Radioactive Waste Management

WPSGD no. WPS/928/01

Geological Disposal:

Guidance on the disposability of waste packages containing chemical decontamination agents

February 2017

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WASTE PACKAGE SPECIFICATION AND GUIDANCE DOCUMENTATION

GUIDANCE ON THE DISPOSABILITY OF WASTE PACKAGES CONTAINING CHEMICAL DECONTAMINATION AGENTS

This document forms part of the Waste Package Specification and Guidance Documentation (WPSGD), a suite of documents prepared and issued by Radioactive Waste Management Ltd (RWM). The WPSGD is intended to provide a ‘user-level’ interpretation of the RWM packaging specifications, and other aspects of geological disposal, to assist UK waste packagers in the development of plans for the packaging of higher activity waste in a manner suitable for geological disposal.

Key documents in the WPSGD are the *Waste Package Specifications* (WPS) which define the requirements for the transport and geological disposal of waste packages manufactured using standardised designs of waste container. The WPS are based on the high level requirements for all waste packages as defined by the *Generic Waste Package Specification* (GWPS) and are derived from the bounding requirements for waste packages containing a specific category of waste, as defined by the relevant *Generic Specification*.

This document has been produced to assist waste packagers in achieving the safe and efficient packaging of low heat generating wastes that contain chemical decontamination agents.

The WPSGD is subject to periodic enhancement and revision. Users are therefore advised to refer to the RWM website to confirm that they are in possession of the latest version of any documentation used.

WPSGD DOCUMENT NUMBER WPS/928 - VERSION HISTORY		
VERSION	**DATE**	**COMMENTS**
WPS/928/01	February 2017	Initial version of document based on 2010 DSSC and NDA Report No. NDA/RWMD/068.

List of Contents

Abbreviations and acronyms used in this document

DSSC	Disposal System Safety Case
EA	Environment Agency
EBS	engineered barrier system
EDTA	ethylenediaminetetraacetic acid
EPR 10	Environmental Permitting Regulations 2010
GDF	geological disposal facility
GWPS	Generic Waste Package Specification
IAEA	International Atomic Energy Agency
ILW	intermediate level waste
ISA	isosaccharinic acid
LHGW	low heat generating waste
LLW	low level waste
LLWR	Low Level Waste Repository
LoC	Letter of Compliance
NAPL	non-aqueous phase liquid
NDA	Nuclear Decommissioning Authority
PVC	polyvinyl chloride
RWM	Radioactive Waste Management Limited
UV	ultraviolet
WPS	Waste Package Specification
WPSGD	Waste Package Specification and Guidance Documentation

1 Introduction

The Nuclear Decommissioning Authority (NDA), through Radioactive Waste Management Ltd (RWM), is responsible for implementing UK Government policy for the long-term management of higher activity radioactive wastes, as set out in the *Implementing Geological Disposal* White Paper [1]. The White Paper outlines a framework for managing higher activity radioactive waste in the long term through geological disposal, which will be implemented alongside the ongoing interim storage of waste packages and supporting research.

RWM produces packaging specifications as a means of providing a baseline against which the suitability of plans to package higher activity waste for geological disposal can be assessed. In this way RWM assists the holders of radioactive waste in the development and implementation of such plans, by defining the requirements for waste packages which would be compatible with the anticipated needs for transport to and disposal in a geological disposal facility (GDF).

The packaging specifications form a hierarchy which comprises three levels:

- The *Generic Waste Package Specification* (GWPS) [2]; which defines the requirements for all waste packages which are destined for geological disposal;
- *Generic Specifications;* which apply the high-level packaging requirements defined by the GWPS to waste packages containing a specific type of waste; and
- *Waste Package Specifications* (WPS); which apply the general requirements defined by a Generic Specification to waste packages manufactured using standardised designs of waste container.

The WPS, together with a wide range of explanatory material and guidance that users will find helpful in the development of proposals to package waste, make up a suite of documentation known as the *Waste Package Specification and Guidance Documentation* (WPSGD). For further information on the extent and the role of the WPSGD, all of which can be accessed via the RWM website, reference should be made to the *Introduction to the RWM Waste Package Specification and Guidance Documentation* [3].

Chemical decontamination agents have been used in the nuclear industry for many years for a variety of reasons, e.g. to facilitate decommissioning so that operations can be carried out safely with wider manual handling and reduced waste volumes and disposal costs. Some of these operations have, and will continue to, generate waste packages containing amounts of chemical decontamination agents that are expected to be disposed of in a GDF. In some instances, the chemical decontamination agents may have the potential to affect the properties and performance of the waste packages during transport to, and disposal in, a GDF.

This document has been produced to assist waste packagers in the packaging of low heat generating wastes[1] (LHGW) that contain chemical species derived from decontamination agents in a manner that is suitable for geological disposal.

[1] This broad category of waste includes intermediate level waste (ILW) and other wastes with similar radiological properties which can be disposed of in accordance with the same geological disposal concepts as those defined for ILW.

The remainder of this document is structured in the following manner:

- Section 2 provides background information on the manner in which RWM defines the requirements for waste packages, and the role that packaging specifications play in assessing the suitability of proposed waste packages for geological disposal.
- Section 3 discusses the chemicals used in decontamination operations together with the active species found in products.
- Section 4 identifies the wasteform requirements for LHGW and how they might be affected by chemical decontamination agents.
- Section 5 describes how to use the guidance in the development of a packaging proposal for LHGW containing chemical decontamination agents.

2 Background

2.1 The concept of geological disposal

The 2014 White Paper *Implementing Geological Disposal* sets out the UK Government's framework for managing higher activity radioactive waste in the long term through geological disposal, which will be implemented alongside ongoing interim storage and supporting research [1]. Whilst the precise manner in which geological disposal would be implemented in the UK is not yet defined, RWM envisages that any approach to long-term management of waste (including disposal) would comprise a number of distinct stages which could include:

- the manufacture of passively safe and disposable waste packages;
- a period of interim surface storage, usually at the site of waste arising or packaging;
- transport of the waste packages to a GDF;
- transfer of waste packages underground and emplacement in the disposal facility;
- back-filling of the disposal areas; and
- eventual sealing and closure of the facility.

The exact nature, timing and duration of each stage would depend on a number of criteria, including the geographical location and host geology of a GDF, as well as the disposal concept selected for implementation for each distinct category of waste.

2.2 The role of the waste package in geological disposal

The waste package provides the primary barrier to the release of radionuclides and other hazardous materials both during interim storage, transport and when it forms part of a multiple barrier geological disposal system. It can also play a role in protecting individuals from the radiation emitted by the radionuclides it contains during interim storage, transport and the GDF operational period.

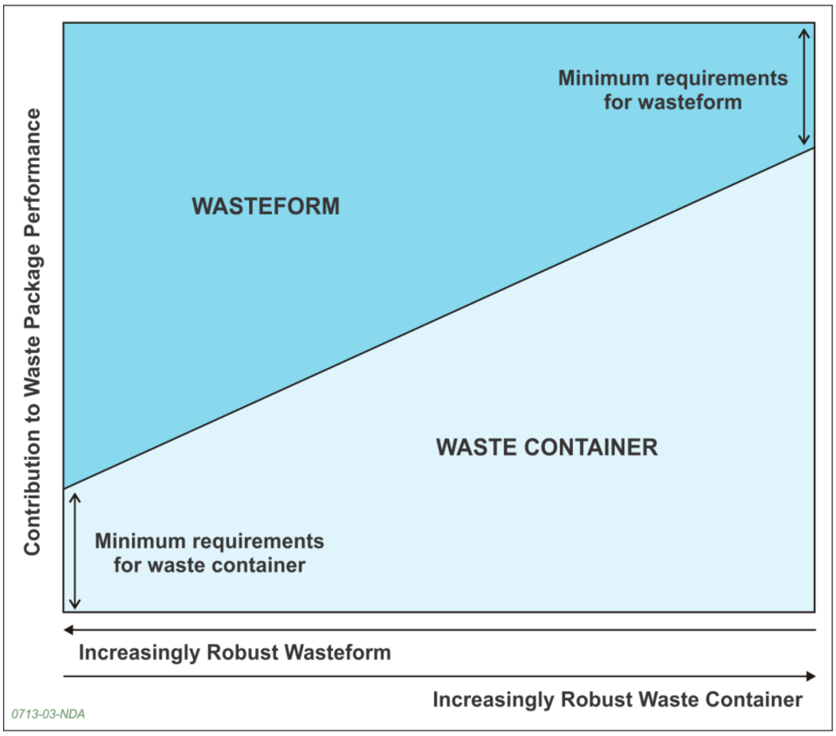
The barrier provided by a waste package can be considered to comprise two components, each of which can act as a barrier in its own right as part of an overall engineered barrier system (EBS):

- The waste container, which provides a physical barrier and also enables the waste to be handled safely during and following waste package manufacture. Containers can be manufactured from a range of materials with designs selected to suit the requirements for the packaging, transport and disposal of the wastes they contain.
- The wasteform, which can be designed to provide a significant degree of physical and/or chemical containment of the radionuclides and other hazardous materials associated with the waste. The wasteform may comprise waste which has been 'immobilised' (e.g. by the use of an encapsulating medium such as cement) or that which may have received more limited pre-treatment prior to packaging (e.g. size reduction and/or drying).

Packaging specifications are designed to address the performance of the barrier(s) provided by the waste package. They do this by defining requirements for waste packages which have been derived from the needs relating to their long-term management.

Both the waste container and the wasteform can contribute to achieving the required performance of a waste package, the relative importance of each generally depending on the robustness of the former. This is illustrated in Figure 1 which shows in stylised form how the use of a more robust waste container can reduce the required contribution of the wasteform to overall waste package performance. Figure 1 also shows that for all waste packages both the waste container and the wasteform will be required to play some role. It should also be noted that it is the overall performance of the waste package, rather than that of its two components, that is the governing factor in judging its disposability.

Figure 1 Relative contribution of the waste container and the wasteform to waste package performance



2.3 Waste containers and wasteforms used in the packaging of LHGW

2.3.1 Waste containers

A variety of waste container designs have been proposed for the packaging of LHGW for geological disposal. These designs can be grouped into three basic types, on the basis of the general nature of the waste packages they are used to produce:

- For use with LHGW with low specific activity, such as would not generally require the extensive use of remote handling techniques, waste containers, typically made from thin section stainless steel and/or concrete, and incorporating integral radiation shielding[2] can be used to create *shielded waste packages.* Such waste packages would generally be expected to be capable of being transported through the public domain without additional protection and would therefore qualify as transport packages in their own right.

- For use with LHGW with higher specific activity, such as would generally require the use of remote handling techniques, waste containers typically made from thin-section stainless steel, can be used to create *unshielded waste packages.* Because of their high external radiation dose rate, or requirements for the containment of their contents, such waste packages would be expected to be transported through the public domain in a protective transport container.

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[2] If needed, to ensure that external radiation dose rates do not exceed the regulatory limits for transport.

- For all types of LHGW, thick-walled (i.e. many 10’s of mm) containers, typically made from ductile cast iron, can be used to provide both radiation shielding and physical containment of their contents, and to create *robust shielded waste packages.* Such waste packages are capable of being stored, transported and disposed of without the need for remote handling techniques or for additional shielding or containment.

2.3.2 Wasteforms

Waste can be packaged using two basic approaches to their conditioning; with or without the use of an encapsulating medium. In the latter case, the waste will only be subject to basic conditioning processes, such as size reduction, compaction and/or drying. The use of a ‘non-encapsulated’ wasteform is not suitable for all types of waste container/waste combinations but can have significant cost advantages when it is suitable.

A range of wastes have been packaged for geological disposal using conditioning processes that involve encapsulation of the waste using a cementitious or polymeric encapsulant material. Three basic approaches to the ‘intimate encapsulation’ have been used, or proposed for use, with a range of intermediate level waste (ILW); grout infilling of heterogeneous solid wastes, in-container mixing of fluid wastes with grout, and external mixing of waste and grout followed by pouring the mixture into the waste container. Encapsulation has also been achieved by surrounding the waste, which may have been compacted, with an annulus of grout to form an ‘annular grouted’ wasteform.

RWM has produced guidance containing more information on the production of both types wasteform [4,5].

2.4 The assessment of packaging proposals

RWM has established the Letter of Compliance (LoC) Disposability Assessment process [6] to support waste producers in the development of plans to package higher activity wastes. Specifically, the Disposability Assessment process is used by RWM to demonstrate that proposals to package waste would, if implemented, result in ‘disposable’ waste packages. In this context a disposable waste package is one that is compliant with all of the relevant regulations and safety cases for transport to and disposal in a GDF, and in line with regulatory expectations for the long term management of the waste [7].

The Disposability Assessment process also plays an important role in underpinning the generic *Disposal System Safety Case* (DSSC) [8] by providing confidence that the safety cases for the transport and disposal of waste, which are based on generic assumptions regarding the wastes that are anticipated to be accommodated by a GDF, are compatible with the ‘real’ waste packages that are being manufactured. The performance of disposability assessments also helps to show that the disposal concepts considered within the generic DSSC will be appropriate for the wastes they will be expected to cover, as well as identifying wastes that could challenge current disposal concepts and allow early consideration of the changes that may be required to these concepts to permit these wastes to be accommodated.

General guidance is available on the manner in which waste packagers should prepare submissions for the disposability assessment of packaging proposals [9]. Where wastes contain chemical decontamination agents, this should be acknowledged in disposability assessment submissions, and the submissions should contain sufficient information to allow RWM to assess their potential significance. Assessment areas that are likely to be of particular importance are Wasteform and Post-closure safety (further information on the potential impacts of chemical decontamination agents in these areas is presented in Section 4).

3 The use of chemical decontamination agents

3.1 Introduction

Decontamination in the nuclear industry is carried out for a variety of reasons:

- to reduce the radiation dose to operators;
- to remove the build-up of deposits to improve plant efficiency;
- to reduce the quantity of waste requiring geological disposal; and
- to facilitate decommissioning so that operations can be carried out safely with less radiation exposure to workers and reduced waste volumes and disposal costs.

A wide range of products are used in decontamination operations on internal and external surfaces of equipment, plants and structures, including commercially available products and those developed by the nuclear industry. They generally fall into two categories:

1. Detergents and cleaners:
    - specialist products developed by the nuclear industry;
    - commercially available products used by laboratories and industries; and
    - commercially available household cleaning products.
2. Paints, fixatives and coatings:
    - temporary peelable coatings developed for industrial use;
    - a very wide range of paints available commercially with varying compositions and properties used in a large number of applications outside the nuclear industry; and
    - PVA adhesive and expanding foams developed for a variety of uses outside the nuclear industry.

The range of materials is very varied and likely to become more so as more products enter the market and are used by waste producers. Since the composition of many commercial products is not readily available, this document aims to provide guidance on the disposability of the chemical species present in these products, rather than on the products themselves. In terms of chemical compositions, there is some overlap between the two categories of materials; for instance, some strippable coatings contain some of the same active ingredients as detergents and cleaners. The chemical species that can be found in products used in decontamination operations are presented in the tables in Appendix A.

The following sub-sections present further information on each of the two categories of chemical decontamination agents in turn.

3.2 Detergents and cleaners

Detergents and cleaners are generally used to remove surface contamination by washing and wiping during decontamination operations. A range of household products and specialised radioactive decontamination agents are in frequent use in the nuclear industry. Household cleaning products are available in various forms: liquid, powder, gel and impregnated wipes. A modern household detergent or cleaning product might contain many ingredients, with the formulation not often openly published. In addition to household cleaning products, some specialist radioactive decontamination agents are also used for the treatment of wastes. These agents have typically been developed based on the ingredients used in conventional detergents and cleaners and are therefore not fundamentally different to household cleaning products, although there are some differences in their typical compositions.

Detergents and cleaners are typically used in relatively small amounts in radioactive decontamination work, and much of the material that is used will often be absorbed on solid materials and routed as solid Low Level Waste (LLW) to the LLW Repository (LLWR) or disposed of in bulk liquor form via liquid effluents streams, rather than being disposed of as LHGW. Detergents and cleaners typically contain a high proportion of water, and given that most active ingredients in detergents and cleaners are typically present at concentrations of only a few weight percent, it seems unlikely that more than gram quantities of any of the ingredients would be present within individual waste packages containing LHGW. Some traces of detergents and cleaners might remain on the surfaces of waste items that have been decontaminated, although the amounts in such a form are likely to be very small. The majority of any applied detergent or cleaner is likely to be rinsed or wiped off the item being decontaminated. Detergents and cleaners are most likely to find their way into LHGW in the form of soft wastes such as swabs, absorbent materials, tissues and wipes used to apply and remove materials from the surfaces being decontaminated.

3.3 Paints, fixitives and coatings

Paints, fixatives and coatings are used to fix radioactive contamination on internal and external surfaces of equipment, plant and structures, and thereby prevent the release of activity into the environment. Some types of coatings, often termed strippable coatings, are used to remove loose contamination, by adhesion of solid material to the coating, thus leaving a relatively clean surface. A very wide range of paints, fixatives and coatings with different compositions and properties are available commercially, and these are used in a large number of applications outside of the nuclear industry. Most are based on organic polymers, although some based on inorganic binders are also available. The organic polymers found in these products are commonly found in many other materials (e.g. plastics and rubbers) and products (e.g. adhesives). Early forms of strippable coatings were based on latex rubber, sometimes with added detergents. A variety of strippable coatings are now available with many having a wide range of applications outside the nuclear industry. The compositions of these products are not openly declared or published; however, some are known to also contain potential complexing agents.

When used to fix contamination, paints and fixatives are expected to be left in-situ on items of waste. Strippable coatings may be left in-situ or they may be removed from decontaminated items and disposed of separately. The amounts of these materials that might be present as part of a waste package inventory are not expected to be greater than the amounts of similar materials found in other LHGW packages, e.g. in the form of contaminated plastics and rubbers.

4 Application of the wasteform requirements for LHGW containing chemical decontamination agents

4.1 Introduction

Materials used in decontamination operations that are present in LHGW will form part of the wasteform in waste packages destined for disposal to a GDF. The generic specification for waste packages containing LHGW [10] requires that the physical, chemical, biological and radiological properties of the wasteform shall (i) make an appropriate contribution to the overall performance of the waste package; and (ii) have no significant deleterious effect on the performance of the waste container. These requirements must be met not just at the time of wasteform production, but also as the wasteform evolves over time as a result of chemical, biological and radiation-induced processes.

The wasteform specification for waste packages containing LHGW [11] identifies and defines requirements for a range of specific wasteform properties that may have an influence on the ability of the wasteform to make an appropriate contribution to overall waste package performance. These are listed in Table 1.

Table 1 Wasteform properties and their requirements [11]

Wasteform property	Requirement
Physical immobilisation	The wasteform shall be designed to immobilise radionuclides and other hazardous materials so as to make an appropriate contribution to waste package performance during all stages of long-term management.
Mechanical and physical properties	The wasteform shall be designed to provide the mechanical and physical properties necessary to ensure appropriate performance of the waste package during all stages of long-term management.
Chemical containment	The wasteform shall not be incompatible with the chemical containment of radionuclides and hazardous materials as embodied in the requirements of a GDF. Where they may affect chemical containment, the following items should not be introduced through waste conditioning or packaging, and their presence in wastes should be minimised wherever practicable: • oxidising agents; • acids and/or materials that degrade to generate acids; • cellulose and other organic materials; • complexants and chelating agents, and/or materials that degrade to generate such compounds; • non aqueous phase liquids (NAPLs) and/or materials that degrade to generate them; and • any other materials that could detrimentally affect chemical containment.

Wasteform property	Requirement
Hazardous materials	The wasteform shall not contain hazardous materials, or have the potential to generate such materials, unless the treatment and packaging of such materials or items makes them safe. The means by which any of these materials is made safe shall be demonstrable for all relevant periods of long-term management.
Gas generation	Gases generated by the wasteform shall not compromise the ability of the waste package to meet any aspect of the relevant WPS.
Wasteform evolution (including wasteform-container interactions)	Changes in the characteristics of the wasteform as it evolves shall not result in degradation that will compromise the ability of the waste package to meet any aspect of the relevant WPS. The deleterious effects of the following processes should be considered: • dimensional changes, e.g. shrinkage; • corrosion including, but not limited to, the production of gases and particulate material, and wasteform expansion resulting from the formation of lower density solid corrosion products; • microbial activity; • self-irradiation and irradiation by surrounding waste packages; and • heat generation by the wasteform and its surroundings including, but not limited to, localised heat sources within the wasteform, the effects on the curing of the encapsulant material and the consequential effects on longer term performance.

4.2 The potential impact of chemicals used in decontamination operations on wasteform properties and performance

The presence of chemicals used in decontamination operations in LHGW waste packages could, in principle, affect those aspects of wasteform properties and performance listed in Table 1. The following sub-sections discuss each wasteform property in turn, identifying the key threats that may be introduced by the presence of chemical decontamination agents; and identifying the chemical species in the agents that could (in the absence of evidence to the contrary) threaten the ability of the wasteform to meet the necessary requirements. This information is intended to assist waste packagers dealing with wastes containing chemical decontamination agents, and to aid decision making on the choice and use of chemical decontamination agents. A summary of the key threats identified is presented in Table 2 at the end of the section. It should be noted that the guidance is based on active species in a waste package rather than the raw products.

4.2.1 Physical immobilisation

A key aspect that would be considered by RWM during a disposability assessment is the efficiency of immobilisation of particulates by the waste conditioning process. The behaviour of the wasteform during a fire or impact accident, specifically whether the wasteform will behave in a benign and predictable manner with respect to the retention of potentially mobile activity, would also be a key consideration of an assessment. In general, waste packagers will need to provide evidence that adequate performance requirements in accidents have been met by minimising and immobilising radioactive particulate material, free liquids, and volatile radionuclides and hazardous chemicals; and by ensuring that the wasteform does not burn or otherwise support combustion [11]. These may be achieved by, for example, solidifying any free liquids, ensuring any radioactive particulate is immobilised (e.g. by an encapsulating medium) and providing adequate thermal protection of the wasteform in the final waste package.

In decontamination operations, the 'available' source-term (or release fraction in the case of accident performance) of radioactive particulate material associated with a waste will in some instances be reduced, which could be beneficial in terms of waste package performance. If, however, credit is to be taken for any such source-term reduction, it may be necessary to demonstrate that it persists over all stages of the long-term management of the waste package. For example, it may be necessary to demonstrate that a material used to fix loose surface contamination does not degrade over time, or that it does not degrade to form materials that could affect waste package performance, if credit is to be taken for its contribution to waste package performance.

Liquid decontamination agents are generally used in washing or wiping decontamination work, with much of the material used absorbed on solid materials and the bulk liquor routed to effluent treatment plants. Residual amounts of liquid decontamination agents are expected to be acceptable in wastes (e.g. traces on the surfaces of items decontaminated or small amounts absorbed on solid materials), but any larger quantities would need to be suitably treated (e.g. by solidification prior to, or during, waste conditioning and packaging).

Paints, fixatives and coatings, although applied to surfaces as liquids or gels, generally generate solid wastes, a process which itself achieves a degree of immobilisation. Waste conditioning processes such as supercompaction and encapsulation could enhance the immobilisation of contamination and minimise the effect on wasteform impact performance.

Some paints and coatings used to fix radioactive contamination may be combustible in the event of a fire, and may in some cases have the potential to release hazardous chemicals if they are burnt or pyrolysed. In this regard, however, they are expected to be no different to other similar types of plastics and rubbers that appear in LHGW. The hazards presented by combustible plastics and rubbers in LHGW are typically mitigated by the methods used to condition and package the waste (e.g. encapsulation in a non-combustible medium such as cement, and the provision of layers of thermal protection in the final waste package), and these should be equally applicable to paints, fixatives and coatings.

4.2.2 Mechanical and physical properties

In general, the key aspects of the mechanical and physical properties of a wasteform that would be considered by RWM during a disposability assessment are as follows [11]:

- mechanical strength;
- voidage;
- mass transport properties (in relation to dissipation of gas and containment of soluble radionuclides);
- homogeneity; and
- thermal conductivity.

Waste packagers would need to provide evidence that the requirements for mechanical and physical properties have been met during all stages of long-term management.

Cement is frequently used as encapsulating medium because it often results in a wasteform that has adequate compressive strength, good impact break-up characteristics, acceptable release fractions, homogeneity and good thermal conductivity. Additionally, cement is typically naturally porous to facilitate the release of gases that might be generated in a wasteform. Therefore, consideration should be given to ensuring that a waste does not react with the encapsulating medium during wasteform production in any way that hinders the formation of a strong, essentially monolithic wasteform. Some surfactants, builders and sequestrating agents have the potential to interfere with the setting of cement-based encapsulation media, while some organic solvents and inorganic acids or alkalis can have negative effects on cement setting, strength development and long-term stability. However, in practice, the quantities of such materials that would be likely to be associated with a waste would not be expected to have a significant impact on the encapsulating medium. Notwithstanding this, waste packagers would need to provide evidence that any negative effects have been minimised by, for example, pre-treating the waste (e.g. neutralising acids or alkalis) or modifying the wasteform formulation (e.g. adding set accelerators).

The minimisation of voidage will be important in the case of supercompacted drums of waste grouted into a thin-walled container, in order to avoid creating areas that could harbour unimmobilised particulates or environments in which processes such as corrosion or gas generation could be favoured, leading to compromised integrity of the wasteform. Good compaction and low re-assertion of a supercompacted waste can help to produce a wasteform that is strong, essentially monolithic and void-free. Care may need to be taken if planning to supercompact substantial quantities of strippable coatings, in order to ensure that good compaction is achieved and excessive reassertion is avoided. One possible mitigating action may be to mix the strippable coating with other types of waste before supercompaction is undertaken i.e. ‘diluting’ the wasteform loading.

4.2.3 Chemical containment

Chemical decontamination products used in decontamination operations contain a wide variety of chemical species whose potential influence on chemical containment needs to be considered by waste packagers, and which would be considered by RWM during a disposability assessment. These include oxidising agents, acids and/or materials that degrade to generate acids, cellulose and other organic materials, complexing agents and/or materials that degrade to generate them and any other materials that could detrimentally affect chemical containment [11]. The sub-sections below contain a brief summary of what is currently understood about the potential for various chemical species commonly found in detergents, cleaners, paints, fixatives and coatings to interfere with chemical containment in the near-field environment of a GDF.

Detergents and cleaners

Surfactants

The functional groups in the ‘heads’ of surfactant molecules can act as ligands, forming complexes with metal ions. This can be seen from the fact that surfactants can be used to remove heavy metal ions from wastewaters in a process known as ion flotation, where heavy metal-surfactant complexes are attached to gas bubbles rising through the solution being treated. Smaller ions such as calcium, magnesium and sodium ions can, however, interfere with such processes by successfully competing for the available surfactant molecules. The affinity of surfactant molecules for the same ions is also the reason for the reduction in the effectiveness of surfactants and the formation of soap scum in hard water. All of this suggests that, in relation to any potential complexation of heavy metal ions by surfactant molecules, calcium, magnesium and sodium ions in groundwater are likely to successfully compete with, and displace, dissolved heavy metal ions from the wastes disposed of in a cementitious deep geological repository.

It has been suggested that surfactants might stabilise mobile colloid species in the repository near-field by allowing the colloids to become attached to gas bubbles and NAPLs. It might also be conceivable for surfactants to emulsify and disperse NAPLs themselves (for further information on the potential for NAPLs to migrate through a GDF, see [12]). As before, however, the presence of high concentrations of calcium, magnesium and sodium ions in the repository groundwater will probably limit the participation of surfactants in such processes [13].

Degradation of surfactants in a GDF is considered likely with anionic surfactants degrading to form long chain alcohols and sulphates; therefore, they are expected to have a low impact in a GDF provided a cementitious environment is prevalent. Non-ionic surfactants could potentially degrade to form polycarboxylic acid complexing agents; these species are also expected to have a low impact provided a cementitious environment is prevalent [14].

Builders/sequestrating agents

Builders are added to detergents to enhance the cleaning efficiency of the surfactant. The inorganic compounds that act as builders by precipitation and absorption should not have any obvious undesirable effects on contaminant mobility in a repository environment [13]. The organic compounds that act as builders by sequestration have, however, received considerable attention because of their ability to form strong complexes with ions of contaminants, including radioactive isotopes.

The effects of complexants in a deep geological repository and their evaluation in performance assessments have been the subject of a number of studies, and similar work has also been undertaken by LLWR.

Aminopolycarboxylic acids e.g. Ethylenediaminetetraacetic acid (EDTA) and alkanolamines – EDTA and other related species are strong complexing agents for actinides, as are some of their degradation products. Studies focusing on the release and biodegradation of EDTA have been carried out by LLWR [14,15] which indicate that EDTA degrades to form a range of secondary complexing agents under aerobic conditions. However, its detection in trench leachates suggests that this species is broken down in the LLWR trench disposal environment at a slower rate than polycarboxylates such as citrate [15]. EDTA and related species are typically reasonably resilient to radiolysis and so may persist for some time under anaerobic conditions in a GDF if microbes are not very active. Some localised areas of higher concentrations may exist (e.g. around waste packages with high EDTA loading) but, overall, only trace levels are expected. It is not considered that these species need to be excluded entirely from a GDF, but their quantities may need to be limited.

Phosphonates – There is a possibility that some phosphonates might be present in LHGW packages. Whilst some of these species (e.g. sodium tripolyphosphonate) are strong complexing agents, their impact is generally expected to be low in a cementitious environment, providing only small quantities are disposed of. Limited work is thought to have been done on degradation of these species under relevant conditions. Hydrolysis could generate species with phosphoric acid functional groups which may have a reduced solubility compared to the parent phosphates. These species are not considered to be biodegradable [14].

Acids and alkalis

Provided they were properly dealt with in the waste conditioning and packaging process, e.g. by neutralisation if necessary, inorganic acids and alkalis should have no significant effects in the post-closure phase of a GDF[3]. See also the discussion in the previous section on phosphonates.

The behaviour of carboxylic and polycarboxylic acids (e.g. citric acid, oxalic acid) in a cementitious environment is well understood and they are known to form anions at near neutral and alkaline pH (e.g. citrate) that are strong complexing agents. Carboxylic and polycarboxylic acids are expected to be present in wastes in notable quantities (more than trace) but these species and their associated anion species are expected to have a low impact in a cementitious environment because of their susceptibility to microbial

[3] Consideration of the requirements of discharges of non-radiological substances under the groundwater daughter directive has not been considered in this document; therefore, there may be additional requirements on some of these substances and RWM is currently developing its position on these.

degradation [16], hydrolysis and radiolysis, and, where the species persist, preferential binding to calcium, sodium, magnesium etc. ions present in groundwater. Citric acid can be degraded (to smaller, non-complexing species) if necessary prior to cementation [14].

Anti-microbial agents

Bleaches are discussed in a later section and no threats have been identified for other anti-microbial agents. Aldehydes, although present in some products, are not expected to be in extensive use on nuclear sites and elsewhere these species are being phased out of use where possible due to concerns over carcinogenic properties. Degradation products include carboxylic acids and or alcohols but these species, if present, are not expected to form species of potential concern [14].

Dispersants and anti-redepositing agents

Carboxymethyl cellulose (CMC) is a common dispersant. It is unclear whether CMC will behave and degrade in a manner wholly analogous to cellulose in a GDF and, therefore, degradation products could include strong actinide complexants such as isosaccharinic acid (ISA). However, the quantities of CMC in LHGW packages are likely to be negligible in comparison to the amount of cellulose disposed of in a GDF [14].

Polyacrylates are commonly used in laundry detergents but their use in the nuclear industry is less common. They may degrade to a variety of complexing agents and therefore have the potential to affect contaminant mobility [14].

Bleaches

A common additive to domestic bleach is tetra-acetyl ethylene diamine (TAED) which can, under some conditions, degrade to diacetylethylenediamine (DAED) and peroxyacetic acid. DAED is relatively stable compared to TAED. TAED has the ability to mobilise actinides by complexation but is considered to have a lower impact than EDTA and is less widely used [14]. See Section 4.2.5 for a discussion of bleaches in the context of gas generation.

Solvents

Glycol ethers are not used extensively in decontamination operations, but some may be used as degreasing agents on swabs. If the swabs contain higher levels of contamination they may require geological disposal. Degradation products could potentially convert to carboxylic acids which are expected to behave in an analogous manner to oxalic acid as discussed earlier, but with less of an effect [14].

Thickeners

Thickeners made from polysaccharides and cellulose derivatives such as methylcellulose have some potential to affect contaminant solubility in the post-closure phase as a result of the formation of complexing agents when the thickeners degrade, but such effects would be masked by the much more plentiful sources of cellulose degradation products in the GDF [14].

Paints and fixatives

Major polymer components

Alkyd resins – Full hydrolysis of alkyd resins leads to carboxylates which are not expected to have an impact on chemical containment in a cementitious GDF. Other degradation products are dicarboxylates and triols which may be significant complexing agents. Partial hydrolysis may give hydroxycarboxylates which are also strong complexing agents. Moderate or strong complexants may affect contaminant solubility if present in significant quantities. However, the amount of these polymers in paints and coatings will be a small fraction of the total inventory of the same (and similar) organic polymers in other LHGW disposed of in a GDF. Irradiation of hydrolysis products could potentially lead to introduction of extra functionality and formation of stronger complexants but their concentrations are expected to be low [17].

Acrylic polymers – There are various starting molecular structures of acrylic polymers which can produce different products as a result of hydrolysis such as polycarboxylic acids. Little detailed information is available on the identity of acrylic polymers in chemical decontamination agents or their likely decomposition products. These materials are used as coatings and the quantity in wastes is expected to be very small [17].

Polyvinyl acetate - Hydrolysis reactions will lead to the production of poly (vinyl alcohol) which can produce polyalcohols and polyhydroxycarboxylates (similar to those associated with the degradation of cellulose) which can complex at high pH. They are very soluble and their solubility increases with pH. The quantity and strength of complexants is expected to be less than cellulose degradation products [17].

Polyurethane - Hydrolysis is likely to lead to diamines which are significant complexants and diols which are relatively weak complexants. Polyurethane has been used in high-activity cells and found to be very durable and stable under those conditions [17].

Epoxy resins – Little chemical degradation of epoxy resins is expected. They have been used on the inside of fuel flasks and as a result proven to be stable to high radiation. They are chemically stable and have good adhesion to metals [17].

Polyvinyl chloride (PVC) – PVC has been used widely in the nuclear industry and will also be present in paints, and potentially, in strippable coatings. The PVCs used will include plasticised PVCs, which contain large quantities (>50% by volume) of additives, including plasticisers. Some of these plasticisers have the potential to act as complexants in a GDF environment (in a freely available form) and some are radiation tolerant (e.g. phthalates). Plasticisers are known to be released from PVC when it is heated or irradiated, however, they are susceptible to alkaline hydrolysis, so might be expected to be readily degraded to form carboxylic acids and alcohols in a grouted waste package in a cement-backfilled vault. The quantities of PVCs in paints and strippable coatings are expected to be insignificant compared to any that may occur from the larger PVC and polymer containing waste streams in a GDF [17].

Diluents

Diluents are liquids, usually organic solvents, used to adjust the fluidity of the coating so that it is suitable for application. Very low levels of the original organic solvent are expected to be present in a GDF because diluents are designed to evaporate rapidly after application of the paint or coating. Any remaining diluents are expected to be closely bound to other organic material [17].

Pigments

Little degradation of both inorganic and some organic pigments present in paints, fixatives and strippable coatings is expected. Inorganic pigments are relatively inert materials and are expected to be bound within the polymer matrix. Organic pigments which do not contain macrocyclic ligands and are non-complexing are expected to pose minimal risk to GDF performance. There is a wide range of organic pigments used in paints that could degrade to a variety of degradation products and these include macrocyclic ligands, which are complexing substances. These could be a threat if present in large enough amounts, but the quantities of organic pigments present in paints and coatings found in LHGW would typically be expected to be too small to be of significant concern.

Extenders

The extenders used in paints and coatings are generally inert solids some of which may react with cementitious grout or backfill. This is, however, expected to be insignificant when compared with other reactions of other waste components in the wider inventory [17].

Additives

Additives found in paint and fixatives include pigment dispersants and stabilisers, defoamers, thickeners, drying agents and anti-oxidants. Pigment dispersants are likely to be polymeric materials that adsorb to pigment surfaces. They are likely to be present in small quantities and bound in the polymer matrix. Three types of defoamers are used in paints: hydrocarbon oils, silica-based and non-ionic surfactants. They are expected to be present in very small amounts and encapsulated in their own matrix. Defoamers are not expected to have any interaction with contaminants or the wasteform. Little degradation is expected from drying agents; with small amounts present and bound in the polymer matrix, complexation formation with contaminants is unlikely. Although there is uncertainty over the range of chemicals used, anti-oxidants used in a variety of paints and coatings are not expected to be complexing agents with the materials present bound within the polymer. Thickeners are also additives in paints and fixatives, and were covered under detergents and cleaners. Ultraviolet (UV) absorbers present in UV cured paints are not expected to form complexants [17].

Coatings

Poly(vinyl chloride) terpolymer – This has been discussed on the previous page under the section on *major polymer components*.

(Ethylene)-vinyl acetate copolymer – Used frequently in industry and a possible component of strippable coatings which may hydrolyse at high pH to form poly (vinyl alcohol) (see below). It is unclear what likely quantity could be present in LHGW packages but it may be high in packages containing strippable coatings [17].

Poly(vinyl alcohol) (PVOH or PVAl) – Used frequently in industry and a possible component of strippable coatings. Hydrolysis of poly (vinyl alcohol) via radiolysis can produce polyalcohols and polyhydroxycarboxylates, such as those associated with the degradation of cellulose, which can complex at high pH. They are very soluble and solubility increases with pH [17].

Poly(vinyl butyral) – Possible component of strippable coatings, but expected to be relatively stable to chemical degradation [17].

Rubber – Rubbers are generally stable materials, and research has indicated that neoprenes and isoprenes do not form significant complexing agents under radiolysis [17].

Additional components of strippable coatings include surfactants and unspecified sequestrating agents which were discussed in detergents and cleaners.

4.2.4 Hazardous materials

Waste packages for disposal in a GDF shall not contain hazardous materials, or have the potential to generate such materials, unless the treatment and packaging of such materials makes them safe. In this context, hazardous materials includes flammable, explosive, pyrophoric, chemotoxic and oxidising materials; sealed and/or pressurised containers; and/or mechanical devices containing stored energy [11]. As chemical decontamination products contain chemical species which could be classified as hazardous materials, the impact of packaging of these species needs to be considered by the waste packager.

For chemotoxic materials, the Environment Agency (EA) expects that the developer of a GDF for radioactive waste will demonstrate that appropriate consideration has been given to the non-radiological hazard presented by the waste in demonstrating compliance with the groundwater activity provisions of the Environmental Permitting Regulations 2010 (EPR10). Further information on groundwater activities, including guidance on what constitutes a hazardous substance in that particular context, has been published by the EA [18]. RWM is currently developing its position on the disposability of non-radioactive hazardous contaminants, and additional guidance on the subject may be produced in the future.

During the development of a packaging proposal, the waste packager should demonstrate that hazardous properties of the waste have been considered, and that if present, they will be removed, eliminated or adequately mitigated. Some materials used to fix and remove radioactive contamination may contain potentially hazardous components, e.g. bleaches and other oxidising agents. However, given the way in which most of these materials were intended to be used, and their similarity to products used in household and conventional industrial applications, it is likely that any hazards posed by the materials would be modest; and that they would be readily mitigated by typical approaches to waste packaging and ordinary precautions taken during waste package handling, storage and transport (e.g. conditioning of wastes and remote handling of waste packages). Furthermore, many of the components present in materials used to fix and remove radioactive contamination will also be found in other wastes destined for disposal as LHGW to a GDF, e.g. plastics and rubbers in operational wastes, and paints and coatings in decommissioning wastes. Notwithstanding these mitigating factors, however, it will still be necessary for waste packagers to identify any hazardous components of chemicals used in decontamination operations; and to treat, condition and package wastes containing such materials in a way that renders them safe.

4.2.5 Gas generation

The ability of gases generated by the wasteform to affect waste package performance would be considered during a disposability assessment; in particular the potential issues resulting from gas generation are as follows [4,5]:

- the release of radioactive, flammable or toxic gases from the waste package;
- pressurisation of the waste container; and
- pressurisation of the wasteform.

Chemicals used in decontamination operations will often have components that could generate gas, e.g. from the radiolysis of organic polymers in paints, fixatives and coatings. In most instances, however, the components and mechanisms of gas generation are not unique to the materials used to fix and remove radioactive contamination; organic polymers, for example, will appear in many LHGW streams. A different example would be the potential for chlorine gas to be generated from bleaches used in detergents and cleaners [14]. As with any other type of waste, waste packagers will need to identify any potential sources of gas generation and provide sufficient information to allow RWM to quantify and assess their significance.

4.2.6 Wasteform evolution (including wasteform-container interactions)

The characteristics of a wasteform can evolve over time due to a variety of processes such as dimensional changes, corrosion, microbial activity, irradiation and heat generation [11]. The rate, extent and significance of evolution are wasteform-specific depending on the nature and quantities of materials present and the environmental conditions. In most cases, it would be expected that materials used in decontamination operations would have little potential to detrimentally affect wasteform evolution. As with any other type of waste, waste packagers will need to identify any potentially detrimental wasteform-container interactions and demonstrate to RWM that appropriate measures would be taken to minimise or prevent such interactions.

In the case of detergents and cleaners, the small amounts that might typically be expected to be present in wastes are perhaps likely to have little influence on wasteform evolution. Paints, fixatives and coatings are typically durable and inert materials, and studies have shown that there is no evidence to suggest that the most common synthetic polymers have a significant effect on radionuclide behaviour compared to cellulose products [13]. It is unlikely, therefore, that their presence in wastes would create any significant difficulties with regard to wasteform evolution. Initial hydrolysis of some of the components of paints and fixatives may occur in packages where these materials have been mixed with a conditioning matrix such as cement; this is, however, expected to be limited by the amount of water present [17].

As well as making its own contribution to overall waste package performance, the wasteform must also not jeopardise the performance and properties of the container during any stage of long-term management. One potential concern would be any wasteform components or degradation products that could enhance the corrosion of thin-walled stainless steel containers. Detergents and cleaners can contain a variety of components that might, in principle, enhance container corrosion, e.g. inorganic salts, acids and bleaches [13,14]. Similarly, paints, fixatives and coatings may contain polymers that could degrade to produce corrosive species, e.g. hydrogen chloride from PVC [17]. Suitable methods of waste treatment, conditioning and packaging can mitigate any such risks, e.g. the neutralisation of acids and the provision of barriers to chloride migration in waste packages. As with any other type of waste, waste packagers will need to identify any potentially detrimental wasteform-container interactions and demonstrate to RWM that appropriate measures would be taken to minimise or prevent such interactions.

4.3 Summary

A summary of the potential threats that may affect the disposability of waste packages containing chemical decontamination agents is presented in Table 2. In defining the approach to packaging wastes containing chemical decontamination agents, waste packagers should consider the potential for these threats to be realised. A packaging proposal to RWM for such wastes should demonstrate consideration of the realisation of the potential threats. Potential mitigations for these threats are discussed in Section 5.

Table 2 A summary of the potential threats to be considered by a waste packager that may affect the disposability of a waste package containing chemical decontamination agents

Key wasteform parameters	Potential threats that may affect the disposability of a waste package containing decontamination agents	
	Detergents and cleaners	Paints, fixatives and coatings
Physical immobilisation	Presence of free liquids.	Presence of combustible material which may release hazardous chemicals if they are burnt or pyrolysed.
Mechanical and physical properties	Presence of components that have the potential to interfere with cement hydration: • surfactants; • builders/sequestrating agents; • solvents; • acids; and • alkalis.	Presence of voidage as a result of incomplete infiltration or compaction.

Key wasteform parameters	Potential threats that may affect the disposability of a waste package containing decontamination agents	
	Detergents and cleaners	**Paints, fixatives and coatings**
Chemical containment	Potential sources of complexing agents which could enhance contaminant mobility: • builders/sequestrating agents; • organic acids; • dispersants and anti-redepositing agents; • bleaches; • solvents; and • thickeners.	Potential sources of complexing agents which could enhance mobility of heavy metal ions: • alkyd resins; • acrylic polymers; • poly(vinyl acetate); • organic pigments; • ethylene)-vinyl acetate copolymer; • poly(vinyl alcohol); • thickeners; and • additives.
Hazardous materials	Toxic components and degradation products that may exist or be generated during any phase of a GDF.	Toxic components and degradation products that may exist or be generated during any phase of a GDF.
Gas generation	Sources of gas generation that could potentially undermine wasteform and waste package properties and performance, e.g. organic compounds that could generate gas as a result of radiolytic degradation.	Sources of gas generation that could potentially undermine wasteform and waste package properties and performance, e.g. organic compounds that could generate gas as a result of radiolytic degradation.
Wasteform evolution and wasteform-container interactions	Corrosion of the container by aggressive components: • bleaches; • free liquids; • sodium chloride; • acids; and • alkalis.	Corrosion of the container by aggressive components, such as degradation products (e.g. HCl from PVC).

5 Guidance on the development of a packaging proposal for LHGW containing chemical decontamination agents

Section 4 discussed the species that can be present in chemicals used in decontamination operations, and the potential impacts of these on the properties and performance of wasteforms in LHGW packages. This section provides guidance to a waste packager on how they may consider and address the potential threats associated with chemical decontamination agents in a particular waste during the development of a packaging proposal to RWM for the waste. The key aspects of the guidance are as follows:

- understanding the nature of the decontamination agent associated with the waste in question;
- undertaking a preliminary screening for potential threats to the properties and performance of the wasteform and, therefore, the disposability of the waste package as a whole; and
- applying and invoking mitigation actions to reduce the perceived impact of the potential threat to the properties and performance of the wasteform.

This guidance may be used when developing packaging proposals for existing (legacy) wastes; it may also be used when developing plans for future decontamination operations and the management of the resulting waste arisings, including informing the choice of decontamination agent for use in those operations (noting that the choice will also be influenced by other factors such as effectiveness of the decontamination agent).

Waste packagers may discuss their approach to packaging wastes with associated decontamination agents with RWM at any point for initial advice; however, RWM will need to undertake a formal assessment before endorsing the approach to be taken to package the wastes prior to packaging (for legacy wastes) or prior to first use of a decontamination agent for a particular purpose.

5.1 Information requirements

The information that would allow the waste packager to undertake a preliminary screening of the potential disposability of a waste containing a chemical decontamination agent(s) is as follows:

- the nature of the chemical species in the decontamination agent(s) present in the waste (or likely to be present in anticipated future wastes);
- the indicative % weight of the chemical species in the decontamination agent(s);
- the nature of the wastes (or anticipated future wastes) themselves;
- the proposed plans for what the wasteform and the waste package will look like, including pre-treatment and conditioning plans; and
- the quantities of chemical species of interest which are likely to be present within a single waste package.

5.2 Preliminary screening

Table 2 (in Section 4) summarises the potential threats to the disposability of waste packages containing chemical decontamination agents based on the information available about the chemical species that are likely to be a part of decontamination products and the wasteform requirements. A waste packager can use the information provided in Section 4, together with information available about the decontamination agent products used (or proposed to be used) and proposed packaging arrangements, in order to identify any chemical species present which could cause a potential threat to the disposability to a waste package containing the chemical species. The outcome of a preliminary screening should identify whether there are potential threats to the properties and performance of the proposed wasteform, and therefore the waste package. This outcome, and the information assembled to support the case for their use, should be used to support a packaging proposal to RWM for the disposability of those wastes and associated decontamination agent(s).

5.3 Mitigations

If potential threats to the disposability of the wasteform, and therefore the waste package, are identified, consideration will need to be given to how those threats might be mitigated. Some examples of potential mitigations that could be applied or invoked by waste packagers are discussed below. The use of any mitigation(s) to reduce the potential threat to the wasteform posed by the decontamination agent present in the waste should be used to support a packaging proposal along with the outcome of the preliminary screening.

5.3.1 Quantities

An effective mitigation in most cases will be achieved by limiting the quantity of materials consigned to a single waste package. Based on the information currently available about the behaviour of many of the chemical species, it is not possible to specify waste package limits for general application that would not challenge the case for disposability of a waste package in a GDF. However, it is likely that the quantity of such species present in a LHGW package would be low due to the manner in which the chemicals are used and the amounts that are likely to be disposed of via other routes (e.g. in liquid effluents and solid LLW). For such wastes, it may be possible to make qualitative arguments in the packaging proposal in support of statements of low quantities of decontamination agents being present.

Detergents and cleaners typically contain a high proportion of water, and given that most active ingredients in detergents and cleaners are typically present at concentrations of only a few weight percent, it is unlikely that more than gram quantities of any of the ingredients would find their way into LHGW packages. Some traces of detergents and cleaners might remain on the surfaces of LHGW items that have been decontaminated, although the amounts present in such a form are likely to be very small as the majority of any applied detergent and cleaner is likely to be rinsed or wiped off the item.

Paints and fixatives used in operations involving the removal and fixing of contamination are not expected to significantly increase the inventory of materials in a GDF which could lead to the realisation of the potential threats discussed in section 3 (e.g. an increase in the quantity of complexing agents). Paints and fixatives are widely used in the nuclear industry to protect steel and concrete surfaces in ponds, skips and flasks and to protect and preserve building floors and walls. When used to fix contamination, paints and fixatives are expected to be left in-situ on items of waste and disposed of as LHGW. The quantities of these chemical products that could be placed within a waste package are not expected to be greater than the amounts of similar materials found in other LHGW packages, e.g. in the form of contaminated plastics, rubbers and painted surfaces that have been coated for other reasons. Similar arguments apply to strippable materials, often available as liquids or gels that can be applied in a variety of ways, drying to form a tough, thin peelable coating. The coating can be left in-situ or it can be removed from decontaminated items and disposed of separately as LHGW. In the latter case, it may be possible to employ good practice by spreading it over a number of packages providing it is a safe to do so, thereby reducing the individual quantity placed within a single waste package.

5.3.2 Waste pre-treatment and conditioning and packaging

Some of the key threats may be mitigated during waste treatment, conditioning and packaging. Appropriate pre-treatment and conditioning of wastes could mitigate against the potential threat associated with certain chemical species, e.g. by neutralising acids; chemically destroying bleaches, oxidising agents and complexants; or adding set accelerators to combat surfactants that might retard cement setting.

5.3.3 Barriers to release

The manner in which wastes are packaged could help to mitigate threats presented by the presence of chemical species derived from decontamination agents by introducing ‘barriers to release’. Encapsulation in cement (or polymer) in steel containers introduces barriers to release in the form of the cement (or polymer) matrix and the container walls. When waste is supercompacted in sacrificial drums, and the resulting ‘pucks’ encapsulated in a cement-based grout in an outer container, the resulting waste package would contain multiple barriers to the release of any chemical species derived from decontamination agents that are present in the waste. Wrapping items of waste in plastic prior to encapsulation would be another method of introducing an additional barrier to release.

Such barriers could be effective in mitigating a number of the threats posed by the presence of chemical species derived from decontamination agents in the waste. Barriers between the waste and the conditioning matrix (e.g. the sacrificial drum walls in a supercompacted wasteform or the plastic wrapping on waste items) could mitigate the potential for any species derived from decontamination agents to interfere with setting of the conditioning matrix. The same barriers, and the barrier of the conditioning matrix, could also limit the potential for species derived from decontamination agents to enhance corrosion of the container.

It may be more difficult to incorporate barriers that would be effective in mitigating the long-term threats posed by the presence of complexing agents, due to the long timescales over which these threats may persist, and the difficulty of placing reliance on barriers to release over such timescales. There may, however, still be scope for employing good practice mitigating measures such as spreading the source-term of complexants over larger numbers of waste packages, or avoiding the co-packaging of complexants with large inventories of radionuclides that may be susceptible to complexation.

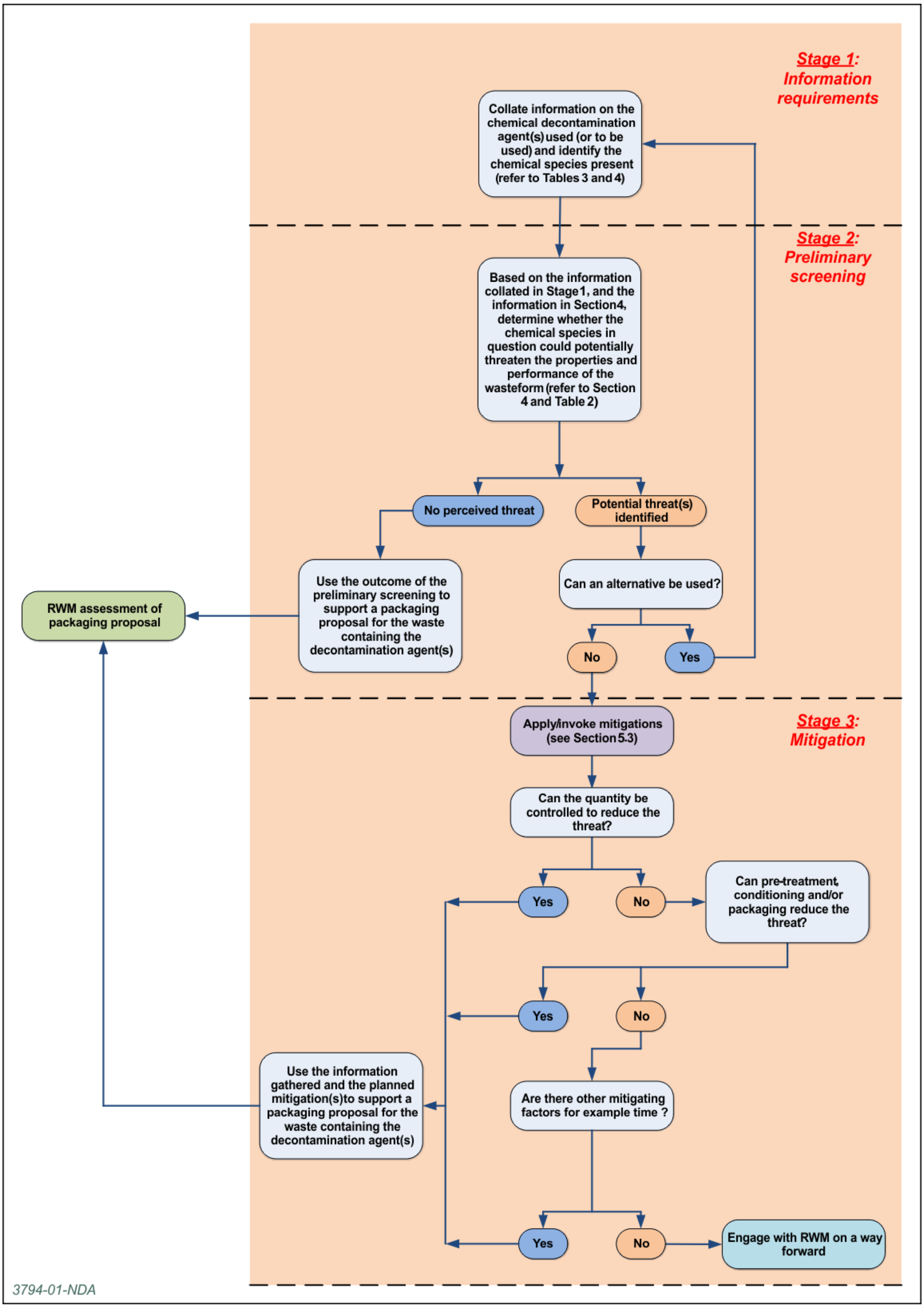
5.3.4 Time

Time may also be invoked as a mitigating factor; for example, set retarding in cement products may not be a threat to disposability in a GDF, because providing the wasteform does set, it will gain strength over time. Some potential complexants (e.g. citrate) may degrade over time under certain conditions (e.g. microbial degradation, hydrolysis, radiolysis) in the GDF environment and the wider environment.

5.4 Summary

A flow diagram which summarises the guidance provided in this section is presented in Figure 2.

Figure 2 Flow diagram for considering and addressing potential threats relating to the presence of decontamination agents



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Appendix A

Table 3 Chemical species found in detergents and cleaners [13,14]

Class of chemical species	Purpose	Examples	Prevalence of use
Surfactants	A surfactant is an organic compound containing a fat-soluble (lipophilic) 'tail' and a water soluble (hydrophilic) 'head'. They form the basis of most detergents and cleaners. They contribute towards cleaning and decontamination performance in a number of ways such as improving the wetting of the surface being cleaned or decontaminated and by emulsifying oily and greasy material. A large number of chemical compounds are used as surfactants in detergents and cleaners and a mixture of surfactants may be present in any one formulation.	Zwitterionic (amphoteric) e.g. betaines	Not known to be used extensively in the nuclear industry; the main application is in shampoos and soaps.
		Anionic (sulphates, carboxylates, sulphonates, phosphate esters)	There is growing pressure on the chemical industry to reduce the use of non-biodegradable cleaning agents, and replace them with alternatives that are biodegradable (particularly under aerobic conditions).
		Cationic (amines and ammonium)	Rarely used in modern cleaning agents (more commonly used in fabric softeners) but may be present in historic decontamination agents.
		Non-ionic (alcohols and glucosides)	Glucosides are used for oily residue removal and also require lower temperatures to act as a surfactant.

Class of chemical species	Purpose	Examples	Prevalence of use
Builders/sequestrating agents	Chemicals added to detergent formulations to combat the negative effect of water hardness on surfactant performance. To do this, builders react with calcium, magnesium and sodium ions in one of three ways: • precipitation; • absorption (ion exchange); or • sequestration - organic compounds are used that act as chelating ligands, forming strong complexes with calcium, magnesium and sodium ions (specialised radioactive decontamination agents may contain relatively high concentrations of sequestrating agents such aminopolycarboxylic acids to boost their decontamination performance).	**Precipitation:** sodium carbonate, sodium bicarbonate, sodium phosphate	Not known.
		Absorption (ion exchange): zeolites	The most common zeolite is MAP (maximum aluminium zeolite P) most common in domestic washing formulations (Duocil A24).
		Sequestration: Aminopolycarboxylic acids, e.g. ethylenediaminetetraacetic (EDTA); nitrilotriacetic acid (NTA); ethylenediamine-N,N`-disuccinic acid (EDDS)	EDTA is extensively used in decontamination activities (typically in liquid solutions, rather than as a cream). Other related species such as NTA and EDDS are also used but to a far lesser extent. Efforts are being made at Sellafield to minimise use where possible. Significant (non-trace) quantities of EDTA-contaminated waste are expected to be consigned to LLWR.
		Sequestration: Alkanolamines (e.g. monoethanolamine)	Not known.
		Sequestration: Phosphonates [aminotris(methylphosphonic acid) (ATMP), 1-hydoxyethylidene-1,1-diphosphonic acid (HEDP), diethylenetriamine penta(methylene phosphonic acid) (DTPMP), sodium tripolyphosphate]	Phosphonates are common in domestic cleaners but are gradually being phased out. Phosphates may be used at Sellafield laundry, but resulting phosphate-contaminated filters are consigned as LLW. Other sites may use cleaners containing phosphates.

Class of chemical species	Purpose	Examples	Prevalence of use
Acids	Acids are added to detergents and cleaners to adjust their pH (and thus improve the effectiveness of other components of the formulation) and as active components of the formulations (e.g. to dissolve limescale). Organic acids such as citric acid also act as sequestrating agents and can be found in relatively high concentrations in specialised radioactive decontamination agents compared to the amounts found in household detergents.	**Inorganic acids:** Sulphamic acid	Not known.
		Organic acids: Carboxylic and polycarboxylic acids (e.g. citric acid, oxalic acid)	Citric acid is employed extensively by the nuclear industry for a variety of uses. Oxalic acid is less extensively used but is nevertheless applied for some decontamination activities at Sellafield. It will be present in some ILW streams.
Alkalis	Alkalis are added to detergents and cleaners to adjust their pH (and thus improve the effectiveness of other components of the formulation) and as active components of the formulations (e.g. to hydrolyse fats and greases). The amount of alkali present in a cleaner may be low or higher if it is present as an active component.	Sodium hydroxide, potassium hydroxide, sodium carbonate	Not known.

Class of chemical species	Purpose	Examples	Prevalence of use
Anti-microbial agents	Added to some household cleaning products such as bathroom cleaners to kill bacteria.	Bleaches	Predominantly oxidising agents and added to enhance performance.
		Alcohols (e.g. ethanol, isopropyl alcohol)	Added to detergents and cleaners.
		Aldehydes (e.g. formaldehyde, glutaraldehyde)	Believed not to be in extensive use on nuclear sites and outside the industry these species are being phased out because of concerns over carcinogenic properties. Trace amounts only.
		Phenolics	Not known.
Dispersants and anti-redepositing agents	Chemicals added to cleaning products to help suspend solid particles of dirt in the liquid cleaning medium and prevent their redeposition.	Carboxymethyl cellulose (CMC)	Not known.
		Polyacrylates (e.g. sodium polyacrylate)	Polyacrylates are commonly used in laundry detergents, although their use in industrial laundries is less clear. They are not known to be in widespread use at nuclear sites. Polyacrylates are often present in cabling within electrical systems and these are not expected to be decontaminated.
Bleaches	Bleach and other oxidising agents are added to enhance performance of cleaners.	Tetra-acetyl ethylene diamine (TAED) (additive to domestic bleach, which lowers the temperature at which bleaching agents operate)	Common additive to domestic bleach. Also widely used in hospital disinfectants. Found in chlorine based bleaches.
		Sodium hypochlorite	Found in chlorine-based bleaches.

Class of chemical species	Purpose	Examples	Prevalence of use
		Peroxides	The most common are sodium perborate and sodium percarbonate.
		Higher oxidation metal ions such as permanganates	Uncommon.
Solvents	Water-miscible solvents added to help solubilise active ingredients and to assist in the dissolution of oil and grease.	Alcohols (e.g. ethanol)	Not known.
		Glycol ethers	Not used extensively, but some use as a degreasing agent on swabs. Most swabs are expected to be routed to LLWR, but some (e.g. assay swabs) may have higher levels of contamination, and require geological disposal.
Thickeners	Added to improve stability, alter consistency and help to prevent the re-deposition of dirt.	Inorganic salts (e.g. sodium chloride)	Not known.
		Polysaccharide (xanthan gum)	Known to have been used already as a thickener in some clean-up operations. This material (when uncontaminated with radioactivity) has been accepted to landfill.
		Cellulose derivatives (methylcellulose)	
Miscellaneous ingredients	Various miscellaneous ingredients are added to detergents and cleaners.	Water	The main miscellaneous ingredient added to detergents and cleaners.
		Fragrances, dyes, preservatives in trace amounts, abrasives and inorganic salts	Commonly found in detergents and cleaners.

Table 4 Chemical species found in paints, fixitives and strippable coatings [17]

Class of chemical species	Purpose	Examples	Prevalence of use
Major polymer components (binders)	Binders are the materials that form the continuous film that adheres to the substrate, bind together the other substances in the coating to form a film, and present an adequately hard outer surface. The binder governs, to a large extent, the properties of the coating film.	Alkyd resins	Commonly used in solvent-based paints and as emulsions in water-based paints.
		Acrylic polymers	Acrylic latex is used in water-based fixatives and acrylates are used in UV-cured paints and as a co-polymer in solvent-based paints.
		Polyvinyl acetate	Present as a latex in fixatives and vinyl acetate is co-polymerised with ethylene in some strippable coatings.
		Polyvinyl butyral	Component of strippable coatings.
		Polyurethane	Polyurethane is used in UV-cured paints and solvent-based paints.
		Epoxy resins	Epoxy polymers are present in UV-cured paints as well as some powder coatings.
		Poly(vinyl chloride)	PVC is reported to be present in some fixatives and strippable coatings.
		Latex Rubber	Pre-vulcanised rubber latex is a major component in some strippable coatings.
Diluents	Diluents are liquids used to adjust the fluidity of the coating so that it is suitable for application. They evaporate during and after application.	Organic solvents solvents (e.g. alkyl acetates, xylene, toluene)	Widely used in solvent-based paints and coatings.

Class of chemical species	Purpose	Examples	Prevalence of use
Pigments	Pigments are finely divided insoluble solids that are dispersed in the binder and volatile components, and remain suspended in the coating after film formation. Generally, pigments are there to provide colour and opacity, although they may also have significant effects on application characteristics and film properties.	Inorganic pigments (e.g. TiO_2)	Present in solvent and water-based paints and some fixatives and strippable coatings.
		Organic pigments	Present in solvent and water based paints and some fixatives and strippable coatings.
		Other pigments mostly organic	Variously used in a wide range of paints and coatings.
Extenders	Extenders are solid components of paints and coatings that may serve a variety of purposes (e.g. improve adhesion to substrate, provide roughness to the finished film or improve the water resistance of the finished film).	Calcium carbonate	Variously used in a wide range of paints and coatings.
		Kaolin (aluminosilicate clay mineral)	
		Talc (hydrated magnesium silicate)	
		Silica	
		Barytes ($BaSO_4$)	

Class of chemical species	Purpose	Examples	Prevalence of use
Additives	Additives are materials that are included in small quantities to modify coating properties (e.g. catalyse binder polymerisation reactions or modify viscosity)	Surfactants and wetting agents	Used in some strippable coatings to aid surface decontamination.
		Complexants	Used in some strippable coatings to aid surface decontamination.
		Pigment dispersants and stabilisers	Likely to be polymeric material that adsorbs to pigment surfaces.
		Defoamers	Used in a variety of paints.
		Thickeners	See detergents and cleaners.
		Drying agents	Used in solvent based paints.
		Anti-oxidants	Used in a variety of paints and coatings.
		UV absorbers	Present in UV-cured paints.

Glossary of terms used in this document

alpha activity

Alpha activity takes the form of particles (helium nuclei) ejected from a decaying (radioactive) atom. Alpha particles cause ionisation in biological tissue which may lead to damage. The particles have a very short range in air (typically about 5cm) and alpha particles present in materials that are outside of the body are prevented from doing biological damage by the superficial dead skin cells, but become significant if inhaled or swallowed.

backfill

A material used to fill voids in a GDF. Three types of backfill are recognised:

- local backfill, which is emplaced to fill the free space between and around waste packages;
- peripheral backfill, which is emplaced in disposal modules between waste and local backfill, and the near-field rock or access ways; and
- mass backfill, which is the bulk material used to backfill the excavated volume apart from the disposal areas.

backfilling

The refilling of the excavated portions of a disposal facility after emplacement of the waste.

barrier

A physical or chemical means of preventing or inhibiting the movement of radionuclides.

buffer

An engineered barrier that protects the waste package and limits the migration of radionuclides following their release from a waste package.

conditioning

Treatment of a radioactive waste material to create, or assist in the creation of, a wasteform that has passive safety.

container

The vessel into which a wasteform is placed to form a waste package suitable for handling, transport, storage and disposal.

containment

The engineered barriers, including the waste form and packaging, shall be so designed, and a host geological formation shall so be selected, as to provide containment of the waste during the period when waste produces heat energy in amounts that could adversely affect the containment, and when radioactive decay has not yet significantly reduced the hazard posed by the waste.

contaminant

A component of the waste that is radioactive or chemically hazardous, or both, in the context of groundwater contamination.

disposability

The ability of a waste package to satisfy the defined requirement for disposal.

disposability assessment

The process by which the disposability of proposed waste packages is assessed. The outcome of a disposability assessment may be a Letter of Compliance endorsing the disposability of the proposed waste packages.

disposal

In the context of solid waste, disposal is the emplacement of waste in a suitable facility without intent to retrieve it at a later date; retrieval may be possible but, if intended, the appropriate term is storage.

disposal facility (for solid radioactive waste)

An engineered facility for the disposal of solid radioactive wastes.

disposal system

All the aspects of the waste, the disposal facility and its surroundings that affect the radiological impact.

disposal vault

Underground opening where ILW or LLW waste packages are emplaced.

geological disposal

A long term management option involving the emplacement of radioactive waste in an engineered underground geological disposal facility or repository, where the geology (rock structure) provides a barrier against the escape of radioactivity and there is no intention to retrieve the waste once the facility is closed.

geological disposal facility (GDF)

An engineered underground facility for the disposal of solid radioactive wastes.

higher activity radioactive waste

Generally used to include the following categories of radioactive waste: low level waste not suitable for near surface disposal, intermediate level waste and high level waste.

immobilisation

A process by which the potential for the migration or dispersion of the radioactivity present in a material is reduced. This is often achieved by converting the material to a monolithic form that confers passive safety to the material.

intermediate level waste (ILW)

Radioactive wastes exceeding the upper activity boundaries for LLW but which do not need heat to be taken into account in the design of storage or disposal facilities.

International Atomic Energy Agency (IAEA)

The IAEA is the world's centre of cooperation in the nuclear field. It was set up as the world's "Atoms for Peace" organization in 1957 within the United Nations family. The Agency works with its Member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies.

Letter of Compliance (LoC)

A document, prepared by RWM, that indicates to a waste packager that a proposed approach to the packaging of waste would result in waste packages that are compliant with the requirements defined by relevant packaging specifications, and the safety assessments for transport to and disposal in a GDF, and are therefore deemed 'disposable'.

Managing Radioactive Waste Safely (MRWS)

A phrase covering the whole process of public consultation, work by CoRWM, and subsequent actions by Government, to identify and implement the option, or combination of options, for the long term management of the UK's higher activity radioactive waste.

Nuclear Decommissioning Authority (NDA)

The NDA is the implementing organisation, responsible for planning and delivering the GDF. The NDA was set up on 1 April 2005, under the Energy Act 2004. It is a non-departmental public body with designated responsibility for managing the liabilities at specific sites. These sites are operated under contract by site licensee companies (initially British Nuclear Group Sellafield Limited, Magnox Electric Limited, Springfields Fuels Limited and UK Atomic Energy Authority). The NDA has a statutory requirement under the Energy Act 2004, to publish and consult on its Strategy and Annual Plans, which have to be agreed by the Secretary of State (currently the Secretary of State for Trade and Industry) and Scottish Ministers.

operational period (of a disposal facility)

The period during which a disposal facility is used for its intended purpose, up until closure.

passive safety

Not placing reliance on active safety systems and human intervention to ensure safety.

post-closure period (of a disposal facility)

The period following sealing and closure of a facility and the removal of active institutional controls.

radioactive material

Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.

radioactive waste

Any material contaminated by or incorporating radioactivity above certain thresholds defined in legislation, and for which no further use is envisaged, is known as radioactive waste.

Radioactive Waste Management Limited (RWM)

A wholly owned subsidiary of the NDA, established to design and build an effective delivery organisation to implement a safe, sustainable and publicly acceptable geological disposal programme. Ultimately, RWM will evolve under the NDA into the organisation responsible for the delivery of the GDF. Ownership of this organisation can then be opened up to competition, in due course, in line with other NDA sites.

radioactivity

Atoms undergoing spontaneous random disintegration, usually accompanied by the emission of radiation.

radionuclide

A radioactive form of an element, for example carbon-14 or caesium-137.

safety case

A 'safety case' is the written documentation demonstrating that risks associated with a site, a plant, part of a plant or a plant modification are as low as reasonably practicable and that the relevant standards have been met. Safety cases for licensable activities at nuclear sites are required as license conditions under NIA65.

safety function

A specific purpose that must be accomplished for safety.

waste container

Any vessel used to contain a wasteform for disposal.

wasteform

The waste in the physical and chemical form in which it will be disposed of, including any conditioning media and container furniture (i.e. in-drum mixing devices, dewatering tubes etc) but not including the waste container itself or any added inactive capping material.

waste package

The product of conditioning that includes the wasteform and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transport, storage and/or disposal.

waste packager

An organisation responsible for the packaging of radioactive waste in a form suitable for transport and disposal.

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