric capacity by maximising the activity, either in total or of specific radionuclides, within a disposal container to the LLWR.
- Disposing of ILW to LLWR is arguably contrary to the current long-term management policy of HAW produced by the UK government, which is to package and hold HAW in secure interim storage until they can be transferred to a GDF[13]. Discrete items or volumes of boundary LLW/ILW within an otherwise LLW waste package are potentially acceptable[14], subject to meeting disposal facility WAC and reflecting proportionate, risk-informed treatment and disposal. However, such practices are not acceptable when used solely as a means to consign populations of ILW to the LLWR, particularly when such populations are easily segregated.
- Several wastes (from different waste streams) might be consigned in a single disposal container (such as a TC01 consigned to the LLWR), whilst ensuring that the whole consignment meets the disposal WAC. This helps ensure that the available disposal volume is used and may enable timely container filling. Such practice is commonplace in the UK nuclear industry and universally acceptable, in part because the waste acceptance process to the LLWR, and indeed its ESC, have assumed LLW streams originating from the same site

[13] Or near-surface, near-site storage in Scotland.
[14] See L3.2.3 Activity Heterogeneity and Discrete Items in: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/690797/Waste_Acceptance_Criteria_-_Low_Level_Waste_WSC-WAC-LOW-Version-5.pdf.

are or can be mixed in a single disposal container. In recent years, such *mixing* practices have been adopted by third-party waste providers, who take volumes of waste from multiple sites and *mix* them in a single disposal container, which has provided considerable benefits, particularly for smaller-volume waste producers.
- Wastes that have been mixed at the time of accumulation during storage may prove impractical to segregate on cost or worker dose grounds. In such cases, a mixed, conditioned waste product of acceptable performance may be considered optimal overall.

Mixing also needs to consider any aspects relating to non-radioactive components and their compatibility with future treatment or disposal routes. The inclusion of hazardous wastes (such as asbestos) requires specialist consideration, and mixing of incompatible, chemically reactive wastes needs to be avoided. For example, the high-profile 2014 event at the US Waste Isolation Pilot Plant was caused by an explosive reaction between waste components [8].

4.2.4 Waste averaging

Averaging of radioactive contents over a waste sentencing volume is established best practice [9]. Hence, higher local concentrations in an otherwise lightly contaminated bulk are to be anticipated when the contamination is heterogeneously distributed. For example, bulk low-activity waste may comprise regions of Higher Activity Waste (HAW) if considered at, say, the micron scale (e.g. the contaminated layer of a surface-contaminated object). However, segregation and characterisation at such scales may be impractical and disproportionate (e.g. on cost, worker-dose grounds, or both) and may achieve no better outcome overall.

Averaging of activity measurements over several waste sentencing volumes can also be used to improve the accuracy of the activity measurement, particularly when considering sentencing of wastes as ‘Out of Scope’ [9].

Examples of averaging practices include the following:

- Radioactivity in soils recovered during contaminated land clean-up. Some localised radioactivity levels may be higher but this is mixed with other bulk soil retrieved during recovery operations, and characterisation measurements relate to a representative quantity.
- Combustible waste routes accept materials from many different suppliers (radioactive and non-radioactive) for incineration. The resulting fly and bottom ash is typically *averaged* when characterising it for disposal as VLLW, where appropriate.
- Operational landfills accept low activity wastes that comply with an activity concentration of 200Bq/g averaged over a 10-tonne load with no individual package having an activity greater than1000 Bq/g. *Averaging/mixing* could therefore be within a single package or within a consignment of multiple packages, as long as the activity concentration in the waste is less than or equal to 200 Bq/g over the consignment as a whole.
- Large integral plant items, such as a reactor boiler or heat exchanger components, that are (predominantly) clean or of very low bulk activity may have localised hot spots. The latter may not be easily decontaminated on

retrieval and prior to onward treatment. Measurements are taken to ensure that the *average* surface activity is no greater than the permissible limits in the transport regulations for Surface Contaminated Object Type I (SCO-I) consignments. This enables direct transport without packaging.

Averaging can therefore enable pragmatic waste treatment routes for bulk items (e.g. by enabling compliance with transport regulations or facility acceptance criteria).

Any waste that is subject to assay and the application of scaling factors and fingerprints to assign the inventory will, in effect, be sentenced by an *average* result. For example, a drum subjected to high-resolution gamma spectroscopy (HRGS) will have an *average* isotopic composition that is assigned, based on the fingerprint of those nuclides not directly quantified by HRGS but known to be present in the waste stream.

In some circumstances, *averaging* is unlikely to be acceptable, unless there is strong justification. Examples include situations where it would be practicable to remove or segregate small areas or volumes containing significant concentrations of radioactivity ("hot spots"), or where there is potential radiological significance associated with the inherent inhomogeneity (e.g. the presence of discrete items [29]).

It should be noted that what constitutes suitable *averaging* will also be determined by the characterisation approach taken and best practice for characterisation. The NDA is currently producing a Good Practice Guide in this area.

4.3 Best Practice Guides

The guidance in the UK Nuclear Industry Guide to Clearance and Radiological Sentencing: Principles, Process and Practices [9] contains the following text:

"<u>4.2 Dilution of Radioactivity in Solid Wastes or Materials</u>

"3.19 Deliberate dilution by mixing of wastes or materials having activities less than the exemptions provisions documents limits with other wastes and materials having activities greater than the limits, in order to achieve clearance, is not an acceptable practice.

"3.20 Unavoidable dilution may occur, and is ***acceptable****, where the extent of dilution is consequent on the technique employed, and the technique is designed to ensure complete removal. For example, the use of an excavator to dig out a volume of contaminated soil may result in some unavoidable mixing of soil with differing levels of contamination.*

"3.21 In cases where unavoidable mixing occurs, or where the distribution of radioactivity is inhomogeneous, care must be taken to ensure that any subsequent sampling or monitoring is suitably representative (see sections following and Chapters 6 and 7)."

5. Conclusion

This document seeks to establish guiding principles that should be considered when undertaking waste management practices that involve mixing. These principles have been developed through a consultative process with the NDA, waste producers, waste management and disposal operators and representatives from regulatory organisations.

The principles do not replace or remove the regulatory and legislative requirements placed on organisations, but have benefited from discussions with regulatory bodies in their development.

Overall, waste managers need to balance a variety of issues when undertaking practices involving mixing. Fundamentally, the benefits of undertaking any mixing should outweigh any detriments when considered across the whole lifecycle of the waste. It is also stressed that both consignors and consignees should communicate throughout the management of radioactive wastes to ensure that appropriate decisions are made at appropriate times with respect to mixing.

These principles have been developed based on existing policy, guidance and practices at the time of publication. As a note of caution users of this report are advised that the validity of the guiding principles established in this report may need to be revisited in the light of any future relevant developments.

The development of these principles enabled waste managers to share examples of both acceptable and unacceptable cases, contributing to Learning from Experience. It would be beneficial to assess the effectiveness of these guiding principles in providing clarity to waste managers and this could be enabled through future engagement and discussions. Updates to the principles should be informed by engagement and discussion within the waste management community and also reflect any changes to the policy and regulatory landscape, plus any relevant developments in industry practices.

6. References

[1] NDA, *NDA Value Framework,* Version 1.2, January 2016.

[2] IAEA, *Safety Reports Series No.67: Monitoring for Compliance with Exemption and Clearance Levels.* International Atomic Energy Agency, Vienna, 2012

[3] NDA (2012). Generic specification for packages containing low heat generating wastes. NDA Report No. NDA/RWM/068.

[4] LLW Repository Ltd, *Very Low Level Waste Service Guidance*, WSC-Guidance-V-001 – Issue 1, May 2017

[5] Department for Business, Energy & Industrial Strategy (BEIS) and the Nuclear Decommissioning Authority (NDA) (2017). *2016 UK Radioactive Waste & Materials Inventory: Context And Methodology Report.*

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Appendix 1: Relevant policy, strategy and regulation

In this Appendix, we set out a brief summary of the relevant policy, strategy and regulatory aspects associated with mixing.

A1. Policy

The most recent, comprehensive government policy statement (a command paper) on radioactive waste management was published in 1995[15]. The current UK and Devolved Government policy on the management of radioactive wastes is set out in four principal documents:

Policy for the Long Term Management of Solid LLW in the UK – 2007 [10]

Implementing Geological Disposal – Working with Communities – 2018 [11]

Scotland's HAW Policy – 2011 [12]

Welsh Government Geological Disposal: Working with Communities – 2019 [13]

In terms of HAW policy for the Devolved Administrations, the most relevant aspects are the policy to pursue deep geological disposal of HAW in England and Wales, and for the long-term management of HAW in near-surface facilities in Scotland. Reference [11] also notes that higher activity radioactive waste must be stored in advance of disposal and advocates early conditioning of this waste into an appropriate form for storage as a significant part of its management.

The LLW policy recognises the large range of LW types, and associated radioactivity. Consequently, the aim of the policy is to "*ensure safe, environmentally-acceptable and cost-effective management solutions that appropriately reflect the nature of the LLW concerned.*" The policy also notes the requirements for LLW management plans, which should be based on:

- use of a risk-informed approach to ensure safety and protection of the environment;
- minimisation of waste arisings (both activity and mass);
- forecasting of future waste arisings, based upon fit for purpose characterisation of wastes and materials that may become wastes;
- consideration of all practicable options for the management of LLW;
- a presumption towards early solutions to waste management;
- appropriate consideration of the proximity principle and waste transport issues;
- consideration of the potential effects of future climate change in the case of long term storage or disposal facilities.

[15] Historically, radioactive waste management policy was expressed in the 1995 White Paper 'Review of Radioactive Waste Management Policy, Final Conclusions, Cm2919'. Some aspects of this policy have subsequently been replaced by more recent policy positions to reflect developments in the management of radioactive wastes. This has resulted in policy for radioactive waste management being fragmented across a number of different policy documents.

The policy also notes the need for application of the Waste Hierarchy and the need for proportionality.

A2. Strategy

To achieve these policies a number of strategies have been developed, the most relevant of which are:

1) UK Government Strategy for the Management of Solid Low Level Waste from the Nuclear Industry (UK LLW Strategy) [14];
2) The NDA's Radioactive Waste Strategy, which captures key themes and strategic objectives from the UK LLW Strategy, but also sets out an updated strategy for the management of HAW in England and Wales;
3) Implementation Strategy for Scotland's Policy on HAW [15];
4) UK Strategy for Radioactive Discharges [16, 17]

In terms of mixing of wastes the UK LLW Strategy notes that segregation of wastes at source, where practicable, is a preferred option in order to reduce reworking of the waste, but notes in some circumstances segregation in later waste management stages may be necessary.

NDA's Radioactive Waste Strategy focuses on integrated waste management through a single strategy that promotes cross-category waste management optimisation, supports a risk-informed approach while protecting people and the environment and supports the development of an integrated programme that will enable suitable and timely waste management infrastructure to support the NDA mission. The strategy also promotes timely characterisation of waste to deliver effective waste management.

The cross-category waste management optimisation and risk-informed strategic intent aligns with the UK LLW Strategy policy statement [14]. This states that, "*The Government notes the potential benefit of moving towards a waste management approach of risk based disposability assessment, rather than through classification; and will work with Regulators, the NDA and waste producers to determine the practicalities and feasibility of adopting such an approach … The Government is supportive of the work being undertaken by the industry and Regulators to identify how waste at the LLW / ILW boundary could be managed more flexibly, according to risk assessment."* The UK LLW Strategy also notes that not all LLW can be safely disposed of at the LLWR, and that some Higher Activity Waste (HAW) may be better managed within a LLW facility; for example, wastes that contain short-lived radionuclides, or waste at the boundary between LLW and HAW. It also notes *"there are synergies between HAW policy and the LLW strategy which could be enabled by managing wastes using disposability assessment, as opposed to radiological classifications."*

The UK Radioactive Discharge Strategy also includes text of relevance when considering best practice in the management of radioactive wastes by noting the need to use BAT in England and Wales, and BPM and BPEOs in Scotland and Northern Ireland, to prevent and, where that is not practicable, minimise waste generation and discharges to the environment. The UK Radioactive Discharge

Strategy also notes the preferred use of “concentrate and contain” in the management of radioactive waste over “dilute and disperse”.

However, these strategy documents give no direct indication on the acceptability of mixing, dilution, blending, and averaging practices.

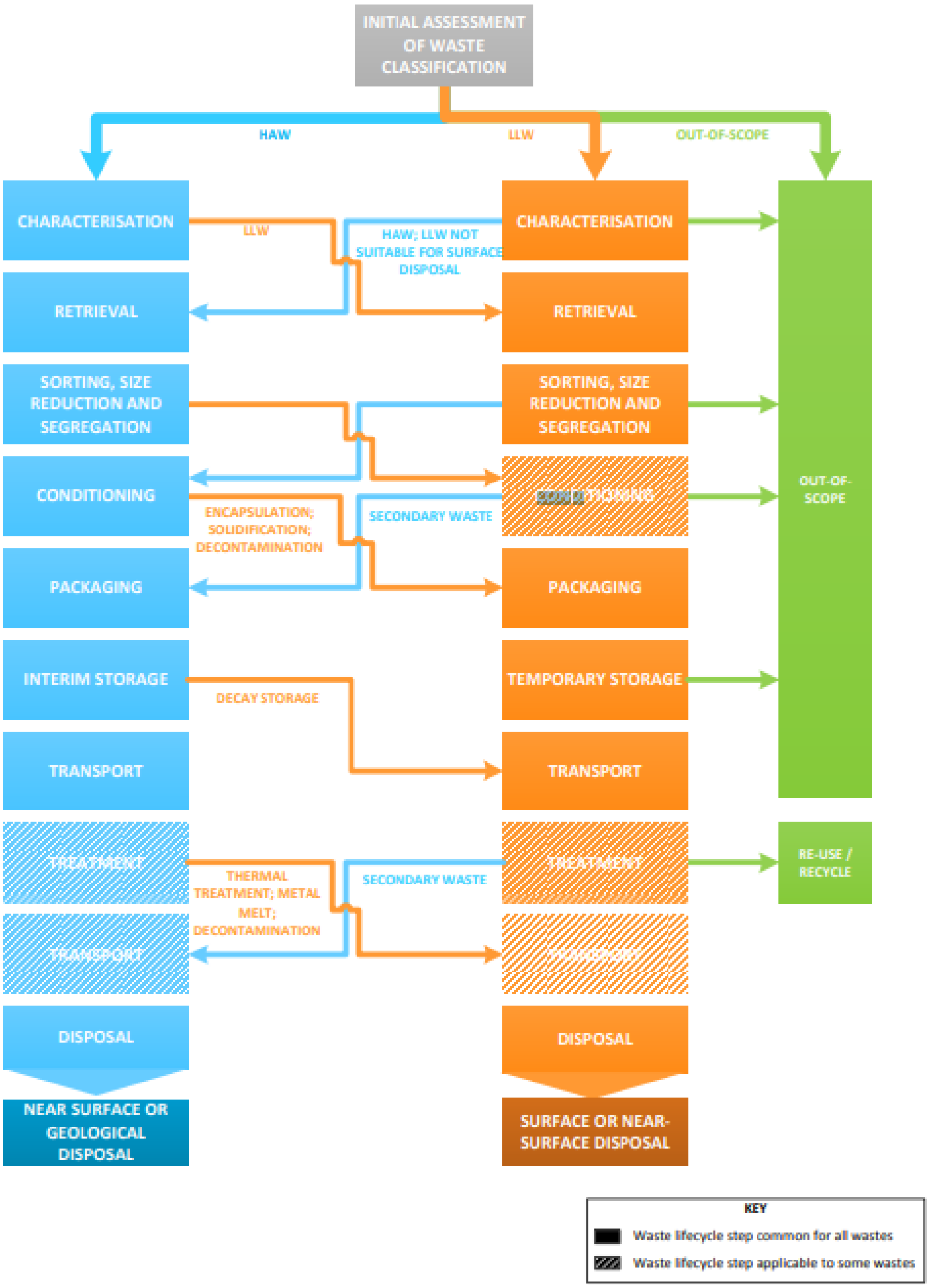

Figure 3 Radioactive waste management – lifecycle steps and integration opportunities. Reproduced from Figure 2 of the UK LLW Strategy.

A3. Regulation

A1.1 Directives

European Directives deal with radioactive waste and non-radioactive waste separately [18] and the definitions of conventional and radioactive waste in the international legislation are quite different. Hence, the Waste Framework Directive (WFD) controls do not apply to radioactive wastes, even when the radioactivity is a minor polluting element of the waste. There are some exceptions to this (as explained further in [18]).

A series of Directives under the 1957 Euratom Treaty provide the basic safety standards for radiological protection and are applicable to the management and disposal of radioactive waste. Dilution and mixing of waste is addressed at a high level in Article 30 (4) of the 2013 Basic Safety Standards Directive (BSSD) [19], where it is stated that:

*"Member States shall not permit the deliberate **dilution** of radioactive materials for the purpose of them being released from regulatory control. The **mixing** of materials that takes place in normal operations where radioactivity is not a consideration is not subject to this prohibition. The Competent Authority may authorise, in specific circumstances, the **mixing** of radioactive and non-radioactive materials for the purposes of re-use or recycling."* (Emphasis added).

A1.2 Key UK legislation.

Radioactive waste management on a nuclear licensed site is regulated by the ONR, the environment agencies and the local waste management planning authority. ONR regulates the on-site arising and storage of waste from a health and safety perspective, and also regulates transport and security aspects. The environment agencies regulate the disposal and offsite transfer of solid waste, as well as liquid and gaseous discharges into the environment.

A review and keyword search of relevant UK legislation relating to radioactive waste (excluding planning legislation) has been undertaken and the findings are summarised below. Notably, as described below, only "dilution" is explicitly discussed in this legislation.

A1.2.1 Environmental Permitting Regulations and the Environmental Authorisations (Scotland) Regulations 2018

The Environmental Permitting Regulations (EPR) [20] are applicable in England and Wales. The terms blending, mixing and averaging do not appear in this legislation.

The legislation clearly state that if deliberate dilution to below Out of Scope levels occurs, then the radioactive waste or material should be treated legally as being within scope.

"…a substance or article is to be treated as having a concentration of radioactivity which exceeds the value referred to in paragraph 4(2) 5(c)(i) or 6(a) [Out of Scope

levels]*, if a person has diluted the substance or article with the intention of ensuring that its concentration of radioactivity does not exceed that value."*

A similar condition applies to the prohibition of dilution of waste to make it exempt (EPR Schedule 23, Part 6, paragraph 16(2)(a) and 21(4)(a) [21]).

Similar clauses also apply to The Environmental Authorisations (Scotland) Regulations 2018 [22], as reflected in the standard conditions for radioactive substances activities on the treatment of radioactive waste [23].

Such conditions support Article 30(4) of the European Basic Safety Standards Directive, and SEPA note in their consultation documents for these regulations [24] that this *"condition does not prohibit deliberate dilution altogether. It prohibits deliberate dilution to remove the radioactive substance from regulatory control, except in specific situations, where this has been authorised in your permit. SEPA expects any dilution to be optimised, and we would strongly recommend that you discuss your plans with us before you undertake any dilution."*

A1.2.2 Nuclear Installations Act 1965

The terms dilution, blending, mixing and averaging do not appear in the Nuclear Installations Act 1965[16] [25].

A1.3 Environmental Permits

Permitting requirements are derived from relevant Government policy and European Directives, as transposed to legislation that applies in the UK. In the permitting process, the relevant environment agency must have regard to applicable legislation, Statutory Guidance, relevant European Commission Recommendations and statements of Government policy and national strategies.

Principal requirements on disposals are based on providing protection of human health and the environment both now and in the future. For solid waste disposals the demonstration that this overarching requirement is ultimately being met is provided by an Environmental Safety Case (ESC) in the case of near-surface disposal sites [26], or a Site-Wide Environmental Safety Case (SWESC) in the case of disposals made on nuclear licensed sites [27], or both an ESC and a SWESC in the case of a disposal facility that is also a nuclear licensed site. ESCs and SWESCs are both underpinned by radiological and non-radiological assessments that assess the risks to human health and the environment. These assessments will necessarily include an assessment of the effect of any locally higher activity concentrations, for instance the effects of the disposal of any radioactive particles or visually identifiable objects [28]. Assessments of this kind may lead to Waste Acceptance Criteria (WAC) prohibiting the activity concentration of certain items (e.g. Discrete Item Limits as implemented by LLW Repository Ltd [29]).

[16] Nuclear Installations Act 1965 has been updated (last published update 22 July 2019) and there are changes that may be brought into force at a future date.

Extant ESCs demonstrate that there is already provision for the disposal of consignments containing heterogenous wastes with different activity concentrations and suggest that the overarching requirement with regard to heterogeneity is the need to demonstrate adequate protection of human health and the environment both now and in the future.

In current permits for nuclear sites issued under the Environmental Permitting Regulations (applicable in England and Wales) there are a number of standard permit conditions (common to all permits) that are relevant to the scope of this project. Typically, under Section 2 "Operating Techniques" there are requirements similar to the following (although the reader should refer to the text in specific permits as this may vary):

"use the best available techniques in respect of the disposal of radioactive waste pursuant to this permit to: …

(b) minimise the volume of radioactive waste disposed of by transfer to other premises;"

Minimising waste as per Condition (b) (above) is clearly relevant to part of the Waste Management Hierarchy (WMH), as described above.

Under Section 3.1 "Disposals of radioactive waste", there are specific requirements relating to compliance with Waste Acceptance Criteria (WAC) and specific requirements relating to mixing and dilution. Typically these will require the operator to:

"only dispose of solid radioactive waste on the premises, other than in a disposal facility:

…

(ii) if all the relevant radioactive waste acceptance procedures have been completed and the waste fulfils the relevant radioactive waste acceptance criteria, if any, as specified in the site-wide environmental safety case, unless otherwise agreed in writing by the Environment Agency; and

(iii) it has ***not been diluted or mixed*** *except where this represents the application of the best available techniques;"*

Once again, the reader should refer to the text in specific permits as the form of words may vary between permits.

The first of these conditions (ii) requires that the relevant WAC are complied with and hence WAC conditions are highly relevant. WAC typically provide the most detailed, prescriptive requirements of relevance to the scope of this document and permit requirements essentially make WAC compliance a legal requirement under the permit. Condition (ii) clearly introduces the possibility of dilution or mixing where this represents BAT[17].

Permits relating to disposal facilities with associated ESCs may also include specific details of relevance to the context of this project. For example, the disposal permit issued to the LLWR (EPR/YP3293SA) has the following:

"*Table S3.4 Disposal by burial on the premises of the LLWR permit, states:*

Solid radioactive waste, ***including any immediate packaging,*** *in which the activity of alpha emitting radionuclides does not exceed 4 gigabecquerels per tonne and the activity of all other radionuclides does not exceed 12 gigabecquerels per tonne when* ***averaged over a consignment***." (bold emphasis added).

This implies that averaging over a consignment is anticipated and indicates that immediate "packaging" (which includes any sack, drum, container or wrapping as per the definitions in the permit) is a legitimate part of any average. As noted above, the facility WAC will be specified to ensure that such permit requirements are complied with. EA and its predecessors have long recognised that averaging over wastes is allowable as part of the practicalities of effective radioactive waste management. At what is now the LLWR site, the authorisation under the Radioactive Substances Act which was extant in the 1970s and 1980s allowed averaging of the activity of all the wastes disposed of the site in a day, for comparison with the authorised limits. When the authorisation was updated in 1988, this requirement was replaced by allowing averaging over a consignment, defined at that time as a lorry load or a skip.

In Scotland, integrated authorisations issued under the "Environmental Authorisations (Scotland) Regulations 2018" appear to include very similar controls to those arising from permitting under EPR. These are as set out in the accompanying guidance, "Guide to standard conditions for radioactive substances activities" [30].

[17] For this review we use the words directly taken from the current permit template (as supplied by the Environment Agency on 17/07/19, personal communication to the project team). Note that these words may differ from extant, issued permits based on older versions of the standard permit, for example: *"(b) it has not been diluted or mixed solely to meet condition ….(a) or any other condition of the permit."* The quoted text is the new wording for nuclear site permits and relates to disposals under the Guidance on Requirements for Release from Radioactive Substances Regulation (GRR) [27]. The wording is intended to place emphasis on justifying that any mixing or dilution is BAT and is intended to address a perceived conflict between the original mixing and dilution clause and achievement of optimisation in waste management, as noted by some waste producers. The revised permit condition is intended to help ensure that operators consider the wider conditions of the permit and the full lifecycle of waste from prevention to disposal and to provide a link to compliance with relevant permit conditions.

A1.4 Site Licence

ONR's nuclear site licences include several standard licence conditions that are directly relevant to waste [31]. There is a requirement to implement adequate arrangements for minimising so far as is reasonably practicable the rate of production and total quantity of radioactive waste (under Licence Condition 32: Accumulation of radioactive waste), and one requiring disposal in accordance with applicable environmental permits (as set out in Licence Condition 33: Disposal of radioactive waste).

The terms dilution, blending, mixing and averaging do not appear directly, but some aspects are described in related regulatory guidance (see Section A1.6.3).

A1.5 Radioactive Waste Transport

Radioactive wastes are assigned to Class 7 under the Carriage of Dangerous Goods (CDG) 2009 regulations. The International Atomic Energy Authority (IAEA) radioactive waste transport regulations (SSR-6) [32] are not binding in UK legislation. Nevertheless, these IAEA "regulations" are used as the basis of the regulatory approach for radioactive waste transport in the UK, as enforced by the Office for Nuclear Regulation (ONR) as the competent authority. Many of the requirements are of a prescriptive nature and therefore significantly influence waste transport packaging and any limitations on package contents.

The term *mixing* does not specifically appear. The regulations discuss mixtures of radionuclides, as per the definition of the activity concentration limits for waste packages, limits for exempt materials and/or the activity limit for an exempt consignment in the case of a mixture.

Averaging is discussed in relation to:

- Low specific activity (LSA) material means radioactive material that has a limited specific activity, or radioactive material for which limits of estimated average specific activity apply (as per Paragraph 226). External shielding materials surrounding the LSA material are specifically not be considered in determining the estimated average specific activity. Specific aspects of averaging are further stipulated for the LSA Types I-III (as per Paragraph 409).
- Surface contaminated object (SCO) comprise three groups SCO I-III (as per Paragraph 412). For each group there are specific averaging requirements in term of the surface area to be included in any average, the nature of the contamination (fixed or non-fixed) and the associated specific activity limits by radionuclide type (broadly defined by emitter type and toxicity).
- Averaging is also considered in relation to package properties, specifically: non-fixed contamination on the external surfaces of any package (Paragraph 508) and average surface heat flux (Paragraph 565).

A1.6 UK Regulatory Guidance

A1.6.1 Guidance issued by the environment agencies

The Environmental Principles for Radioactive Substances Regulations [33], as issued by the Environment Agency, set out the following relevant principles:

"65. The best available techniques should be used to prevent the mixing of radioactive substances with other materials, including other radioactive substances, where such mixing might compromise subsequent effective management or increase environmental impacts or risks.

66. Considerations:
- *The requirements of subsequent radioactive substance management steps through to disposal should be considered before mixing radioactive substance streams, including with other materials. Such steps include the ability to store, characterise, retrieve, treat, condition, and dispose.*
- *Segregation of radioactive substances should be addressed when designing new facilities.*
- *Mixing of radioactive substances should be prevented where the mixing is with other substances or materials with incompatible physical or chemical properties.*
- *Mixing of radioactive substances, including with other materials, may be undertaken where this facilitates subsequent management.*
- *Mixing of radioactive wastes to increase their total volume should only be carried out when it is a stage in the use of the best available techniques to manage the wastes.*
- *The degree to which wastes that are already mixed should be segregated should be determined as part of the assessment of what are the best available techniques to manage the wastes."*

but also note,

"63. When making decisions about the management of radioactive substances, the best available techniques should be used to ensure that the resulting environmental risk and impact are minimised."

and that "*preference should be given to preventing and minimising releases by concentrating and containing activity rather than by relying on dilution and dispersion of the release, particularly for radionuclides that have long half-lives and accumulate in the environment."*

The need for optimised waste management is further reinforced for Higher Activity Radioactive Waste in the Joint Guidance for the Management of Higher Radioactive Waste on Nuclear Licensed Sites (issued by EA, ONR, SEPA and NRW) [34]:

"183. Mixing of wastes need not be precluded where this can be shown to provide net benefits in terms of health, safety and environment. Dilution solely for the purposes of re-categorisation to a lower category, however, should be avoided (e.g.

deliberate mixing of ILW with inactive or lower activity waste to yield a larger volume of LLW).

…

198. For some wastes, e.g. those with a high degree of homogeneity, it may be appropriate to condition the raw waste directly with minimum pre-treatment or sorting and segregation. However, this will not be appropriate for all wastes.

199. Sorting and segregation of wastes should be adopted, where practicable, if this provides:

- *a net benefit in terms of radiological risks overall; or*
- *significantly reduces HAW disposal volumes; or*
- *significantly reduces risks and/ or uncertainties for future waste management*."

A1.6.2 Government Guidance on Exemption

The exemption conditions relating to the disposal of low volumes of solid radioactive waste are supported by radiological impact assessments that demonstrate the relevant dose criteria are unlikely to be breached under all foreseeable circumstances. The Scope of and Exemptions from the Radioactive Substances Legislation in England, Wales and Northern Ireland Guidance document [35] notes that: "*The assessment was based on known common practice:*

• A waste producer, at the point of origin, places waste in a container such that the radioactive content is no more than the concentration limits in Table 3.3 [Exemption levels].

• A batch of such wastes is dispatched to a waste management company.

• The receiver of the waste – the waste management company – disposes of the batch to a landfill or incinerator, possibly following a sorting step.

• The waste management company disposes of several batches of nonradioactive waste immediately prior to, and again after, the disposal of the radioactive batch."

The guidance document notes that the exemptions provisions were intended for 'small users' of radioactive materials, and that the exemption levels are based on the historical disposal of such wastes via the dustbin leading to a volume of 0.1 m^3 being established in the exemptions provisions. As such, a maximum quantity of waste to which the exemptions apply over a given period is stated.

The guidance also notes that, "*nuclear sites are not precluded from using these provisions in the event that they may be appropriate. A principle employed in these exemption provisions is to the effect that the source of radioactive waste is not important; the risks posed by the same radionuclides at the same concentrations do not depend on the source of the waste."*, Nevertheless, it is also noted that "*where dilution by co-disposal as described above is not expected to take place, then the exemption does not apply."*

The guidance also details an exemption condition for low volume solid low-level radioactive waste that waste *"must be transferred to:*

(a) A person who disposes of substantial quantities of non-radioactive waste and where the radioactive waste will be mixed with such nonradioactive waste;

(b) a waste permitted person; or

(c) where the waste is a sealed source, an electrodeposited source or a tritium foil source, to a licensee of a nuclear site or to a person who is situated in another country who is lawfully entitled to receive such waste."

Whilst acknowledging that "*waste producers will not necessarily be certain that this condition will be fulfilled*", the guidance also notes that if the waste producer has made some arrangement with the waste disposer such that the likelihood of co-disposal with significant quantities of non-radioactive waste is not demonstrably the case, then the waste disposal is not exempt.

A1.6.3 Guidance issued by The Office for Nuclear Regulation

Mixing is addressed in the Office for Nuclear Regulation's Safety Assessment Principles (SAPs) [36], which stipulate that mixing of different types of nuclear matter should be justified in the safety case (Paragraph 486). Further, the Radioactive Waste Management SAP on characterisation and segregation states that radioactive waste should be characterised and segregated to facilitate its subsequent safe and effective management. Specifically, Paragraph 806 notes that:

"Decisions to mix waste streams need not be precluded if it can be properly justified and provide a net benefit in favour of safety or environmental factors including the later safe management of the waste through to disposal. Where radioactive waste is to be mixed with other wastes or materials, their mutual compatibility should be established in the safety case. Mixing of incompatible wastes should be prevented. Dilution of wastes solely to reduce their category should be avoided."

The SAPs also note that the generation of radioactive waste should be prevented or, where this is not reasonably practicable, minimised in terms of quantity and activity. The ONR also produces a Technical Assessment Guide (TAG) on the management of radioactive waste [37], which reiterates the SAPs on radioactive waste management, notes that the application of the waste hierarchy is required and notes that the *"anticipated disposal route should be taken in to account in the management of radioactive wastes".*

The TAG on decommissioning [38] clarifies that the ONR Fundamental Objective of Optimisation of Protection should be taken to include environmental protection. However, there is no explicit mention of the terms "mix", "blend", "dilute" or "average" in the relevant ONR TAGs.

As noted above, the ONR are one of the regulators who issued the Joint Guidance for the Management of Higher Radioactive Waste on Nuclear Licensed Sites.

Appendix 2: Case Studies

Case Study Title:	*1. Sorting and segregation of a mixed radioactive stream*

Description:

A mixed radioactive waste stream is segregated on site (in England) in a suitably designed waste sorting and segregation facility. LLW are disposed to the LLWR or via appropriate LLW diversion routes, including metals sent for recycling and combustible wastes sent for incineration. Higher activity waste components are separated, conditioned and stored pending geological disposal.

Supporting information:

Analysis:

All principles were complied with in this case and we note the following aspects in particular:

Principle 1: Government policy and strategy alignment.

The Waste Hierarchy is applied, and wastes are consigned to routes that conform with relevant policy statements.

Principle 2: Ensuring an optimised approach.

This approach is optimised so long as risks during sorting and segregation are kept ALARP.

Principle 3: Regulatory compliance.

Higher activity wastes are conditioned promptly, and LLW is disposed in a timely manner.

All disposals are made to sites that are appropriate to receive them and in compliance with environmental permits.

Outcome:

Acceptable segregation.

Case Study Title:	2. *ILW items consigned with LLW for disposal to LLWR*

Description:

ILW items arise routinely from operations at a site in England and are stored in ancillary buildings in secure storage. These items are ILW (from >12 GBq t^{-1} to several 100s GBq t^{-1}) and will remain as ILW post-conditioning (around 60 GBq t^{-1} post conditioning). It is proposed to co-dispose with other lower activity LLW to meet the consignment specific activity limits for disposal to the LLWR.

Supporting information:

The consignor BAT case argues that prompt disposal of the ILW component to the LLWR, when mixed with lower activity LLW to meet the LLWR activity limits, is lower risk than storage pending geological disposal. An added argument is that this avoids the need to build further interim storage capacity, with attendant cost and future decommissioning burden.

Analysis:

The proposal was rejected for disposal at the LLWR on the basis that this was considered dilution as the items, even post conditioning, are ILW. Mixing was for the purposeful intent of diluting the ILW with LLW and hence producing a consignment that meets the specific activity limits for the LLWR rather than seeking to use optimised routes better aligned to the nature of the waste.

The following principles were not complied with in this case:

Principle 1: Government policy alignment.

The proposal is contrary to the long-term management policy of the UK government (England and Wales), which is to package and hold HAW in secure interim storage until they can be transferred to a GDF.

Principle 2: Ensuring an optimised approach.

Whilst benefits to the consignor are clear the proposal places an undue burden on the disposal facility that is designed to safely dispose of LLW (not HAW). The consignee assessment concluded that the approach did not represent BAT, in addition to not meeting the facility WAC as described below (must be consistent with the disposal route to ensure BAT).

Principle 4: Compliance with waste acceptance criteria.

The proposal leads to considerable activity heterogeneity within the consignment, as such it is not consistent with L3.2.3, "Activity Heterogeneity and Discrete Items" of the LLWR WAC [29]. Specifically, this requires that waste, "*must not be mixed with other wastes solely for the purpose of re-categorisation of the waste as acceptable for disposal at the Low Level Waste Repository.*"

Outcome:

Unacceptable mixing.

Case Study Title:	3. *Mixing of borderline ILW waste and LLW in a consignment for disposal at the LLWR.*

Description: Borderline waste (LLW with suspected regions or components of high end LLW/low end ILW comprising a small fraction of the waste overall) from the same facility are consigned together as it is impracticable to segregate the waste (e.g. co-retrieved pond skips and furniture with varying degrees of contamination that would require extensive cutting efforts to segregate for which radiological risks to workers would not be ALARP). The average activity concentration over the mass of waste in the consignment is below the upper LLW limits even though some discrete parts of the mixed waste may be classed as ILW if considered in isolation and depending on the averaging volume that is used.

The waste is consigned as LLW, but specific regions or items may exceed activity concentration limits if considered in isolation. Any items that exceed the activity concentration limits are compliant with LLWR's Discrete Item Limits.

Supporting information:

A BAT case is provided that details how the approach taken:

- avoids costly, hazardous and detailed segregation and associated worker risk and dose impacts;
- enables prompt disposal (and hazard reduction) relative to storage of the higher activity waste stream components pending a future disposal route (with associated additional costs and uncertainties);
- makes best use of the disposal volume at the LLWR because the consignments are near to the LLW activity limits.

Analysis:

All principles were complied with in this case and we note the following aspects in particular:

Principle 1: Government policy and strategy alignment.

Disposing of regions and components of ILW to LLWR that are readily segregable would be contrary to the long-term management policy of HAW produced by the UK government, which is to package and hold HAW in secure interim storage until they can be transferred to a GDF. However, in this case, the small ILW component is not easily segregated from the bulk LLW waste.

Principle 2: Ensuring an optimised approach.

The BAT case argues that, given compliance with the heterogeneity requirements of the LLWR WAC, consignment to LLWR is an acceptable prompt disposal outcome. Disposal without extensive segregation avoids costly and potentially high hazard and worker dose intensive cutting operations to segregate small regions of waste. As the waste complies with the LLWR WAC (and by inference the LLWR ESC) the case argues that risks are ALARA.

Principle 3: Regulatory compliance. The consignment is considered compliant as radiological risks are reduced ALARP/ALARA, and all permit conditions and other regulatory requirements are met. *Principle 4: Compliance with WAC.* Whilst there is heterogeneity in activity within the consignment this is limited and considered acceptable such that it is judged to meet the requirement that, *“The total Specific Activity of a Waste Consignment must be a reasonable reflection of the Activity of the waste across the volume of the waste.”*
Outcome: Acceptable for disposal to LLWR

Case Study Title:	4. *Combining of sentencing volumes.*

Description:

The average activity of a sentencing volume is determined to be less than the Exemption or Out of Scope values, but not within the specified confidence level (i.e. 95%) because of measurement limitations. The sentencing volume is combined with other sentencing volumes from the same source to produce a larger compliance volume in order to meet the desired level of confidence for the final disposal volume.

Supporting information:

Characterisation data of the sentencing volumes.

Known measurement limitations.

Analysis:

This is an acceptable activity because any *dilution* (or *mixing* with waste that is more confidently Exempt or Out of Scope) occurs after sentencing and the purpose is solely to improve confidence levels, not to alter the apparent characteristics of the waste or material. The different sentencing volumes come from the same source, and so have similar physical, chemical and radiological characteristics.

All principles were complied with in this case and we note the following aspects in particular:

Principle 1: Government policy and strategy alignment.

The proposed approach is aligned with the Waste Management Hierarchy by ensuring that the production of radioactive waste is minimised.

Principle 2: Ensuring an optimised approach.

The approach taken avoids unnecessary disposal of Exempt or Out of Scope waste as radioactive waste.

Principle 3: Regulatory compliance.

The approach taken is fully complaint with legislation because the *mixing* has occurred after sentencing and is solely to increase confidence levels.

Outcome:

Acceptable *mixing* and *averaging.*

Case Study Title:	*5. Excavation of contaminated land for disposal.*

Description:

Soil contaminated with radioactivity has been characterised as suitable for disposal to a landfill with a permit for the disposal of LA-LLW (< 200 Bq g^{-1}). Whilst using an excavator to remove soil contaminated with radioactivity, non-contaminated soil is excavated and included within the disposal volume. The activity concentration of the overall waste volume as a whole is reduced accordingly, but the waste is still disposed to landfill.

Supporting information:

Characterisation data are available that identify the extent of the contamination. Excavation and segregation methodologies are written based upon these data to minimise the excavation of additional non-contaminated material. These methodologies are fed into method statements, risk assessments and working instructions, and robust works control systems are employed to assure adherence to the identified controls.

Analysis:

This is an acceptable activity because non-contaminated excavated soil volumes are minimised and clean soil is not deliberately introduced to purposefully *dilute* the activity concentration. Any *dilution* is purely a consequence of the retrieval approach and the projected waste category has been determined prior to excavation and is then confirmed by sampling, so the *mixing* of the non-contaminated soil and the contaminated soil will have no effect on the final disposal route, and no implications for compliance with that disposal route.

All principles were complied with in this case and we note the following aspects in particular:

Principle 1: Government policy and strategy alignment.

The amount of non-contaminated material excavated has been minimised, and waste has been diverted away from the LLWR.

Principle 2: Ensuring an optimised approach.

Risks are kept as low as reasonably practicable by ensuring that all of the radioactive waste is excavated and disposed to a suitable facility, whilst ensuring the volume of such waste is minimised.

Principle 3: Regulatory compliance.

The precautionary principle has been applied. The risk that any significant radioactive contamination is left in-situ is avoided by consigning a small amount of non-contaminated material to a landfill with a permit for the disposal of radioactive waste.

Principle 4: Compliance with WAC.

Careful recording of the average activity concentration of the excavated waste is required to ensure that there is a clear distinction between the activity concentration of the contaminated soil, and the activity concentration of the excavated soil that includes clean material. Lack of care in this regard may lead to an overestimate in total activity consigned to the landfill by application of the activity concentration in the contaminated soil to the entire excavated volume.
Outcome: Acceptable *dilution*, *mixing* and *averaging.*

Case Study Title:	6. *Use of VLLW soil / spoil /rubble as LLW disposal container infill*

Description:

The voidage within an LLW HHISO container containing high-dose ILW items is filled with VLLW soil, spoil, rubble and excavation material on the grounds that this enables the disposal volume within the container to be better utilised.

However, such practice also provides a bulk of material to lower the specific activity of the consignment, enabling the consignment of high-dose items that are clearly ILW.

The consignment is rejected on the basis that this is deliberate dilution with the sole purpose of recategorising waste to enable disposal to the LLWR.

Supporting information:

Analysis:

This has historically been common practice, but is no longer deemed acceptable, particularly given the availability of landfill disposal options for VLLW. In addition, inclusion of such loose material within a disposal container can preclude successful container grouting producing containers that are not suitable within the LLWR disposal concept.

The following principles were not complied with in this case:

Principle 1: Government policy and strategy alignment.

Disposing of ILW to LLWR is contrary to the long-term management policy of HAW produced by the UK government, which is to package and hold HAW in secure interim storage until they can be transferred to a GDF.

In addition, the consignment of VLLW to the LLWR does not preserve the disposal capacity of the LLWR, and such waste should generally be consigned to suitable landfills. The risks from the VLLW are not sufficiently high that their disposal to the LLWR is proportionate.

Principle 2: Ensuring an optimised approach.

Not an optimised outcome given availability of landfill disposal options for VLLW. In addition, the long-term isolation afforded by the LLWR may not suffice for high dose rate ILW items and any isolation is anticipated to be substantially less than that provided by a GDF disposal option for the ILW.

Principle 4: Compliance with WAC.

The argument that the loose material be used to fill disposal container is not without merit, and if the loose material were LLW and the ILW of borderline activity (e.g. could be LLW within measurement uncertainty), then such practice could be acceptable, so long as the material did not prevent the successful penetration of

grout into the container. However, this case is clearly deliberate *dilution* (of ILW) and, in any case, the *diluting* effect of the loose material may not be strong enough to enable the consignment of high-dose items. Addition of loose VLLW material to a consignment may also be acceptable (where there is no available LLW for the same purpose), if it can be demonstrated that the consignment would meet the relevant WAC without inclusion of the VLLW and the material did not prevent the successful penetration of grout into the container. This can avoid disposal of excess quantities of clean grout by utlising waste that would otherwise be sent to commercial landfill, and offers beneficial cost and environmental outcomes. The average activity of the consignment in this case would not be representative of the wastes contained within. *Principle 5: Avoiding incompatibilities in mixed wastes.* The addition of loose material into the disposal container may create an incompatibility with the requirement for grout penetration.
Outcome: Unacceptable *mixing* and *dilution.*

Case Study Title:	7. *Failing to segregate building rubble.*

Description:

A building suspected of being contaminated by radioactivity and chemicals is subject to a detailed characterisation campaign, with no obvious sources of contamination identified by non-intrusive surveys. In the absence of contamination identifiable by non-intrusive means, a decision is made to demolish the building in advance of the receipt of intrusive sample analysis results, with the resultant materials placed in segregated stockpiles. On receipt of the analysis results of intrusive samples, it is identified that an area of radioactive contamination was present within the building above the Schedule 23 ‘Out of Scope’ limits, thereby requiring the entire stockpile of building fabric to be treated as potentially contaminated.

Whilst the contamination identified was present within a limited volume of specific building fabric, the demolition and stockpile of materials precludes its identification and segregation. As a result, the entire stockpile of segregated material is treated as potentially contaminated. A sample and analysis programme is undertaken to sentence the waste, based on the average conditions and a suitable confidence level (e.g. the use of the US Environment Protection Agency Data Quality Objectives process).

Supporting information:

Analysis:

Other management approaches are possible once it is known that all the demolition waste must be treated as potentially contaminated. For example:

1. The entire stockpile of material could be treated as contaminated and be disposed as a radioactive waste
2. A desk study could be undertaken to determine the maximum possible extent and inventory of contaminated materials present within the building prior to demolition. Following assessment, a sentencing decision based on an average specific activity of the entire waste volume could be made.

Indeed, the BAT approach in this case could be determined by:

- the level of the contamination, both in terms of volume and activity concentrations, and referenced IAEA guidance on specific numerical criteria;
- the effort required to segregate the waste;
- whether the demolition material was Out of Scope on average;
- the need to think about hot spots being sentenced to a suitable end point to ensure any potential risks are mitigated;
- the type of both radioactive and non-radioactive contamination involved;

- the ability of a disposal facility to accept both the radioactive and non-radioactive contamination;
- guidance available for the management of such wastes (e.g., CL:AIRE).

The following points are noted:

Principle 1: Government policy and strategy alignment.

Demolition of the building prior to the conclusion of suitable and sufficient characterisation activities does not align with Government strategy because radioactive waste arisings have not been minimised. However, subsequent measures to sort and segregate the contaminated waste has rectified the outcome.

Principle 2: Ensuring an optimised approach.

As an overall approach, early demolition of this building was not optimised. More radioactive waste was produced than necessary. However, undertaking a sampling and analysis programme ensures that waste above OoS levels is disposed to a facility where the risk the wastes pose are suitably managed.

Outcome:

An unacceptable case of *mixing* has been rectified through undertaking a sampling and analysis programme.

Case Study Title:	8. *Incineration of ILW and VLLW at the same facility resulting in a VLLW ash product.*

Description:

ILW from one waste producer and VLLW from another waste producer are both consigned to an incinerator facility for combustible waste treatment. Waste combustion results in significant waste volume reduction with a secondary fly ash waste produced at approximately 2% of the original waste mass.

The secondary fly ash from the incinerator is a product of all waste (feed stock) subject to incineration during a combustion campaign, and will include both radioactive and non-radioactive wastes. The levels of contamination present within the fly ash are therefore directly proportional to the overall effective concentration of radioactivity within the feed stock*, which are relatively homogenised as part of the normal incineration process.

Incinerator operators are permitted for the receipt and disposal of radioactive materials and typically employ a strategy of balancing the radioactive content of the incinerator feed stock to ensure that resultant secondary fly ash waste can be disposed of as exempt VLLW to a conventional landfill that does not have a permit for the disposal of radioactive waste.

**Noting that certain radioactive isotopes (e.g. tritium) are volatilized during the combustion process and some of this inventory is discharged from the incinerator as a permitted discharge*.

Supporting information:

Analysis:

It should be noted that the only radionuclides that can currently be incinerated in the UK at ILW levels are tritium and carbon-14.

This is considered as an acceptable activity, based on compliance with the following principles:

Principle 1: Government policy and strategy alignment.

This practice prevents large volumes of waste being disposed and so is consistent with the Waste Management Hierarchy. The approach is cost-effective.

However, this practice is arguably against current government policy for HAW management, which is for deep geological disposal in England and Wales and for long-term storage in Scotland.

Principle 2: Ensuring an optimised approach.

Risks are kept as low as reasonably practicable by managing the feedstock to ensure that sufficient non-radioactive material is *mixed* with any radioactive material to ensure that the resultant ash product is suitable for disposal to a conventional landfill that does not have a permit for the disposal of radioactive wastes.

Homogenisation of the ash waste product is important in ensuring that the risks from the secondary waste are kept as low as reasonably achievable.

Principle 3: Regulatory compliance.

Demonstration of regulatory compliance is provided through compliance with the incinerator's WAC and the incinerator provider meeting the requirements of its environmental permit.

Assurance of the activity concentration in the final waste product could be managed through assurance of the feedstock and following incineration.

Principle 4: Compliance with WAC.

Compliance with the specific incineration operator's WAC (typically specified as a total container activity, rather than a specific activity) is required. The waste product from the mixed waste incineration is compatible with the intended disposal route.

Principle 5: Avoiding incompatibilities in mixed wastes.

Combustible waste treatment may be favourable where there is a non-radioactive hazard (such as lead paint or printed circuit boards)

Outcome:

Acceptable *mixing, dilution* and *averaging.*

Case Study Title:	9. *Retrieval of tank residues*

Description:

A redundant radioactive liquid handling and processing facility is under decommissioning. Following characterisation of the delay tanks, a significant volume of settled sediment was identified as remaining within the delay tanks. The sediment is ILW, which needs removing to initiate the dismantling of the discharge system and consignment of the tanks for metal waste treatment.

A BAT study supports the use of a high-pressure jet washer to dislodge and wash the sediment through the discharge system for collection into a number of containers for filtration followed by the addition of conditioning agents to produce a compliant solid waste for disposal.

Following jet washing and collection, the wastes become LLW due to dilution with clean water. The conditioning and processing of the wastes involves the use of filtration using ash bags to remove the solid component of the waste. Following filtration, the liquid component of the waste is disposed of using a liquid effluent treatment facility. The remaining solid material is now ILW and still contains a low percentage of water content, prohibiting its disposal to a Geological Disposal Facility.

To remove all free liquids (and the risk of generation of free liquids during consignment) and to produce a compliant higher activity waste product for GDF disposal, conditioning agents comprising of cement admixtures are required to be added to the waste. It is calculated that on addition of the required amounts of conditioning agents, the activity in the waste will become LLW and the waste package will meet the LLWR WAC. A subsequent decision is made to dispose of the waste to LLWR. The waste started at ILW, became LLW on washing, became ILW again on filtration and finally became LLW on the addition of the required amounts of conditioning agent.

Supporting information:

Analysis:

The process of changing ILW to LLW by treatment (jet washing, capture on filtration media and conditioning) is considered acceptable in this case. However, there is a need to consider the economies of scale with this approach, in that it may be less beneficial for small items that may be more appropriate to condition in situ and dispose of as HAW.

Other examples of similar cases were noted during the initial workshop for this project. In these similar cases, there was a need for a choice between producing a LLW sludge, which can then be conditioned and sent to LLWR or a dried ILW product (as might be stored in robust shielded containers pending deep geological disposal). The conditioned LLW sediments can be viewed as a by-product of a process that is BAT, however, the alternative options that could be used in this case would need to be understood before it can be determined if the approach taken was the best available. However, it was indicated that a key consideration here for optimised waste management might be the available disposal infrastructure, which would give greater weighting to LLW disposal.

There is also a need to consider whether the ILW solids could be added to another ILW feedstock, such as wet ILW wastes.

All principles were complied with in this case and we note the following aspects in particular:

Principle 1: Government policy and strategy alignment.

The approach taken is consistent with Government policy and strategy because it allows optional consignment of the wastes (e.g. tanks for metallic treatment), which is consistent with the Waste Hierarchy.

Principle 2: Ensuring an optimised approach.

The LLW is disposed to the LLWR, which ensures adequate protection of people and the environment from the risks posed by the LLW. The process undertaken enables the consignment of the metal tanks as unpacked waste items, mitigating the need to size reduce and place into containers, which ensures that doses to workers are kept as low as reasonably practicable.

The dilution of the ILW during jet-washing was undertaken to retrieve wastes, and so is not intended merely to change the waste category. Note that tank retrieval processes may be subject to laws of diminishing returns, where lots of water may be used to retrieve a small amount of activity. Hence, the resource use and production of secondary wastes may prevent this sort of retrieval being BAT in some cases.

The process results in an increase in the volume of sediment that is disposed of. However, it has substantially reduced the overall volume of radioactive waste that is required to be disposed of since, if tanks had been subject to alternative size reduction and decontamination, this would have generated significant volumes of secondary waste in the form of PPE, containment system materials etc.

Principle 4: Compliance with WAC.

Waste cannot be disposed of without meeting the requirements on free liquids and leachability. The process of adding conditioning material was specifically to remove all free liquids and to ensure that the waste was within the required limits for moisture content specified in the WAC.

Compliance with the Discrete Item Limits for disposal to the LLWR will be required for conditioned waste drums.

Principle 6: Mixing and waste conditioning.

The waste has been mixed with the minimal amount of waste conditioning product need to stabilise the waste, which is best practice.

Outcome:

Acceptable case of *mixing* and *dilution*.

Case Study Title:	*10. Incineration of high-dose rate sludge*

Description:

Effluent LLW sludge is contained in 60 kg kegs and has a high-surface dose rate. The sludge is suitable for combustible waste treatment, but the surface dose rate of the keg is greater than that specified in the facility's WAC. To reduce the dose rate, the kegs are placed into IP2 steel drums and surrounded with sand. After such packaging, the surface dose rate is reduced and the waste can be safely consigned for combustible waste treatment.

Supporting information:

Analysis:

This is acceptable on the basis that waste is diverted away from disposal and all safety requirements in the facility WAC are met.

All principles were complied with in this case and we note the following aspects in particular:

Principle 1: Government policy and strategy alignment.

This activity is consistent with Government policy and strategy to divert waste away from disposal.

Principle 2: Ensuring an optimised approach.

Risks to workers are kept ALARP by shielding the effluent sludge with sand. In fact, sand is added as a process aid to protect the incinerator kiln. Packaging of waste in this way therefore reduces the requirement for addition of sand as a process feed. On that basis it does not increase the overall volume of secondary radioactive waste that is produced.

Principle 4: Compliance with WAC.

The mixed waste product is compliant with the facility's WAC.

Principle 5: Avoiding incompatibilities in mixed wastes.

Sand is compatible with incineration, and so no incompatibilities are created in the mixed wastes.

Principle 6: Mixing and waste conditioning.

Sand is added to the drums in optimal quantities to enable the safe handling and efficient treatment of the waste.

Outcome:

Acceptable *mixing.*

Case Study Title:	*11. Consignment of contaminated concrete slabs to a landfill with a permit for the disposal of radioactive waste.*

Description:
Contaminated concrete slabs have a range of activity concentrations between 4 Bq g^{-1} -and 1000 Bq g^{-1}. These are placed together into a container for disposal to a landfill site that is permitted to dispose of radioactive waste The average activity concentration of the consignment is less than 200 Bq g^{-1}, the consignment is compliant with both disposal and transport surface dose rate criteria, and the slabs meet the disposal facility WAC with respect to higher-activity items.

This proposal is acceptable on the basis that radiological risks from disposal of the consignment are kept as low as reasonable achievable, and the approach delivers diversion of material away from the LLWR. All disposal facility WAC are met.

Supporting information:

Analysis:

All principles were complied with in this case and we note the following aspects in particular:

Principle 1: Government policy and strategy alignment.

LA-LLW is diverted away from the LLWR.

Principle 3: Regulatory compliance.

The consignment is compliant with both disposal and transport surface dose rate criteria.

Principle 4: Compliance with WAC.

All relevant WAC are complied with. The average activity concentration of the consignment meets the requirements of the disposal facility.

Outcome:

Acceptable *averaging* of radioactive wastes with a range of activity concentrations.

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