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Reworking intermediate level radioactive waste

Science report: SC040047

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Steve Killeen

Head of Science

Executive Summary

Final Report

This work supports the Environment Agency's Nuclear Waste Assessment Team. The objectives of the study were:

- to assess the reasons why reworking of drummed or packaged Intermediate Level Waste (ILW) might be required;
- to identify different reworking methods and their feasibility;
- to assess the potential strategies for reworking and their implications.

Reworking might become necessary if a waste package were to deteriorate or be damaged, or become out of specification due to external factors such as changes in Government policy. A wide range of reworking methods is available, but there is little experience of using them. Previous case studies indicate that for loose, drummed waste etc, the waste is generally unpacked, treated and repacked or unpacked and then compacted. For grouted wasteforms the favoured method is overpacking plus a non-intrusive remediation of the wasteform if necessary. Under current legal and regulatory constraints, waste management operators prefer to avoid breaking up grouted wasteforms.

A workshop exercise involving regulators, operators and experts was undertaken to support all of the main objectives of this study. However, no common viewpoint was expressed on what constituted best practice for determining an appropriate reworking strategy for a given waste package and wasteform. This was because of specific issues associated with each of the considered product types. Therefore a logical stepwise process was developed, which could be applied to any waste package and wasteform. The approach enunciated in this report allows proper consideration of the no or low intervention options instead of proceeding immediately to the more complex, costly and invasive options, which ultimately may not be necessary. The impact of different reworking strategies was qualitatively assessed. The most invasive strategies were found generally to have the highest environmental, safety and cost impacts.

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Introduction

1.1 Background

Currently within the UK there is no ultimate disposal route for Intermediate Level Radioactive Waste (ILW). Until one is found, many high-profile ILW waste streams are conditioned at an early stage, typically within a cementitious matrix, and stored in stainless steel drums. The principal reason for this is often operational risk reduction. Stabilising the waste in this manner lowers risk, by reducing the likelihood of leakages into the working and wider environments. This reduces the potential for the public and workers being exposed to radiation.

For some ILW waste streams there are concerns that early conditioning excludes future disposal options, and might result in waste packages requiring future rework. Reworking can be applied to the wasteform (i.e. the waste plus any conditioning matrix such as cement), to the waste container (often a 500 litre capacity stainless steel drum), or both (i.e. the “waste package”).

Reworking has had a fairly narrow definition, encompassing specific processes such as overpacking, or cutting up of the waste package and repacking etc. This study gives it a wider definition as *a process involving physical intervention to packaged waste arising from deviation from the planned storage, treatment, or intended disposal process for that packaged waste*.

The Nuclear Waste Assessment Team’s (NWAT) role within the Environment Agency is to provide technical assessment of packaging and conditioning proposals, and associated plans for waste management. One aspect of the work of NWAT aims to obtain assurances about the management of ILW, with particular regard to eventual disposal and reworking of waste packages.

For example, NWAT is reviewing the approach taken by Nirex to assess the long-term evolution of waste packages during storage. This review will contribute to our understanding of the potential need to rework waste packages due to degradation during long periods of storage. This project and the Nirex review are closely linked.

The Environment Agency seeks to be an influential and a well-informed regulator. It is proposed that guidance on reworking will be produced by the Environment Agency, based on this report, and to meet the requirements of NWAT to fill a key knowledge gap. The Environment Agency will then be able to contribute effectively to the statutory decisions taken by the Health and Safety Executive (HSE) dealing with ILW. These decisions affect the expenditure of many hundreds of millions of pounds by the nuclear industry and government, who therefore have a strong interest in the robustness of regulatory decisions.

1.2 Study objectives

The objectives of this study were to:

1. Identify examples and case studies of reworking waste streams and other relevant materials;
2. Identify different reworking methods;
3. Assess the potential for reworking following different waste treatment and conditioning strategies (to include but not be limited to: in-drum mixed cemented products; compacted pucked wastes placed within a cementitious matrix; annular grouted packages; polymer and novel encapsulants);
4. Assess strategies for facilitating reworking (to include but not be limited to: postponement of conditioning; use of non-monolithic void fillers such as sand; use of non-standard types of cementitious materials and the use of novel encapsulants);
5. Assess the implications of such strategies in terms of key impacts including waste degradation during long term storage, volumes of secondary waste and safety implications;
6. Make recommendations that will underpin future regulatory guidance.

1.3 Methodology

The study was undertaken in two parts:

1. A literature survey was undertaken to:

    - identify examples and case studies of reworking of waste streams and other relevant materials;
    - identify reworking methods;
    - review the findings from ongoing studies into the stability of conditioned radioactive wastes. The findings from stability studies were used to indicate potential for deterioration of conditioned wasteforms and therefore one of the reasons for reworking.

2. A workshop involving regulators, operators and experts was arranged to:

    - identify potential reasons for reworking a conditioned waste package;
    - identify reworking methods for different waste types;
    - identify strategies to facilitate reworking;
    - assess the implications and effects of reworking.

Section 2 summarises the UK's current position on ILW. Section 3 reports the findings of the literature survey, and a description of the workshop and its outcomes are given in Sections 4 and 5. The overall findings of the study are discussed in Section 6, with the conclusions and recommendations set out in Section 7.

2 Current UK ILW Position

2.1 United Kingdom ILW strategy

2.1.1 Management of ILW

ILW is defined in Cm2919 (HMSO 1995) as waste "with radioactivity levels exceeding the upper boundaries for low level waste, but which does not require heating to be taken into account in the design of storage or disposal facilities". (The upper boundaries for low-level waste are 4 GBq/te of alpha and 12 GBq/te of beta/gamma.) The definition is broad and the term "ILW" covers a multitude of waste types with varying activities and half-lives.

Intermediate-level waste comes mainly from dismantling and reprocessing used nuclear fuel and from operating and maintaining nuclear plants. The volume of ILW in store in the UK in 2001 was 75,400 m^3 and the total activity of this was 5,290,000 TBq (Nirex 2005).

In the past, most ILW has been stored in special buildings, within a variety of tanks, vaults and silos. A key step in the long-term management of radioactive waste is its immobilisation. Where necessary, this involves changing the waste into a form that limits the escape of radioactive material into the surrounding environment, and is part of the packaging process for wastes containing long-lived radionuclides.

Raw intermediate-level wastes are typically immobilised in cement within steel drums. The UK nuclear industry is spending many billions of pounds to do this. It began work on ILW in 1990; the wastes now being produced are often treated as they arise. The backlog is also being dealt with. So far, some 21,600 drums of cemented ILW have been produced.

The immobilised ILW is then stored, usually near to the treatment plant. The next step is for the Government to decide on how it should be managed for the long term (Nirex 2005).

2.1.2 Assessment of ILW Conditioning and Packaging Proposals

Prior to ILW being conditioned, it is necessary for specific proposals to be assessed against various standards and principles (Environment Agencies 2003). In particular, the regulators will expect proposals to demonstrate that:

- radioactive waste can be retrieved after an appropriate period in a form that would be suitable for disposal;
- there is adequate management of the ageing of structures, plant and waste packages;

- the long-term aspects of disposal have been satisfactorily considered by:
  - meeting acceptance criteria for established disposal sites; or
  - showing that all Nirex safety criteria can be met.

In the UK, ILW is packaged according to waste package specifications devised by Nirex. These specifications cover a small range of different standard package types (500 litre drum, 3 m^3 drum, 3 m^3 box and 4 m ILW box). The waste package specifications contain guidance enabling waste producers to package waste into a form that is compatible with Nirex plans for transport and deep repository disposal (Barlow *et al.* 2000).

Where it is not possible to demonstrate compliance with all Nirex general safety criteria in the short term, waste producers must be able to demonstrate that credible plans are in place for developing future reworking schemes with a view to achieving a “disposable” form.

Alternatively, they must show that, for the specific waste stream being assessed:

- it is not necessary to meet all of the Nirex general safety criteria;
- decisions have been reached in a systematic and transparent way and are documented appropriately;
- an appropriate balance between short-term actions and long-term commitments has been achieved.

The regulators recognise the need to adopt an approach that takes a balanced view of all relevant factors in assessing proposals from licensees. These include safety, radioactive waste management and environmental performance, cost and practicability. Licensees’ proposals will be scrutinised and, where necessary, robustly challenged on a case-by-case basis to yield transparent, consistent, judgements.

2.1.3 Interim Storage of ILW

For ILW there is at present no UK disposal route, so licensees need to plan for a significant period of interim storage. Given the extended periods of storage that are now likely, and regulatory concerns about the existing storage conditions of some ILW waste streams, the regulators consider that, for these wastes, emphasis should be placed on the implementation of safe passive storage programmes as soon as is reasonably practicable.

During a typical period of prolonged interim storage, it is anticipated that a certain number of packages will be inspected in order to verify their integrity for further storage. Should the delay in availability of a final disposal facility be greater than the lifetime of presently available interim stores, then either they must be re-licensed, or new stores constructed. Package integrity must be verified either for an extension to the operating life of an existing store or for the transfer of packages to a new store. A failed package has to be reconditioned properly for further safe storage (Curtis 2002). Thus, the Nuclear Installations Inspectorate (NII) expects that any future storage facilities, or modifications to existing ones, should be designed to facilitate inspection, retrieval and remediation of waste and facility (RWMAC 2002). During the period of interim storage both the wasteform and its container are important for safety (Constable *et al.* 2001).

A typical example of interim storage would be Magnox swarf, which is ILW resulting from the mechanical de-canning of Magnox fuel elements. This is encapsulated in a cementitious wasteform within 500 litre Nirex specification drums. The resulting waste packages are placed in modern purpose built stores in which the environment is controlled to minimise package degradation. Once encapsulated in this form, the waste is immobile, retrievable and more resistant to external events such as fire and handling accidents.

The UK strategy for the management of radioactive waste is currently being reviewed by the Committee on Radioactive Waste Management (CoRWM). At the time of writing, CoRWM is completing the second stage of public consultation on the subject. The four short-listed options for the future management of radioactive waste all involve a period of interim storage of greater than 50 years.

However, proposals to store ILW for long periods prior to conversion to a disposable form will be given due consideration by the regulators. They will expect such proposals to justify how the delay involved represents best practice, and also to demonstrate how and when conversion to a disposable product will be achieved.

2.2 Reworking of ILW packages

2.2.1 Reworking: definition of terms

In the Environment Agency's Guidance on the conditioning of ILW (Environment Agency 2001a) the term "reworking" is used to cover repackaging of waste that has already been packaged in a waste container. The definition of reworking was widened as a result of the workshop exercise (see subsections 1.1. and 4.3.1), and it was concluded that it did not apply to the *planned* repackaging of raw waste.

In this guidance, it states that reworking involving the requirement to process (or reconstitute) the conditioned waste is likely to incur significant cost, generate secondary wastes, and may result in potentially significant dose uptake.

Reworking could consist of:

- repair of the waste container;
- use of an overpack (e.g. for cases where only the waste container had deteriorated);
- stabilisation of the matrix (e.g. via pressure injection);
- retrieval and reconstitution of the wasteform.

It should be noted that the term "repackaging" is also used in this report. This can be a subset of "reworking" in that it involves removing waste from the original container and placing it into a new container (or the original container if still suitable). The words “repack”, “repackage” and “repackaging” are used in this report as they are more precise descriptions of what is done, than using the parent term “rework(ing)”. “Repacking” excludes some procedures which come under “reworking” such as container repair or overpacking. Repacking may also involve waste that has been packaged for final disposal, in which case it is not part of reworking.

2.2.2 Potential reasons for reworking

Despite stringent measures taken to ensure the long-term viability of ILW packages prior to their disposal, they may require reworking. There exist a variety of reasons why reworking might be required, but typically they fall into the following areas:

- out-of-specification waste package;
- damaged waste package;
- degraded waste package;
- incompatible waste package.

Examples of specific issues where reworking might be required include:

- some element of failure of the waste package;
- excessive radiation dose rates from the package;
- policy changes affecting future disposal concepts;
- non-compliance with future waste acceptance criteria (e.g. packages may be inconsistent with a revised disposal concept, which differs significantly from that for which they were designed);
- loss of or insufficient knowledge of the contents and form of the waste package.

Thus, reworking might conceivably be required, as a result of eventual government policy for long-term waste management. However, delayed conditioning, or conditioning using a reworkable non-monolithic void filler, may produce unacceptably high volumes of waste (including secondary wastes), or have other safety and environmental impacts. In the absence of a preferred disposal route, it is necessary that the Environment Agency understands the issues surrounding the reworking of wastes that may be required as a consequence of waiting for, and following, decisions on the disposal route.

Modern waste storage facilities have been designed to minimise waste package degradation through control of the environment in the store. Nirex, in their waste package specification (Barlow *et al.,* 2000), give guidance on the interim storage of packages. Interim storage facilities need to control temperature, humidity and chemical contamination in order to prolong the lifetime of packaged waste.

The following subsections elaborate on why a waste package may need to be reworked. The reason for reworking a package may influence the choice of technology to perform the reworking task.

Failure of waste packages

These may occur during interim storage due to:

- undetected defects in the waste container during manufacture;
- interaction between the waste container with the wasteform.

Both of these occurrences could indicate failures within the quality assurance programme. In practice, these undetected defects may cause deformation of the waste package during handling, loading, storage and retrieval. Container defects tend to manifest themselves early, and this is a good reason to segregate waste by the date of its conditioning. In this way, systematic problems with container integrity can be avoided (IAEA 1998).

Excessive dose rate

The surface radiation dose rate of a waste package may increase during interim storage. Such an increase could be due to:

- migration of radionuclides within the waste package, leading to their concentration in a certain part of the package;
- failure or degradation of the shielding capability of the container;
- in-growth of higher dose rate radionuclides.

This situation may indicate a significant problem with the waste package as a whole. In that case, the waste package should be retrieved from the storage facility, examined, and reconditioned if necessary. From a radiological protection standpoint, if the change in dose rate is acceptable, and if the dose rate does not exceed the limits established for the facility, the waste package may remain in the store after verification of the container's integrity (IAEA 1998).

According to the Nirex waste package specification (Barlow *et al.* 2000), there is no limit placed on the radiation dose rate from an ILW package. The dose rate limitations arise from the need to comply with the International Atomic Energy Agency transport regulations (IAEA 2003). These specify that the dose rate from a transport package (the combination of the ILW package within a shielded transport container) shall not exceed 0.1 mSv/hour at a distance of 1 metre from the transport container or 2 mSv/hour in contact with the transport package. These criteria apply not only at the time of transport of the waste from the donor site to the repository, but also within the interim storage facility.

Damage to the waste package

Damage to a waste package may occur through accident (drum drop, collision or fire), or by excessive handling (wear and tear). Handling and placement of a waste package in a storage facility using non-specialised equipment have been known to cause deterioration of waste containers. In such cases, the damage ranged from paint scratches, which accelerated corrosion of the container material, to destruction of the container. The latter caused subsequent failure of the wasteform containment, resulting in surface radioactive contamination of the package itself, as well as of adjacent packages (IAEA 1988).

Changes to acceptance conditions or regulations

Reworking of packages may be necessary due to:

- failure of the chosen disposal concept;
- the need to recover valuable materials from the waste;
- a better means of ILW disposal being implemented in the future (Abbott *et al.* 2004).

It is conceivable that regulations may be tightened before a disposal option becomes available. Such changes could result in existing waste packages being unsuitable for current interim storage facilities, transport, or ultimate acceptance at a repository.

2.2.3 Role of UK Regulatory Controls

It should also be noted, that the strict regulatory controls already in place within the UK are important for preventing the future need for reworking.

Extensive measures are in place to prevent production of out-of-specification packages. These include use of the quality assured development process, and assessment of packaging proposals through the "Letter of Comfort" (LoC) process (preventive action). Furthermore, compliance checking is employed to provide feedback on the process, and undertake corrective action where possible.

As it is possible for packages to degrade during storage, the LoC process (itself scrutinised by the regulators) assesses the potential for unacceptable levels of degradation prior to any endorsement of packaging proposals. Nirex has also issued supporting guidance on appropriate environmental conditions for storage and on monitoring requirements, both of which reduce the risk of future reworking.

Furthermore, Nirex assesses packaging proposals for compliance with a generic Phased Geological Repository Concept and associated Waste Package Specification, thus reducing the potential for non-compliance with any specific disposal concept adopted. The LoC process also works to ensure the generation of the appropriate records to accompany waste packages, and has issued guidance on the maintenance of such records.

2.2.4 Experience of reworking within the UK

Encapsulation of ILW in Nirex standard waste packages in the UK has been carried out for about 15 years, and there have been no published instances of any of them requiring reworking. The Nirex waste package specifications require waste packages to be suitable for disposal for a period significantly longer than 15 years. Consequently, no significant non-conformities would be expected within this timeframe. Hence, there is no experience of reworking with respect to encapsulated wasteforms in the UK.

3 Literature Survey

3.1 Introduction

A literature survey was carried out to establish what experience of reworking exists across the world. Although this study specifically focuses on intermediate level radioactive waste, the literature survey included all types of radioactive waste and, where relevant, industries not involving radioactive material.

The details of the literature survey methodology and the identified case studies are presented in Appendix A1. The remainder of this section identifies the key findings from the survey, as follows:

- reworking methods in subsection 3.2;
- strategies for the avoidance of reworking in subsection 3.3;
- key findings from the literature survey in subsection 3.4;
- summary of the case studies in the table at the end of the section.

3.2 Reworking methods

The following subsections describe various methods for the reworking of packaged waste that have been identified through the literature survey.

3.2.1 Generic methodologies

Overpack waste container

An outer package is used to prevent leakage and to provide additional shielding or handling features. This outer package is referred to as an overpack. The IAEA recommend that packages with serious container structural problems must always be overpacked.

Overpacks may mitigate mechanical- or corrosion-connected problems associated with waste packages. Overpacking can also help reduce surface dose rate levels to acceptable levels. Various types of overpack are currently in use. As an example, 200 litre drums containing long-lived ILW can be inserted into either 400 litre drums or a large rectangular container manufactured of steel or reinforced concrete. The open space in these overpacks may be grouted with cement to increase the mechanical and shielding properties. The 200 litre and 400 litre drums are commonly used outside the UK. However standard UK practice is to use the 500 litre drums.

Overpacking only provides additional containment of the waste package– it does not correct intrinsic problems with the wasteform. For example, where the problem with a waste package is due to chemical reactions within the wasteform, overpacking is unlikely to prevent further chemical reaction occurring.

The use of an overpack, however, increases the weight and dimensions of the package. This may have consequences for the compatibility of the overpacked waste package with handling, transport and storage equipment. There are also waste volume considerations. Overpacking of a large number of waste containers could result in a significant increase in the disposal volume.

In other cases, the packages retrieved from the storage facility may be reconditioned in order to comply with transport regulations and waste disposal acceptance requirements (e.g. non-immobilized wastes). Special precautions, including use of an overpack, should be taken to ensure safety and prevent environmental discharges during transport to the reconditioning facility.

A waste package can be deformed from the effects of gas pressurization. Also, chemical changes in the package can damage the waste container, e.g. from chemical reactions leading to expansion of the wasteform, or corrosion of the container from the inside. Under these conditions, overpacking or other more invasive methodologies will be necessary in order to meet the ongoing storage, transport or disposal waste acceptance requirements.

With respect to Nirex standard waste packages, in principle, larger standard packages could be used as overpacks in some cases. 500 litre drums can be overpacked with 3 m^3 boxes, and the latter can be overpacked with 4 m ILW boxes. The 4 m ILW box is the largest waste package acceptable by Nirex. This package type would require size reduction in order to be repacked (Constable *et al.* 2001). It is important to note that the 4m ILW boxes are designed as Industrial Packages (IPs), and they could not readily be used to overpack packages that caused any of the associated IP restrictions to be exceeded.

Repair damage to waste container

Mechanical failure of a waste container may be due to minor or major damage. Minor dents, scratches, rust or corrosion that are the result of external impacts or other influences may be repaired so long as the package integrity has not been compromised. Repair of the package may also be a suitable method of correcting defective lifting features.

Where a package has a defective vent, rework may be achieved by complete replacement of the package lid (as the lids of Nirex specification packages are bolted on). A defective vent, however, may have resulted in the build up of pressure within the waste package. Piercing the original lid, or backflushing the vent may be appropriate remediation techniques.

For the Yucca Mountain project, different welding methodologies are being investigated. One reason for this work is the requirement that damaged waste packages are capable of being repaired using a remotely operated welding technique (Yucca Mountain Project 2004). Repair to a drum may simply be a matter of repainting the drum to maintain corrosion resistance.

Legacy waste drums at the Jülich Research Centre in Germany are to be managed by applying a thick polyurethane coating to the outside of each drum to prevent water ingress. In this case, the source of the problem was water within the wasteform. A drying process was used to remove this residual water, then the polyurethane coating was applied to prevent future water ingress to the package.

However, it should be recognised that there are negative aspects associated with some proposed repair mechanisms. Bolts and lids may not be readily removed. Furthermore, it is not standard practice to paint ILW disposal containers in the UK, and paints may have adverse effects.

Injection of stabiliser

A stabilising compound can be injected into the package to fill voids and seal cracks. Drilling through the waste package may be necessary to allow injection.

Should inspection reveal that liquid has been generated in the waste package, or that organics are present (which may degrade, possibly resulting in waste package expansion), the preferred option from the standpoint of cost and the As Low As Reasonably Practicable (ALARP) principle, is in situ package remediation. A number of techniques are available to drain fluids through container penetration, e.g. by adding flocculants, absorbents and anticorrosive agents.

Grout or polymer injection into cracks or voids in the wasteform or for filling voids following core removal, has been demonstrated on inactive materials (Constable *et al.* 2001). Taylor Woodrow undertook a short experimental programme of core-drilling and grout-filling of holes on 200 litre drums. Cement grout was poured into the holes whilst simultaneously vibrating the drum using an air-driven machine attached to the outside of the drum. No major experimental difficulties were encountered, confirming that holes left after coring can be grout-sealed prior to sealing (Green *et al.* 1992).

Physical break-up and repackaging of waste

This involves the container and wasteform being physically dismantled and its size reduced. The resultant material is then placed inside new waste containers.

Dismantling of the container and wasteform, if required, may result in environmental discharges, since containment of the waste package has been deliberately breached. Gas filtration and effluent treatment processes will reduce these discharges. However, dismantling and repacking may substantially increase the overall waste volume unless reduction methods are used during the reworking.
Two documented methods of volume reduction are:

- segregation and sorting to, for e.g., separate ILW from low-level waste (LLW);
- supercompaction to physically compress waste into a smaller volume.

In the case of segregation of a mixture of ILW and LLW waste, there would be no overall volume change for the total volume of waste, but the volume requiring treatment as ILW would reduce. Some LLW would be produced and would require management and disposal. Segregation and sorting could result in small discharges due to opening of waste containers.

If the ILW contained some soft material, then that ILW could be compacted (at high pressure using a process usually referred to as “supercompaction”) and its volume reduced. However, if the waste were grouted, then it would not be possible to supercompact. Supercompaction generates discharges through the expulsion of dust and free liquids, and therefore has the potential to give rise to small environmental discharges.

Theoretically, there are no sizes limits for these types of processes - in the US whole concrete reactor structures have been remotely cut up and packaged as waste. Much experience exists in size-reducing techniques of remote demolition and decommissioning.

Supercompaction can be applied to waste that has been packaged loose and is therefore relatively straightforward to remove from the waste container, and segregate and condition into a higher quality waste package. There are no known examples of this technique being applied to intimately grouted waste.

Wasteform chemical separation and reconstitution

Using currently available technologies and conditioning matrices, it seems unlikely that reconstitution and/or separation of components of a grouted wasteform will be practicable. Chemical separation might have been easier on the raw waste, but even this was considered unfeasible, given the mixture of substances in ILW, e.g., the variety of different radionuclides etc. Many studies have examined the chemical separation of ILW, prior to disposal, to reduce waste volume or to recover valuable materials from the waste (e.g. chemical decontamination). However, in many cases, chemical decontamination results in an increase in radioactive effluents and so has not been used.

3.2.2 Reworking strategy variations

As well as considering the actual technical methods for reworking of waste packages, it is also important to consider where, within an ILW strategy, reworking of waste should be considered. Different variations of the ILW strategy are discussed below. For this report, it will be assumed, that a deep waste repository will be the destination of the waste packages.

No reworking

Ideally, repacking of waste should be avoided. Nevertheless, the need for reworking will be determined by the integrity of the packaged waste:

- during the period of interim storage;
- transport to a disposal facility;
- the operational phase of the disposal facility.

Should a waste package fail to meet operational, transport or disposal safety or acceptance criteria, then remedial action must be taken. However, a package that has degraded could still be accepted by a concession route, subject to the precise nature of the degradation.

Decisions as to whether or not reworking might be necessary could be supported by the retention and storage of waste coupons, or dummy waste drums (containing non-active waste simulant). These samples, if stored under equivalent conditions as the corresponding waste stream, and assuming they are amenable to detailed analysis, could provide an insight into the underlying condition of the wasteform.

Repack at repository

Assuming they are capable of safe transport, all waste packages could be shipped to the repository complex whether or not they comply with the conditions for acceptance. Non-compliant packages could be reworked in a facility within the repository operating area.

In accordance with the pre-closure retrievability concept, this may require a waste reworking facility to support the surveillance phase of repository operation. However, this would also require changes to the Nirex phased disposal concept for this option to be feasible. The Nirex waste package specification (Nirex 1995) states that a waste package is designed not to be opened or unpacked at the repository.

Also, regardless of the possible risks in transporting non-compliant packages, it may not be feasible to construct waste package reworking facilities at certain nuclear sites. For example, where there has been a long period of care and maintenance, the site's infrastructure may be unable to support a process facility.

Repack at donor site (Nirex 2003)

Here it is assumed that waste packages would not leave the donor site unless they comply with repository's acceptance and transport safety requirements.

Complete reworking of waste packages at a donor site may not be feasible if the number of non-compliant drums is small or the site infrastructure can no longer support the processing of radioactive materials. Consideration could be given to the design and provision of a mobile waste reworking plant that could service all interim

ILW stores. In addition, the use of simple overpacks could be considered, that would require a minimum of operational complexity to use.

Delayed packaging of waste (1) – interim storage of unconditioned raw waste

Here, there is no processing of the waste, as it would simply be moved from one storage facility to another until transport to a long-term repository is imminent. Storage of unconditioned waste may not be in line with the concept of passive safety. The interim storage period may have higher environmental and safety risks associated with it than with the current strategy.

Delayed packaging of waste (2) – interim storage of partially conditioned waste

Here, the waste is conditioned towards passive safety but without packaging for disposal. There is an opportunity to sample and characterise waste further to improve final packaging arrangements and this option has the added advantage of being more robust against external changes to packaging requirements.

However, with respect to these two delayed options, it should be noted that the regulator's current preference is for directly disposable waste packages (HSE, Environment Agency & SEPA 2005).

Re-categorisation of waste

Long-term storage may allow some low activity or short-lived waste packages to decay below the clearance levels established by regulatory authorities. In this case, prolonged storage is a benefit, because it results in a certified waste package that may be disposed of in a less expensive waste disposal facility, or recycled back to industry. Waste packages may be retrieved after a decay period when they have become very low-level or cleared waste. In a few countries, clearance levels have been defined to allow consideration of the packages as cleared waste.

It is essential to account carefully for all of this waste when characterising the waste package. Otherwise, it will not be possible to demonstrate that the initial levels were correct, making it difficult to re-categorise the material to a lower level.

Waste that may be subject to clearance should be segregated and, if a large backlog of waste exists, should preferentially be left in storage. The controls at retrieval must be commensurate with future utilization (no reuse of the installation, no reuse of the decayed waste) and take into account the related conventional hazard risks. For example, chemical toxicity (i.e. the presence of hazardous materials) will play an important role in the case of disposal at industrial waste disposal sites.

The following referenced examples take advantage of decay storage:

- Amersham sea-dump drums;
- Harwell tube store waste; and
- management of short-lived sealed sources.

The applicability of decay storage is dependent on the nature of the waste itself. The radionuclides within the waste must be relatively short lived so that the period of interim storage is sufficient for the radioactivity to fall to such levels that the waste could be reclassified.

3.3 Strategies for the avoidance of reworking

3.3.1 Introduction

Only a few reworking avoidance strategies could be found. Two are discussed below. The primary UK approach to avoiding reworking is outlined in Section 2.

3.3.2 Disposal of spent fuel in Finland

The Finnish strategy for spent fuel management is not to reprocess, but to directly dispose of the fuel. The fuel packaging and encapsulation plant will be located above the proposed deep repository. Fuel will be packaged immediately before emplacement in the repository. This is to avoid an interim storage phase where waste reworking may have been necessary (Vira 2003). This approach, therefore, can be regarded as essentially a strategy for the avoidance of reworking. It should be noted, however, that this applies to a specific type of waste, i.e. irradiated fuel.

3.3.3 Interim Safe Storage Strategy

The Interim Safe Storage (ISS) concept was developed as an idea (see discussion in Appendix A1), which could mitigate against the need for future (unplanned) reworking. The raw waste would be stored for a considerable time in an unconditioned or partially-conditioned state. The waste would then require some (planned) reworking prior to disposal. This reworking would require minimum effort and risk because of the initial conditioning and packaging. However, in the current regulatory climate, this idea may be regarded as obsolete: the regulators have stated their preference is for waste to be stored in a form that is suitable for final disposal.

3.4 Key findings from the literature survey

Many ILW strategies worldwide have acknowledged the fact that reworking of waste packages might be necessary in the context of a long-term waste management strategy. However, there are a few examples of detailed plans (i.e. consideration of the technology required, or the environmental discharges resulting from waste reworking).
Examples where waste packages have been reworked come from where there has been a requirement to retrieve legacy drummed waste from old storage facilities. The waste was then reworked into a form that meets modern standards for interim storage and disposal.

Where legacy waste has been drummed loose, two general strategies are used:

1. Legacy drums are retrieved from the historic store and overpacked, if necessary for transport to a waste reworking facility. At the waste reworking facility, the legacy drums are emptied of waste, the waste is inspected, sorted and treated to render it chemically inactive before being repacked into new drums for further interim storage or disposal; and

2. Legacy drums are retrieved from the historic store and overpacked, if necessary for transport to a waste treatment facility. Following inspection, the legacy waste drums are compacted and grouted into a larger disposal container.

There is little experience of reworking a grouted wasteform. One example of this is from the Jülich facility in Germany. Here, grouted wasteforms were dried and then the waste container coated to ensure future waste package stability. Drummed grouted wastes are also to be overpacked at the Różan facility.

These two examples illustrate the preferred strategy used by most waste management entities. This is to avoid where possible, breaking up grouted wasteforms, and overpack the waste packages (although some non-intrusive remediation of the wasteform may also be necessary, e.g. drying of the wasteform).

Consideration was also given to experience of industries processing non-radioactive wastes. Some key differences between the radioactive and non-radioactive waste sectors were noted. Although it is now a requirement to consign hazardous materials to special landfills in a conditioned form, the chemical industry is not generally faced with operational constraints, such as the need for remote handling. Furthermore, many non-radioactive chemical wastes can be destroyed or converted to non-hazardous chemical forms by treatment processes, or re-used as raw materials in other chemical processes. Accordingly, no specific input to this study was drawn from the non-radioactive waste sector.

In the UK, ILW strategy, reworking has yet to be considered in detail. ILW is immobilised to Nirex specification at the earliest opportunity, and the packages placed into interim storage for an indefinite period. The interim stores are designed to keep the packaged ILW in conditions that minimise degradation of the packages. It is possible that some packages may require reworking in the future. The Regulators recognise the value of the LoC process in mitigating this risk (Environment Agencies 2003). Any future reworking projects would depend on the number of waste packages affected and the reason for reworking.

As no firm ILW reworking strategy exists in the UK, the opportunity exists for environmental guidance to be formulated before a UK strategy is devised.

The lack of sufficient practical experience to define “best practice” is acknowledged. However, the Environment Agency remains concerned that, given the uncertain time period before an UK facility might become available for disposal of ILW, there is significant risk that waste packages might require reworking during an interim storage period. It is therefore considered important that the potential consequences of reworking are more fully explored, and further strategies are developed to mitigate against this risk in pursuit of Best Practicable Means (BPM).

However, as work continues in other parts of the world, the Environment Agency should keep a watching brief on some of the identified projects, particularly those at Jülich, Karlsruhe, Lanyu and Różan, and any developments on the repair of damaged waste packages using remotely operated welding techniques at the Yucca Mountain Project.

Summary of case studies identified in literature survey

Facility / Project	Location	Type of Waste	Rework Methodology
Amersham legacy sea-dump drums	Harwell, UK	Annular grouted waste from isotope production	Wasteform broken up and segregated into ILW for decay storage, LLW and free release
Drigg PCM waste	Drigg, UK LLW repository	Ballasted drums of LLW and PCM	Drums overpacked with larger drums and transported to Sellafield site
AWE legacy sea-dump drums	Aldermaston, UK	Plutonium, uranium and tritium contaminated material within an inner drum grouted into an outer drum	Inner drum will be extracted from package. Outer drum and grout annulus to be sent to Drigg. Inner drum material will be treated as ILW
Winfrith sea-dump drums	Winfrith, UK	PCM	Transport to Harwell for unspecified treatment
Post destructive testing (EA waste verification)	Winfrith, UK	Sample waste consignments to Drigg repository.	Waste unpacked for inspection, sampled then repacked.
Nirex	UK ILW repository concept	ILW 500 litre drums within backfill grout	Example of cutting drums from simulated repository backfill using remote water jetting
Advanced waste retrieval programme	UKAEA Harwell, UK	Legacy canned waste within B462 tube store at Harwell	Cans to be remotely opened, contents to be characterised and segregated into ILW or LLW and repackaged
Lanyu repository	Taiwan LLW repository	Legacy drummed waste in LLW repository which is to be emptied.	Drums to be overpacked or repaired

Facility / Project	Location	Type of Waste	Rework Methodology
Różan Facility	Poland Radwaste repository	Drummed, conditioned waste (grouted) and drummed unconditioned waste.	Grouted waste drums unsuitable for long term storage to be overpacked. Ungrouted waste to be sorted and repacked
Non-nuclear industry	UK	Drummed chemical waste	Damaged chemical drums are typically overpacked to maintain waste containment
Sellafield legacy ponds and silos	Sellafield, UK	Legacy bulk stored waste in ponds (B29 and B30) and silos (B38 and B41)	Waste may be immediately encapsulated with risk of costly future rework or waste may be conditioned and safe stored prior to future packaging to meet disposal conditions
IFE, Kjeller	Norway	Recovery of shallow buried waste in 210 litre drums	Retrieved drums grouted into larger drums for underground vault disposal
Management of spent sealed sources	UK	Spent sealed sources	It is proposed to separate source active material from source containers in B459 at Harwell
El Cabril Repository	Spain	Legacy drummed LLW stored in old mine	LLW drums to be grouted into large (18 drum capacity) overpacks

Facility / Project	Location	Type of Waste	Rework Methodology
Waste Isolation Pilot Plant	Carlsbad, New Mexico, USA with donor sites at Fluor Hanford, Idaho National Laboratory, Savannah River and Oak Ridge	Drummed transuranic waste (similar to PCM)	At donor sites, legacy drums are unpacked, waste conditioned to a passive state and repacked into new drums. Repacked waste is then sent to WIPP site for repository emplacement
Yucca Mountain repository	Nevada, USA	Spent fuel	Research ongoing into remote welding apparatus for waste package repair
Finnish spent fuel	Finland, Europe	Spent light water reactor fuel	Spent fuel is to be immobilised immediately prior to repository emplacement at the repository site to avoid interim storage
Karlsruhe Research Centre	Germany	Legacy interim stored drums	Drum reworking method not known
Jülich Research Centre	Germany	Legacy interim stored drums	Grouted drums to be dried then coated with thick polyurethane
Drigg PCM	Drigg, UK	Legacy stored PCM in 400 litre drums	Drums to be overpacked for transport to Sellafield then “supercompacted” and grouted into Nirex specification 500 litre drums

4 Workshop

4.1 Introduction

4.1.1 Background

In order to support the main objectives of this study, a workshop was conducted involving regulators, operators and experts in the field.

Prior to this, a worldwide literature survey had been undertaken to review relevant examples of reworking: this was described in Section 3. As a result, an initial definition of reworking was made. In addition, see Section 3, the types of reworking which had been undertaken on various sites were described, and generic descriptions provided. Some of the reasons for the requirements for reworking were also explored. The main purposes of the workshop were to refine the definition of reworking, to explore the reasons for reworking and to identify those procedures that may be considered as best practice.

4.1.2 Scope and objectives

The specific objectives of the workshop were to:

- identify the potential reasons for reworking a conditioned waste package;
- identify reworking methods for different waste types;
- identify strategies to facilitate reworking;
- assess the implications and effects of reworking, with the main focus on potential environmental impacts.

It was anticipated that the output from the workshop might be useful in refining some of the conclusions from the literature review: together, it was thought these could form a basis for the development of future guidance.

A detailed description of the scope and objectives of the workshop, including the scope and objectives of the individual workshop sessions, is provided in Appendix A2.

4.2 Methodology

The workshop study was divided into four sessions. The first two sessions were high-level sessions to identify the reasons for reworking, and the strategies to facilitate reworking. The last two sessions were focussed on identifying specific reworking methods and the implications of applying them.

A detailed description of the methodologies used in the workshop and how the workshop sessions were conducted, together with the main outputs, are provided in Appendix A2. The main findings from the workshop are discussed below.

4.3 Findings from the Workshop

4.3.1 Definition of reworking

The definition of reworking was broadened when compared with the definition that had previously been adopted from the results of the literature review.

The new definition is as follows: *A process involving physical intervention to packaged waste arising from deviation from the planned, storage, treatment or intended disposal process for that packaged waste*.

Based on this definition processes such as overpacking, stabilisation of waste and retrieval, and reconstitution of the wasteform would still be classed as “reworking”. However, in addition, invasive processes such as coring or assay of the waste would also be regarded as reworking. However, monitoring of the surface of a contaminated waste package by means of wipe analysis, or non-destructive assay of a waste package, would not be regarded as part of the reworking process.

4.3.2 Reasons for potential reworking

The reasons identified for potential reworking are shown in Table A2.1 in Appendix A2. They were found to fall into broad categories as follows:

- damage or deterioration resulting in:
    a) loss of shielding or containment;
    b) generation of hazardous substances; or
    c) damage to external handling features.
- package out-of-specification;
- insufficient records;
- external policy, economic, or other pressures.

4.3.3 Strategies for dealing with out-of-specification packages

Various strategies/methods were identified which could be implemented for out-of-specification packages. These are shown in Table A2.2 of Appendix A2.

Each strategy had a different level of complexity, and a potential environmental, safety, and cost impact associated with it. The strategies identified were of three main types:

1. No requirement for physical intervention on package:
    - no intervention;
    - monitoring and observation of package leading to possible package segregation.

2. Other requirement for physical intervention (but not on package):
   - intervention in waste production plant (e.g. change wasteform manufacturing process);
   - intervention in waste store (e.g. provide means of drying atmosphere within the store to mitigate against moisture build-up and ingress on packages).

3. Requirement for physical intervention on package:
   - simple container repair or overpack package (e.g. weld or patch drum);
   - complex package disassembly or treatment (e.g. drill out cores and inject stabiliser, dissolve package);
   - change of disposal route or other special arrangements with disposer.

Most of the strategies identified involved no physical intervention on the waste package.

4.3.4 Development of process for out-of-specification packages

It was considered impractical to identify best practice in terms of reworking methods for a given out-of-specification waste package and wasteform. This was because of a lack of data on reworking methods and strategies and the diversity of options that were judged to be available.

Therefore, it was agreed to try to define a series of generic logical steps that could be followed to decide on the most appropriate action for any given out-of-specification waste package and wasteform.

In particular, this approach allowed proper consideration of the options that may be available for the specific problem being considered. It emphasizes the importance of assessing the problem and, where appropriate, obtaining more information before making a decision. Examples from where this additional information may come include more detailed inspection and on-going observation and assay of the waste package. Additionally, doing nothing or carrying out limited repairs would be expected to have significantly lower environmental impacts than the costly and complex invasive options.

Integral in the stepwise process is a series of feedback loops allowing lessons that have been learned, and information from observations, to be fed back into earlier processes. This is discussed further in Section 5.

4.3.5 Implications and effects of reworking strategies and methods

A qualitative assessment was performed to consider the environmental, safety and cost implications of the various reworking methods and strategies, which had been identified previously as part of the workshop study. The implications of the strategies/methods are shown in Table A2.3 of Appendix A2.

Environmental factors that could be of relevance in reworking activities include:

- repackaged waste volumes;
- secondary waste volumes;
- liquid and gaseous discharges;
- additional use of natural resources.

The qualitative assessment considered these factors in identifying whether the environmental impact for a particular reworking approach was likely to be high, medium or low. However, it was recognized that this approach could only be indicative, and the results from the assessment should not be used for decision making. However, there are some broad conclusions that can be reached:

1. The overall impact of no or low intervention strategies, such as performing observations, monitoring, or re-assay, is likely to be low.
2. Options that are non-invasive, such as relatively simple package repairs, or overpacking, are likely to have an overall medium impact. However it should be noted that overpacking may increase the volume of the waste package, and therefore also the overall volume of waste requiring disposal.
3. Options that involve invasive techniques, such as disassembling by mechanical crushing, and shredding or dissolving the package, or breaking the package down by heating, will tend to have the highest environmental impacts. These strategies will generate the most diverse and active secondary wastes, and will present the highest hazards and financial costs.
4. The potential impacts of changing disposal routes, or making special arrangements for disposal can only be assessed on a case-by-case basis once the details are known, and the agreement of the organisation accepting the waste has been secured. However it is likely that these options will have a lower overall impact than the high impact options described above, because they will not involve physical intervention on the waste package.

5 Process for Out-of-specification Packages

5.1 Background

The workshop showed that it was not practical to identify best practice in terms of reworking methods. However, it was considered that best practice would be to follow a clearly identified strategy to establish the right approach for each specific instance of potential waste package reworking.

This strategy takes the form of a logical step-wise process to determine the most appropriate course of action. Thus, a series of logical steps was developed from the workshop discussions, and these can be applied to any out-of-specification waste packages.

5.2 Description

Figure 5.1. shows a schematic diagram of this series of logical steps to determine an appropriate reworking strategy for any out-of-specification waste packages. The steps should be followed from left to right. The start point is package production and the endpoint is package disposal.

Key phases in this process are:

- detect and identify problem;
- review possible problem;
- identify and implement an approach (after the problem has been thoroughly reviewed).

5.3 Discussion

5.3.1 Problem identification

The first phase of the process is concerned with problem detection and identification.

Problems may become apparent immediately after the package is manufactured, as a result of post-production examination, or after the package has been stored for some time.

For example, a problem could be identified by routine physical inspection of packages within the store, or by routine monitoring in the store. Routine physical inspection could detect swelling of a package, cracking of welds, and leaks. Routine monitoring within the store could detect increases in airborne radioactivity concentrations that could indicate package damage, leading to a loss of containment.

A review of paper records could reveal additional details concerning packages, which could indicate they are out-of-specification.

Changes in external policy could lead to waste packages that had previously been within agreed specifications, becoming out-of-specification. For example, changes in government policy and regulation could result in the Nirex standards and specifications being changed.

It should be recognised that there might also be a proportion of packages in which underlying problems exist (e.g. non-expansive cracking of the wasteform) that are not readily detected.

5.3.2 Review possible problem

In each case, a thorough review of the problem is required before an approach is identified. This will ensure that progression to highly invasive and expensive reworking methods will only occur after other lower impact approaches have been discounted.

Inputs to the problem review process may be data from ongoing observations or monitoring, and information gathered as part of the problem detection and identification process.

5.3.3 Identify and implement approach

Once the problem has been thoroughly reviewed, it should then be possible to identify an approach.

The possible approaches identified were as follows:

- apply lessons learned from the problem review process leading to:
- no intervention;
- ongoing observation;
- immediate intervention;
- special arrangement at the Waste Repository.

Apply lessons learned from the problem review process

Two examples are provided which illustrate this type of approach:

Example 1: If one percent of waste packages were out-of-specification, this could mean that there had been a one-off manufacturing error in the waste encapsulation and packaging plant. However, if ten percent of waste packages were out-of-specification, this could mean that a systematic error might be present in the waste encapsulation and packaging process. In each case, details of the problem could be referred back to the plant, and the production process could be modified to eliminate the problem, without resorting to physical intervention on a large number of packages.

Example 2: Similarly, if generic problems have been identified in waste packages within a particular store, the solution may be to modify the storage arrangements. An example could be moisture ingress into the wasteform or packaged waste in a store, leading to swelling of the wasteform and distortion and weakening of the package. Modification of the store atmosphere by provision of additional ventilation or heating, would represent a possible solution, and would not require any physical intervention on the package.

In both the examples cited above, lessons learnt from the problem review process were fed back into earlier process phases to prevent the recurrence of out-of-specification waste packages. However, there was still a requirement to repeat some of the earlier phases of the process, to check if a problem still existed once appropriate modifications had been made.

In the examples above, application of this approach would result in the production of new packages, using a modified production process or the storage of packages in a modified store. The packages would then be monitored to determine if a problem still existed, and if indicated, the problem review process would be repeated and a further approach would be identified. There may be several iterations of this part of the process until the problem has been solved and package disposal could proceed. Different types and frequencies of monitoring regimes could be applied during the iterations of the process as appropriate. Some reworking of particular packages that are identified as the source of the problem may also still be required.

No intervention

If sufficient evidence is gathered at the problem identification and review stage, there may be a decision to undertake no action i.e. no intervention. An example of this is provided below.

Example 3: Regular inspection of waste packages reveals that a few are showing stains and signs of corrosion on the lids. Sampling and analysis is carried out of the corroded material as part of the problem review process. This reveals that there is no egress of waste material from the package. It is noted that the corrosion is not limited to packages of one type. Further investigation reveals that rainwater leaks from the store roof are causing the corrosion. Thus the roof is repaired, and no further action is required on the waste packages.

Ongoing observation

An example of this type of approach is provided below.

Example 4: Regular inspection of a particular type of waste packages in a store reveals that a few are showing signs of swelling which could lead to weakening of the packages and potential damage to lifting gear. The store atmosphere has already been optimised and the waste encapsulation process and package manufacture has been ruled out as a cause. The approach taken is to increase the frequency of physical examination, to gauge the degree of distortion. Ultimately, this will provide confidence that packages will be robust enough to be moved once this is required. The situation is regularly reviewed to see if the monitoring frequency is still appropriate and to assess if another approach is required. Monitoring regimes are discussed in more detail, below.

Immediate intervention

An example of this type of approach is provided below.

Example 5: A review of records indicates that one of the waste packages in a store contains a highly active item, which should not have been placed in the package. It is estimated that the item will cause the package to greatly exceed the package dose rate acceptance criteria. Leaving the package to undergo radioactive decay is discounted, as the radionuclides in the package have long half-lives. It is estimated that provision of an overpack will not sufficiently reduce the external dose rate. The approach taken is to disassemble the package, re-encapsulate the waste and repack it for ultimate disposal.

Special arrangement at waste repository

If a waste package is slightly out-of-specification, it may be possible for the waste producer to negotiate with the waste acceptor to take the waste package, if special arrangements at the repository can be agreed. It is anticipated that in most repositories, these special arrangements will normally mean placing the waste package in a different location to that originally planned.

In theory, other special arrangements could be made. For example, in a phased disposal concept, in which waste packages would be temporarily stored before final encapsulation and disposal, changes could be made to the conditioning or ventilation of the atmosphere. However, each situation would have to be negotiated on a case-by-case basis.

An example of this type of approach is provided below.

Example 6: The heat generation limit for a package is 50 W. A waste producer has a waste package in storage that generates heat at a rate of 70 W, and is therefore out-of-specification. The waste producer negotiates with the waste acceptor and agrees that the planned location of the package in the store will be changed. Instead of being surrounded by 50 W packages, the 70 W package will be surrounded by 30 W packages, thereby reducing the average heat generation value to no more than the 50 W limit.

5.3.4 Consideration of monitoring and observation techniques

The question of frequency and type of observation and monitoring regimes is a complex one. A strategy for determining an appropriate monitoring regime for a given set of waste packages, has been reviewed (Constable *et al.* 2001). In this study, threats to the ability of a waste package to meet acceptance criteria have been defined in terms of 'observable' characteristics that were used as a basis for deriving an appropriate monitoring regime. Packages containing the following wastes were considered:

- immobilised ion exchange compounds;
- immobilised sludges, liquors and concentrates; and
- grouted solid wastes.

The greatest potential threats, and therefore observable characteristics, were found to lie with grouted reactive metal wastes and immobilised ion exchange resins. The threats and observable characteristics are described in detail for grouted reactive metal/solid wastes in a 500 litre drum (Constable *et al.* 2001) and are summarised as (observable characteristics are shown in parentheses):

- dimensional stability of the cementitious wasteform (wasteform integrity – cracks and particulates);
- chemical containment (pH, complex content);
- container integrity (cracks, corrosion, deformation, gas generation, obscuring of package identifying marks);
- corrosion (corrosion, gas generation, deformation, heat output, package thermal conductivity);
- criticality (wasteform configuration may affect criticality);
- deformation (deformation, damage to lifting features);
- dimensional movement (deformation and cracking);
- gas generation (gas generation, pressurisation, container integrity);
- handling (may obscure identifying marks);
- hazardous materials (mostly hydrogen generation);
- radiation stability (wasteform and container integrity);
- radionuclide decay e.g. ingrowth of americium-241 from plutionium-241 (radioactivity content);
- stacking of packages (may cause deformation);
- strength (wasteform or contained degradation);
- thermal effects (heat output and wasteform integrity);
- vents/seals (vent efficiency, surface contamination) and
- wasteform integrity (cracks and particulates, thermal conductivity).

Thus a tiered approach was developed for monitoring/observation, with the least invasive techniques described as Category 1 and the most invasive as Category 3 (Constable *et al.* 2001):

- Category 1-I covers simple monitoring techniques that can be performed in-store, in-situ, but without moving the waste packages;
- Category 1-M covers simple monitoring techniques, possibly inside the store (depending on the store design), but probably performed outside the store, and therefore require package movement;
- Category 2 covers complex non-destructive analysis and monitoring techniques, performed outside of the store in a new or modified monitoring facility;
- Category 3 covers techniques for the destructive or intrusive inspection of the waste package performed outside of the store in a new of modified monitoring facility.

It should be noted that many of the techniques could also be used to confirm the suitability of the waste package for ultimate disposal to a waste repository. It is anticipated that destructive analysis of waste packages would only be performed as a last resort under the following circumstances:

- because of engineering difficulties;
- external radiation exposure;
- production of secondary wastes and contamination;
- the problems of reworking the analysed package into a suitable condition for disposal.

Statistical approaches are available which allow selection of a suitable number of waste packages for monitoring (Constable *et al.* 2001). The frequency of monitoring will be dependent on the likelihood of change, but in steady conditions Category 1M monitoring may be as infrequent as 30 years. The frequency of Category 2 monitoring will be dependent on the output from Category 1: the frequency of the Category 3 monitoring will be dependent on the output from Category 2.

5.4. Conclusions and recommendations

It is impractical, at the current time, to identify best practice in terms of reworking methods. Instead, best practice should follow a clear strategy to establish the right approach for each specific instance of a waste package potentially requiring reworking. This strategy takes the form of a clear process that should be used to determine the most appropriate course of action for any out-of-specification waste package.

Key phases in the process are:

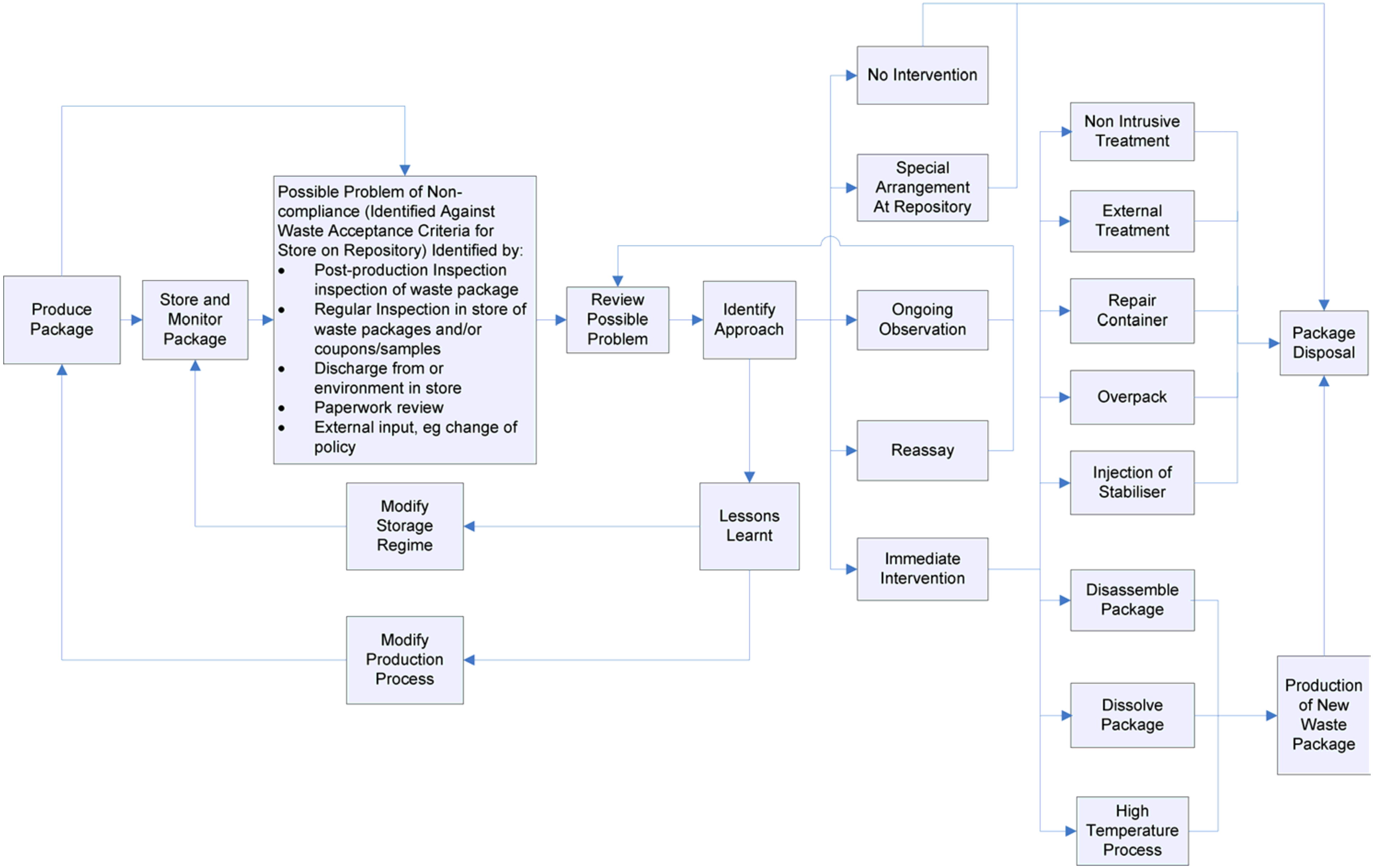
- detection and identification of the problem;
- review of possible problem;
- identification and implementation of an approach.

The most crucial part of the process is how a particular problem is thoroughly reviewed.

Following a logical stepwise process will ensure that progression to invasive and expensive reworking methods will only occur after other lower impact approaches have been followed or discounted.

It is recommended that this stepwise process should be trialled to assess its practicability and whether it needs refinement.

Figure 5.1 Process flow-chart for determination of appropriate strategy for out-of-specification waste packages



6. Discussion

6.1. Objectives

The objectives of this study were:

1. To identify examples and case studies of reworking waste streams and other relevant materials and to identify different reworking methods;
2. To assess the potential for reworking following different waste treatment and conditioning strategies (to include but be not limited to: in-drum mixed cemented products; compacted pucked wastes placed within a cementitious matrix; annular grouted packages; polymer and novel encapsulants);
3. To assess potential strategies for facilitating reworking (to include but not be limited to the following: postponement of conditioning, use of non-monolithic void fillers such as sand, use of non-standard types of cementitious materials, and use of novel encapsulants);
4. To assess the implications of such strategies in terms of key impacts including waste degradation during long term storage, volumes of secondary waste and safety implications; and
5. To make recommendations that will underpin future regulatory guidance.

6.2. Identification and feasibility of reworking methods

Case studies were described as an output from the literature survey (Section 3) and reworking methods were identified from the literature survey and workshop. In general, experience of reworking ILW packages in the UK is extremely limited due to the:

- relatively low volume of waste that has actually been encapsulated and stored for any length of time;
- detailed development, modelling and assessment studies that are applied to ILW packages, prior to processing and encapsulation of wastes.

6.2.1 Non-intrusive treatment

Examples of this include decontamination of, or removal of stains arising from localised corrosion from the external surface of the waste package.

6.2.2 Overpacking of waste package

An overpack may be large and bulky or may be a simple layer of polyurethane foam. Overpacking is a term normally used to describe the placing of a smaller non-compliant package inside a larger package with or without the addition of more encapsulant.

Overpacking can be used to provide containment, to mitigate against loss of chemical containment, or can be used to provide additional shielding. Overpacking can also be used as a technique for achieving compliance for deformed packages. However, it will increase the size and weight of the overall package that can lead to handling problems.

At present, overpacking may only be carried out using the standard Nirex-approved containers. 500 litre drums may be overpacked into $3m^3$ ILW boxes or 4m ILW boxes. Overpacking into the $3m^3$ ILW drum may also be possible depending on the aperture of the lid opening.

There is experience of overpacking drummed grouted waste at the Różan facility in Poland, but in the UK it has been limited to overpacking of raw waste. However overpacking (as explicitly mentioned in the Nirex LoC output) was recognised at the workshop as a relatively straightforward option and, should reworking be necessary, is likely to be a standard technique in the UK.

6.2.3 External treatment of waste container

This could involve spraying a package with paint or another compound, which will form a mechanically strong and non-porous layer, stopping egress of contaminant. It is a feasible technique for most packages as it can be undertaken with a hand-held spray gun for low dose rate packages or remotely using a robotic arm for high dose rate packages. Any materials used, especially if organic, would have to be compatible with the repository constraints. Coating techniques have been successfully applied at the Jülich Research Centre Germany to grouted legacy drums that were dried and then coated with thick polyurethane. This could be regarded as a special type of overpacking.

6.2.4 Repair waste container

Depending on the level of damage this may consist of:

- repainting;
- weld repair and patching of the waste container;
- vent filter remediation, followed by weld repair or patching;
- container hole cutting, followed by weld repair and patching.

The application of paint to the outside of a container would probably be undertaken by means of a spraying process (see coating of waste container above). Weld repair and patching are important techniques that can be used to add extra shielding, repair damaged areas and to improve the integrity of lifting gear which may not be compliant. Welding and repair represents a feasible option for most packages, and proven techniques are available for remote in-cell operation e.g. for waste in 500 litre drums (Constable *et al.* 2001). For the Yucca Mountain project, welding methodologies are currently being investigated. One driver for this work is the need to be able to repair damaged waste packages, using a remotely operated welding technique (Yucca Mountain Project 2004). However consideration needs to be given to the type of material to which the weld is made. Some shielded containers are made of cast iron, which is less suitable for repair.

It may be possible to use welding techniques to cut through an outer metallic layer in the package, revealing concrete which if damaged could be repaired by means of a concrete-spraying technique.

Vent filter repair is feasible manually for any low dose rate package. However, at higher dose rates, the challenge is to develop a remote-system for performing this operation. Currently, this is probably not feasible.

Techniques for hole cutting and core drilling are well developed and can be applied to all types of waste package (Constable *et al.* 2001) to take samples, drain free liquids, inject stabilisers, or release gas pressurisation.

6.2.5 Injection of stabiliser

A stabilising compound can be injected into the package to seal gaps, fill voids and to absorb liquids. Free liquids, which cannot be treated by this means, may be drained.

6.2.6 Disassemble waste package

The package and wasteform are physically dismantled, size-reduced and placed inside other new packages. Typically, this has been applied to loose, drummed waste (where it is a feasible option) and not to grouted waste.

Cutting of grouted wastes represents a more radical solution. There are well-established technologies for cutting of packages using proprietary equipment such as diamond saws, wire-saw and core drilling and bursting techniques. Many of these techniques have already been used on sea-dump drums. The challenge remains to develop remote techniques for comminution and re-encapsulation of wastes, following cutting of a package.

6.2.7 High temperature process

This represents a radical reworking option, which relies on vitrifying the waste by subjecting it to a high temperature. It first involves cutting up the waste package, and placing the pieces into a high temperature bath of inorganic liquid or molten metal. This process would be applicable to all waste types. However the main disadvantages of this technique would be the generation and treatment of any gases produced, compatibility of the wasteform with the acceptance criteria for the repository, and the additional transport required (suitable melters are likely to be in only a few locations).

6.2.8 Dissolve waste package

This is an easier process to perform on raw ILW, than on conditioned waste. Evidence suggests that it is considered to be generally unfeasible given the variety of chemical substances and radionuclides in the ILW.

Examples where waste has been reworked are cases where there has been a requirement to retrieve legacy drummed waste from old storage facilities and rework the waste into a form that meets modern standards for interim storage and disposal.

6.2.9 Summary

Where legacy waste has been drummed loose, two general strategies are in evidence:

1. Legacy drums are retrieved from the historic store and overpacked, if necessary for transport to a waste reworking facility. Here, the legacy drums are emptied of waste; the waste is inspected, sorted and treated to render it chemically inactive, before being repacked into new drums for further interim storage or disposal:

2. Legacy drums are retrieved from the historic store and overpacked, if necessary for transport to a waste treatment facility. Following inspection, the legacy waste drums are compacted and grouted into a larger disposal container.

There is little experience of reworking grouted waste. The only example of this is from the Jülich facility in Germany where grouted wasteforms are dried and then coated to ensure future waste package stability. No attempt was made to break up the grouted waste.

From the evidence available, it appears most entities involved in ILW management would prefer to avoid breaking up grouted wasteforms if possible. The favoured method for grouted wasteforms is to overpack, with possibly some non-intrusive remediation of the wasteform, if it is considered to be necessary (e.g. drying of the wasteform).

The feasibility of applying simple coating and package repair and coring techniques is well-established for most types of encapsulated waste, but some of the more invasive and complex techniques such as high temperature treatment, or dissolution of waste, are still under development.

6.3. Reasons for reworking

The reasons for potential reworking were found to fall into the following broad categories:

- damage or deterioration, resulting in loss of shielding or containment, generation of hazardous substances, or damage to external handling features;
- package out-of-specification;
- external policy, economic or other pressures.

Detailed reasons for reworking were identified as part of the workshop study. These were grouped into the following 'generic' reasons:

- damage or deterioration:

1. Loss of package containment – minor;
2. Loss of package containment – major;
3. Weakened container structure; and
4. Loss of package shielding.

- package of out-of-specification:

5. Surface contamination of packages;
6. Deterioration of matrix structure – no breach of containment;
7. Excessive gas generation above safety limits;
8. Generation of hazardous material within package;
9. Unacceptable appearance;
10. Loss of package identification marks;
11. Damage to package handling features;
12. Failure of package mechanism to close;
13. Package outside waste product specification;
14. Package outside acceptance criteria e.g. radiation levels, heat output etc.;
15. Proscribed item in package;
16. Package outside dimensional specification.

- external policy, economic or other pressures:

17. Waste items become an asset;
18. Changes to requirement for early conditioning;
19. Incomplete records for a package; and
20. Change of national policy standards or disposal route requires repackaging.

Appropriate reworking strategies were assigned for each of these reasons.

6.4. Strategies for reworking

These were divided into two groups. The first could be applied before the waste (which might require future reworking) had been encapsulated. The second group was developed once an out-of-specification waste package had been produced.

6.4.1 Strategies prior to waste processing

Delayed packaging of waste involving interim storage of unconditioned raw waste is robust against changes to packaging requirements for ILW disposal. It requires no processing of waste, which would simply be moved from one storage facility to another until transport to repository is imminent. Storage of unconditioned waste may not be in line with the concept of passive safety. The interim storage period is considered to be higher risk than the current strategy.

Delayed packaging of waste involving interim storage of partially conditioned waste is robust against changes to packaging requirements for ILW disposal. In this case, the waste is conditioned towards passive safety without packaging for disposal. There is also the opportunity to sample and characterise waste further, to improve final packaging arrangements.

6.4.2 Strategies post waste processing

No common viewpoint was expressed on what constitutes best practice in determining an appropriate reworking strategy for any given out-of-specification waste package and wasteform because each case may be unique. Consequently, a logical stepwise process was developed. This allowed proper consideration of no or low interventions, instead of proceeding directly to more complex and costly invasive options, that may not ultimately be necessary.

Key phases in the process are:

- detect and identify problem;
- review possible problem;
- identify and implement the approach only after the problem has been thoroughly reviewed.

Each strategy has a different level of complexity, and potential environmental, safety and cost impacts associated with it. The strategies identified were of three main types:

1. No requirement for physical intervention on package, including:

- no intervention;
- monitoring and observation of package leading to possible package segregation.

2. Other requirements for physical intervention (but not on package), including:

- intervention in a waste production plant;
- intervention in a waste store.

3. Requirements for physical intervention on package, including:

- simple container repair, or overpack package;
- complex package disassembly or treatment;
- change of disposal route, or other special arrangements with disposer.

Most of the strategies identified involved no physical intervention on the waste package.

In the event of a problem, the production of samples, coupons and/or dummy waste packages (at the time of waste package production), and then stored along with the waste packages, could provide useful information on the condition of the waste packages. This may make it easier to carry out the review of the situation in the event of a potential problem being identified.

6.4.3 Location of reworking facilities

The location of the reworking facilities was considered. The present situation is that these are likely to be situated at the donor site, which is usually a nuclear-licensed site. However, in the future as business needs change, so changes are likely to the types of facilities which are present on the donor sites. Under these circumstances, each nuclear-licensed site may not be able to support its own reworking facility. Therefore, within an overall reworking strategy, perhaps covering waste from multiple sites will be required. Consideration should, therefore, be given to the provision of a reworking facility at the repository, or a mobile reworking facility, which could serve several sites.

6.5. Implications of reworking strategies

A qualitative assessment was performed to consider the environmental, safety, and cost implications of the various reworking methods and strategies identified as part of the workshop study.

The results of this qualitative assessment indicate that the overall impact of no or low intervention strategies, such as performing observations, monitoring, or re-assay is likely to be low.

Options that are non-invasive, such as simple package repairs, or overpacking, are likely to have an overall medium impact. However, it should be noted that overpacking will increase the volume of the waste package, and therefore the overall volume of waste which requires disposal.

High impact options are those that involve invasive techniques, such as disassembling, crushing or dissolving the package, or breaking it down by heating. These tend to have the highest environmental impacts, as they will generate the most diverse and active secondary wastes. Consequently, they will present the highest hazards and financial costs.

The potential impacts of changing disposal routes, or making special arrangements for disposal, can only be assessed on a case-by-case basis, once the details are known, and the agreement of the organisation accepting the waste has been secured. However, because they will not involve physical intervention on the waste package, it is likely that these options will have a lower overall impact than the high impact options described above.

7 Conclusions and Recommendations

7.1. Conclusions

1. The main reasons for reworking were identified as damage or deterioration of an ILW package, or the package becoming out-of-specification due to external factors such as changes in Government policy.

2. A wide range of reworking methods is available, but there is little experience of using them. For loose, drummed waste, the waste is generally unpacked, treated and repacked, or repacked and then compacted. For grouted wasteforms, the favoured method would appear to be overpacking plus a non-intrusive remediation of the wasteform if necessary. It is evident that most waste management entities would prefer to avoid breaking up grouted wasteforms if at all possible.

3. The feasibility of applying simple coating and package repair and coring techniques is well-established for most types of encapsulated waste. Further advances are required in some technologies before applying these techniques remotely to high radiation dose rate packages.

4. Some of the more invasive and complex techniques, such as high temperature treatment or dissolution of waste are still under development, and further technology advances are required.

5. Prior to waste processing, there are strategy options available to not condition or partially condition the waste. The first option is not consistent with the concept of passive safety, but the latter might provide an opportunity to improve the characterisation or treatment technology to be applied to the waste.

6. The specific issues associated with each product type meant no common viewpoint was expressed on what constitutes best practice in determining an appropriate reworking strategy for a given out-of-specification waste package and wasteform. Therefore a logical stepwise process was developed, which could be applied to any waste package and wasteform. This approach allowed proper consideration of the no/low intervention options, instead of proceeding immediately to the more complex and costly invasive options that may not ultimately be necessary.

7. The location of the reworking facility should be considered in the development of an overall reworking strategy. It is also necessary to consider whether this should be on the waste donor's site, at the waste-repository site, a mobile facility, or a facility at another location.

8. The impact of different reworking strategies was qualitatively assessed. The most invasive strategies involving considerable physical intervention on the waste package, were found to have the highest environmental, safety and cost

impacts. From an environmental perspective, the favoured approach would be to carry out no reworking, as this would have no or minimal environmental impact. However, this will not be a practical option for all cases.

7.2. Recommendations

No specific recommendations can be made at this stage, which could serve to help underpin regulatory guidance. This is because no common viewpoint was reached concerning best practice in the reworking methods and strategies that could be applied to specific wasteforms and packages. Nevertheless, the following general recommendations can be made.

1. It is recommended that the process developed for determining the appropriate action to take for an out-of-specification work package, be trialled. This could be achieved by taking a series of hypothetical reworking scenarios and following the process identified in Figure 5.1 to ascertain its robustness, and identify any refinements that should be made.

2. It is recommended that further work be carried out to ascertain whether it is practical to identify best practice for some specific examples of potential out-of-specification waste packages.

3. As work continues in other parts of the world, it is recommended that the Environment Agency keep a watching brief on some of the identified projects, particularly those at Jülich, Karlsruhe, Lanyu, Różan and Chernobyl. It is further recommended that a watching brief be kept on any developments in the repair of damaged waste packages using remotely operated welding techniques at the Yucca Mountain Project.

Appendix A1 Literature Survey

A1.1 Objective of Survey

The main objective of the literature survey was to identify examples and case studies of the reworking of radioactive waste packages. These examples were from the nuclear industry and, where relevant, other industries.

A1.2 Literature survey method

A1.2.1 General Approach

Initially, a scoping literature survey was performed to identify waste management projects or strategies where reworking of waste has been performed or has been identified as an issue.

Sources of nuclear publications examined for information of waste reworking and ILW strategies were:

- Nirex publications;
- International Atomic Energy Agency (IAEA) publications;
- British Nuclear Fuels (BNFL);
- United Kingdom Atomic Energy Authority (UKAEA); and
- Waste Management Symposium proceedings.

The Google search engine was used with combinations of following keywords:

Drum	Rework	Repack	Waste	Radioactive
Remediation	Sea	Dump	Package	Repackage
Degraded	Encapsulated	Immobilised	Recovery	Retrieval

Although the keywords above generated hundreds of irrelevant hits, several led to waste reworking examples that were new to the project. These examples were noted for a more in depth search. For example, where the initial search using ‘sea dump drums’ identified Winfrith as being a site with an inventory of these wastes, the search was then further targeted / refined by using “Winfrith sea dump drums” or “Winfrith waste drums” to try and obtain further information sources for Winfrith. Another set of World Wide Web searches was conducted using keywords that were linked to specific examples of waste drum reworking. These case-specific keywords were combined with those listed above to narrow the search:

Drigg	Amersham	Lanyu drums
Chernobyl repack	Yucca Mountain	WIPP
Rozan	Karlsruhe	Julich
AMWTP	El Cabril	Sealed sources

Kjeller	ILW	Chemical
Harwell	Sellafield	

The findings from the scoping survey were used to construct a document layout, including the types of information that could be gained from various sources.

The literature survey then focussed on the particular examples discovered during the scoping literature survey or on examples given in the project specification.

A1.2.2 Waste package case studies

The following sections report information on case studies of situations where waste package reworking is an issue. Where only limited information is included for a facility, this reflects the extent of information available on it. It should be noted that some of the examples refer to reworking scenarios where (by definition) the interventions on the waste packages were unplanned, and these were the types of scenarios which were the focus of the workshop e.g. change of disposal route for sea-dump drums. Some of the examples given below involve the planned retrieval and processing of raw wastes, which were also used to inform the study about the types of techniques which may be employed etc, and therefore have implications for reworking, but may not be themselves regarded as reworking, e.g. post-destructive testing which is a planned activity.

The case studies that are reported in this appendix are those which represent examples of activities that either involve reworking or could potentially be used as part of a reworking strategy.

The summaries of the case studies are presented in the following subsections:

- subsection A1.3- UK case studies;
- subsection A1.4- overseas case studies;
- subsection A1.5- experience with spent sealed sources;
- subsection A1.6- non-nuclear experience.

A1.2.3 Analogues from indefinite surface storage of waste

Waste packages stored for an indefinite period will be subjected to many more additional movements, as stores are refurbished and replaced, than if emplaced in a repository that is subsequently backfilled after a relatively short period (King 2003).

Therefore, some waste packages may become damaged and require reworking to remain in a suitable condition for handling. A sample of waste packages will require inspection to confirm their ongoing suitability for handling and transport.

The rate of repackaging would depend on the performance of packages over time, which in turn will depend on the evolution of the container and the evolution of the wasteform. Maintaining package integrity over long timescales will require carefully controlled storage conditions, possibly surface cleaning and regular inspection to monitor for early signs of degradation. Alternatively, the appropriate environmental conditions would need to be achieved passively.

The ongoing refurbishment or replacement of the interim stores and the repackaging of wastes for an indefinite period of time would raise the following issues:

- ongoing creation of large additional radioactive and non-radioactive waste volumes resulting from decommissioning of older stores and reworking of wastes;
- ongoing use of natural resources for replacement of equipment and stores, and repackaging of wastes.
- radiation doses and other health hazards incurred by workers, over many thousands of generations,
- operating/constructing the stores and the repackaging plant,
- moving the packages to permit store refurbishment.

Included in the results of the literature search are examples of reworking analogues. These are scenarios which cannot strictly be regarded as examples of reworking because they involve the planned retrieval of raw wastes. Some examples are also included in this section of proposed strategies which have not been implemented, but which could inform the discussion on reworking methods and strategies.

A1.3 Results from the UK

A1.3.1 Sea-dump drums

A1.3.1.1 Background

Until 1983, all wastes destined for sea disposal were sealed into reinforced concrete ballasted steel drums that were then transported by road to a holding facility. This facility was used to store all nuclear waste prepared in the same manner by operators within the UK Nuclear Industry. Once sufficient stocks had been amassed to fill a specially modified merchant ship, the stock was loaded and sent for sea disposal (Abbott e*t al.* 2004).

When the ban on sea dumping became permanent, a number of sea drums had already been produced for disposal. These packaged wastes therefore required reworking to be compatible with an alternative waste management strategy.

Sea dump drums were produced by various operators in the UK nuclear industry. The following paragraphs report how individual nuclear operators have managed their inventories of legacy sea dump drums.

A1.3.1.2 Amersham sea-dump drums

Amersham plc (now GE Healthcare) is a manufacturer and distributor of products that utilise the characteristics of radioactive isotopes. Radioactive wastes are produced during the production operations. These consist mainly of small (in comparison to other nuclear operators) items of laboratory equipment, glass, tissues, rubber and residual amounts of spent stock (Abbott e*t al.* 2004).

The sea-dump drums contained waste encased within an eighth of an inch (3 mm) of steel, which in turn was encased within 6 inches (150 mm) of reinforced concrete. The drums were vented, resulting in radioactive discharges to the environment during their storage (Environment Agency 2005b). The sea-dump drums had been prepared for sea disposal 13 years earlier, which meant that waste package deterioration was an issue. There were also different configurations of waste package (Abbott e*t al.* 2004):

- All package types consisted of 0.75 cubic metre steel outer primary containment. Within this were placed three configurations, each surrounded by a reinforced cement annulus and completed by a reinforced cement cap.
- The first configuration was three layers of 7 x 5 litre containers. Each layer was in a circular configuration, and then the three layers were stacked on top of each other. The interstitial spaces were back filled with cementitious grout.
- The second configuration was a 200 litre drum which had been placed in a reinforcing cage, within the primary containment, with at least 100 mm spacing between the drum and the primary containment in all directions, and the annulus filled with cementitious grout as before.
- The third configuration was lead-shielded drums of various volumes of approximately 100 litres, placed singly within the primary containment, and the remaining space filled with cementitious grout as before.

The separated ILW was placed in a new ILW store. Much of the waste will decay to LLW levels during the interim storage period and will thus be suitable for LLW disposal in the future.

The reworking of the sea-dump drums took place in a specially designed containment structure on the Harwell Site. The reworking facility is a purpose built facility inside an old building, where waste is cut up and sorted into ILW, LLW and free release fractions. The containment structure was constructed in such a way as to minimize waste arising during its decommissioning (Environment Agency 2005b).

During the reworking of these drums, several issues presented themselves:

- the disposal drums were not manufactured to a tight tolerance and therefore significant variations in drum geometry were encountered. This required careful design of the remote tooling equipment to handle and open the drums;

- drum internal structures were variable in layout. Ballast and strengthening features in the drum were not always positioned in the same place in each drum;
- internal package locations were variable;
- external contamination of the drums;
- there were a variety of materials in the waste.

By repacking, the ILW strategy was optimised by minimizing required space for ILW storage and maximizing disposal routes for lower levels of waste. However, the repacking process results in small environmental discharges. GE Healthcare opted not to overpack the sea-dump drums as a reworking method (Environment Agency 2005b). Overpacking was seen as being especially expensive (since the overpacked drums would have been treated as ILW) and the company had experience of sorting and repacking of wastes.

As of 1998 there were 800 m^3 of waste stored in sea-dump drums at the Amersham facilities on the Harwell site. The volume of such waste has already been reduced by sorting and re-categorisation of part of it as low level waste (LLW) for disposal at Drigg. It was estimated that the volume of waste for long-term storage would be reduced to about 120 m^3 which will be accommodated within facilities at the Amersham and Cardiff sites (HMNII 1998).

The reworking of the sea-dump drums is an ongoing project (Environment Agency 2005b). In addition, it is proposed to rework some 141 sea-dump drums that are owned by UKAEA Harwell through this facility (Environment Agency 2005b).

It is considered that the reworking of Amersham sea-dump drums is the best example of reworking of wasteforms in the UK, although these wasteforms consisted of annular grouted waste, not intimately encapsulated waste.

A1.3.1.3 AWE legacy sea-dump drums

There are approximately 700 drums of waste stored at Aldermaston which were originally designed for sea disposal. These sea-dump drums are mostly filled with plutonium-contaminated material (PCM) but there are also drums containing uranium-contaminated waste and other drums containing tritiated waste. The sea-dump drums are described as being a waste drum grouted into an outer drum (HSE 2003).

The current strategy is to extract the inner ILW drum and to dispose of the LLW component of the overall drum (ballast and drum materials of construction) at Drigg. This strategy appears to be similar to that adopted by Amersham for their sea-dump drums.

This work is scheduled to start in 2009, though this date might be brought forward. The reference strategy in the NII quinquennial review submission states that the work depends on availability of the new ILW facilities, however an unspecified alternative strategy is being considered (HSE 2003).

A1.3.1.4 Harwell sea-dump drums

Sea-dump drums at Harwell that are owned by the UKAEA are of two types: beta-gamma wastes and contact handling ILW.

The drums containing beta-gamma waste will be opened and the contents will be segregated in a hot cell complex consisting of heavily shielded cells where radioactive material is handled remotely. LLW component will be packaged for disposal to the LLW repository at Drigg as it is generated in the reworking process (RWMAC 2002).

The contact handling ILW drums will be taken apart and the waste will be segregated by operators wearing pressurised suits. This operation will take place in a waste storage and treatment complex at Harwell. The segregated PCM fraction will be packaged for transfer to the Waste Treatment Complex at Sellafield (RWMAC 2002).

A1.3.1.5 Winfrith sea-dump drums

There were 228 sea-dump drums containing PCM that were transferred to the Harwell site (UKAEA 2004b) for reworking in the waste complex at Harwell (RWMAC 2002) as described above.

A1.3.2 Removal of drums from Nirex Reference Vault Backfill

The current Nirex ILW disposal strategy involves the emplacement of ILW packages in a deep waste repository. The waste packages will be stored in large underground vaults for a period of surveillance. During the period of surveillance, the waste will be retrievable by reversal of the waste package emplacement procedures. When the decision to close the repository is taken, the vaults will be backfilled with the Nirex Reference Vault Backfill (NRVB), encapsulating the waste packages. The shafts and access tunnels will be sealed.

Although it is not the intention of Nirex to retrieve waste packages following closure of the repository, the situation whereby waste packages need to be retrieved at this late stage has been considered.

The need to retrieve waste following repository closure could be one of the following (NEA 2001):

- new technical information regarding the site and design;
- new technological developments relevant to nuclear waste management;
- changes in social and political conditions and acceptance;
- changes in regulatory guidance and its interpretation or even, possibly, in basic safety standards.

Reworking of packages from a backfilled repository may be necessary due to failure of the chosen concept, retrieval of valuable materials from the waste, or in the future, a better means of ILW disposal is implemented (Grupa *et al.* 2001).

The most obvious issue concerning retrievability after backfilling is the ability to remove waste packages from the cement backfill. Nirex have demonstrated this in a large-scale trial, so Nirex have high confidence in the technical feasibility of this operation (McKirdy 2001).

A large-scale demonstration consisted of a stillage containing four 500 litre drums placed on top of a dummy stillage to simulate a stack in a disposal vault. Grout was used to backfill the simulated stack and allowed to cure. Remotely operated, high-pressure water-jet cutting was then used to cut through the grout, to enable a lifting frame to be attached to the stillage (McKirdy 2001). It took four hours to cut out one package ready for lifting. This generated 2.5 m^3 of an alkaline abrasive slurry from the cutting water. This slurry was not suitable for direct recycle to the cutting head. In order that the cutting water could be recycled, a treatment process would be required.

Given that a standard package unit in the Nirex repository consists of a 3 m^3 drum, a 3 m^3 box or a stillage of four 500 litre drums, for every 2 to 3 m^3 of waste volume removed, 2.5 m^3 of potentially radiologically contaminated wastewater would be produced. The potential for producing radiologically contaminated water would increase with increasing time post closure. Nirex have recognised that a disposal route would be required for this secondary waste although none are considered in the available documentation.

If waste packages were substantially degraded at the time of retrieval then mining methods (digging out a contaminated mixture of rock, backfill and degraded packages) would be required to recover the packages.

While retrieval after repository closure would pose a significant challenge, the component activities could all be carried out using techniques that are similar to those currently used within the nuclear and mining industries. Nirex have confidence in the technical ability to retrieve the waste should this be required (McKirdy 2001).

If the results of this trial are considered in the context of dismantling the grouted ILW packages themselves, then the sectioning of grouted ILW waste packages would generate a considerable amount of contaminated slurry as well as pieces of the waste package itself. The break-up and repacking of grouted ILW wastes could therefore generate a waste volume several times greater than that occupied by the original package.

A1.3.3 Sellafield legacy ponds and silos decommissioning

Before the introduction of modern waste immobilisation facilities in the late 1980s, ILW at Sellafield, resulting mainly from reprocessing operations, was interim-

stored in bulk with little conditioning. This waste is known as historic or legacy ILW. It is poorly documented, difficult to characterise, and the storage facilities are not of modern standard. BNFL maintain that it is inappropriate to remove historic wastes from the current stores and place them in new stores in an untreated condition (Bonser 2003).
BNFL have considered two approaches to the treatment of historic ILW:

1. The waste would be retrieved and encapsulated in 'Nirex' containers. It is believed that not all of these packages would satisfy Nirex repository acceptance criteria but would, nevertheless, be suitable for 100 years interim storage. Those encapsulated waste packages that did not comply with Nirex conditions of acceptance would require reworking. These cemented, drummed wastes may prove difficult, costly and slow to rework.
2. Waste would be retrieved, conditioned and packaged in a form that would be suitable for 100 years interim safe storage. The waste packages would not comply with the Nirex specification but minimal rework of the waste would be required should the packages, through inspection, be found to require reworking to remain compliant with Interim Safe Storage. The waste would require some reworking prior to disposal although the initial conditioning and packaging would ensure that such reworking would require minimal effort and involve a minimum of risk.

BNFL's "Interim Safe Storage" (ISS) strategy for the Sellafield site was a significant development in the field of ILW management, and required careful consideration by national and local stakeholders (Bonser 2003). In view of safety concerns about the storage of historic wastes on the Sellafield site, Bonser 2003 acknowledged that in certain circumstances, it might be necessary to adopt interim packaging arrangements for specific waste streams. In this context, an interim packaging arrangement meant that a packaged waste had not secured a Nirex Letter of Comfort. However, the report highlighted that "interim" arrangements require convincing and transparent case-by-case justification. In addition, where such arrangements might be justified, it recommended approaches, which facilitated final treatment at a later date, rather than requiring complete reworking to meet future needs.

The Radioactive Waste Management Advisory Committee/ Nuclear Safety Advisory Committee (RWMAC/NuSAC) recommended that Government policy should acknowledge the potential need for interim packaging arrangements. However, it is expected that these would only be adopted in openly declared and justified cases, and with the agreement of NII and the appropriate environment agency (RWMAC 2002).

The regulators' strong preference is for a waste package that meets the requirements for future long-term waste management, without the need for reworking, such as further conditioning or re-packaging. The ISS concept could in theory be applied where a waste producer could not, in the short term, condition waste to a form compatible with the Nirex concept. However, the waste producer would have to demonstrate that plans were in place to rework such waste into a disposable form at some point in the future (Environment Agencies 2003). The UK regulator would only give permission for Interim Safe Storage if the waste producer could demonstrate that all options for short term passivation of the waste had been exhausted, the Nirex LoC process had been followed and the ‘compliance gap’ was understood with plans in place to close it.

It should be noted that ISS is no longer being pursued as a waste management concept (RWPG 2003), and may be regarded as an obsolete term, but may be regarded as a useful generic concept.

A1.3.4 Harwell tube store retrieval

The Active Waste Retrieval Programme (AWRP) is a collection of projects dedicated to the supply of equipment and facilities for the retrieval, repackaging, cementation and storage of beta/gamma waste from below ground storage tubes at Harwell (UKAEA 2002).

The complex where this is taking place is a group of buildings and facilities whose primary function is the treatment and storage of contact handled and remote handled solid ILW. It is known as the ‘tube store’ as radioactive materials enclosed in metal cans are stored in an array of vertical tubes set in concrete (UKAEA 2004a).

Regular monitoring has shown that the condition of waste in some of the tubes has deteriorated, prompting the UKAEA to recover and immobilise the wastes.

Cans retrieved from the tube store will be opened using remote handling equipment. The cans and contents will be segregated based upon radioactivity. Material that can be classified as LLW will be packaged for disposal to the LLW repository at Drigg. ILW will be immobilised. ILW will be mixed with concrete and repackaged into stainless steel 500 litre drums. This will ensure that the waste will be passively safe and suitable for final disposal. The immobilised waste will be stored in a purpose-built store at Harwell in anticipation of the national intermediate level waste repository (UKAEA 2002). Around 8000 cans of waste will be retrieved from the tube store and reworked.

The predicted end date of this project is 2020. The Waste Encapsulation and Treatment Plant (WETP) is to be designed and built, comprising a cementation plant and a flexible waste handling facility. A flexible waste handling facility is needed to examine and sort any waste not suitable for direct encapsulation and requiring additional treatment e.g. ion exchange resins. Construction of the WETP is planned to start in 2007 and the plant is expected to be operational by 2012 (UKAEA 2002).

This waste management strategy involves retrieval, sorting and characterisation of the waste in order to identify those wastes requiring additional treatment (WRATS). Such wastes are then diverted off, in order to carry out the appropriate additional treatment. The waste is then packaged into disposal containers for short-term storage, pending construction of the grouting plant. This approach has been developed to take account of the subsequent grouting step and the disposability of the resultant waste packages. As a consequence of following this strategy, the risk of deterioration of the waste is reduced.

A1.3.5 Drigg plutonium contaminated material (PCM)

Between 1959 and 1964, PCM resulting from military operations at Windscale, Winfrith, Dounreay and Aldermaston, was stored in ten munitions bunkers at the LLW repository site at Drigg. The waste was packaged in 400 litre drums and large waste packages and there has been degradation during storage. Drigg's site licence does not allow for the long term storage of PCM. These drums of PCM will be retrieved from storage and removed from the Drigg site by December 2006 (British Nuclear Group 2004).

The Near Term Work Plan for Drigg (British Nuclear Group 2004) states that there will be retrieval and dispatch of PCM drums to the engineered drum store at Sellafield. These retrievals will comprise direct retrievals from the Drum Store, repacked drums from the Drum Store, 400 litre drums and management of secondary waste that will result from Drum Store retrieval operations. Furthermore, assay will be carried out before the PCM is transported to Sellafield using overpacks. At Sellafield, the PCM will be "supercompacted", stacked and grouted into 500 litre Nirex specification drums.

The large waste packages will undergo retrieval, size reduction and assay prior to transport to Sellafield.

The Near Term Work Plan also states that hex drums (assumed to contain uranium hexafluoride-contaminated items) will be retrieved as PCM but will be treated and disposed of as LLW.

Since the waste inside the drums has not been processed, then overpacking or repacking of the waste may not be strictly regarded as reworking. However, lessons could be learned from the handling of aged drums and containerised waste.

A1.3.6 Post-destructive testing

The Environment Agency operates a Waste Quality Checking Laboratory (WQCL) for monitoring LLW disposals in the UK (Environment Agency 2001b). Destructive testing of a small percentage of drums takes place in order that radiochemical sampling of the contents can be performed. The LLW drums were packaged to meet Drigg conditions for acceptance and so would be of 200 litres capacity. The testing is performed to verify that waste consignors are abiding by the Drigg conditions for acceptance and Environment Agency waste disposal authorisations. A drum selected for testing is attached to a glovebox and the lid of the drum is opened. The contents of the drum are then examined. Prohibited items, if found, are segregated from the remainder of the waste. The waste is repackaged with representative samples being taken for chemical analysis (Environment Agency 2005a).

LLW is accepted by the WQCL in ISO containers, half-height ISO containers in drums, and as loose-bagged waste from the nuclear-licensed sites. The Non-Destructive Testing (NDT) facility at WQCL can only accept 200 litre drums so bagged waste is repacked into 200 litre drums prior to examination. In the recent past this was undertaken in a tenting arrangement, but now purpose-built modular containment units are proposed. Because of the low external dose rates involved, many of the operations are mostly “hands on” and are not carried out remotely. In addition, because of the low dose rates and the precautions taken to reduce contamination levels, doses are kept ALARP. There are future plans to install a purpose-built facility for tipping out and examining waste.

A1.4 Results from overseas

A1.4.1 Lanyu waste packages (Taiwan)

The Lanyu Storage Site began operating in 1982. It was originally managed by the Radwaste Association of China but was turned over to Taipower in 1990 (Atomic Energy Council). The site has 23 storage trenches with walls of 35 cm thick reinforced concrete. A complete rainwater interception and water treatment system was engineered to prevent radionuclides from leaching into the environment.

During the period 1982 to 1996 over 90,000 55-gallon drums of LLW were shipped to Lanyu Island for temporary storage on land. Taipower rented this land in the South-east of the island from the local Lanyu Rural Township (Taipower 2005). The rental agreement expired on December 31, 2002, but was renewed in 2003.

The Fuel Cycle and Material Administration of Taiwan has also stipulated that older storage drums at the site which may be corroded, must be inspected and reconditioned or repacked by the end of 1998 (Atomic Energy Council 2005).

Some of the metal drums in which the waste was stored have become corroded, an estimated 10% of the total (Underwood 2005). It was estimated that repairs on these drums would take about 6 years to complete. No information regarding the method of drum repair is given.

A1.4.2 Różan facility (Poland)

The Polish National Radioactive Waste Repository at Różan is located in an old fort structure that, in 1961, became the National Radioactive Waste Repository for Poland. It is operated by the Radioactive Waste Management Plant and regulated by the National Atomic Energy Authority (Thompson 2005).

Solid and solidified institutional radioactive wastes have been disposed in the Różan repository. The majority of the solid waste (~ 60%) has not been conditioned, and the remainder has been compacted and grouted. The solidified wastes contain radioactive concentrates (post precipitated silt, post evaporated concentrates, used ion exchange resins and filters etc.) that have been grouted using combinations of cement, asphalt and polymeric resins, as well as other binding materials. Wastes are mainly contained in metallic drums (predominantly 50 or 70 litre capacities), although a variety of packaging is used for solid wastes including foil, wooden boxes, plastic containers and glass containers.

An options study was performed to identify the best strategy for retrieval and repackaging of waste in the facility. For drummed waste the following was selected as the preferred methodology:

- 200 litre drums that are identified as already cemented would be assayed and examined by real time X-ray for confirmation. If the drum were suitable for long term storage it would be directed to Half Height ISO (HHISO) packing. If unsuitable, it would be overpacked into a larger drum then placed in the HHISO. The larger drum overpacks would increase the complexity of downstream handling equipment (since downstream equipment would now have to be capable of handling two drum sizes);
- 200 litre drums that are known not to be cemented would be assayed and directed to the Repackaging Cell;
- 200 litre drums of uncertain state would be assayed and examined by real time X-ray. If found to be cemented, they would be treated as the first stream; if waste was loose or the state still unresolved the drum would be directed to the Repackaging Cell; and
- Small drums, boxes and other packages would be assayed and sent to the Repackaging Cell.

If 200 litre drums of waste have been immobilised by cementation or encapsulation in bitumen or other matrices, it will not be possible to tip the contents into another 200 litre drum. Such drums will have to be overpacked in a larger drum, increasing the complexity of downstream equipment that would have to handle two differently sized containers. If the original 200 litre drum has to be cemented inside the overpack, the complexity of the grouting system might be increased. Using two containers could affect the packing arrangement in the Half Height ISO container used to hold the reworked drums.

A1.4.4 IFE Kjeller (Norway)

All low and intermediate level waste arising in Norway is received, treated and packed by the IFE at Kjeller. Most of the waste is packed in 210 litre steel drums (with concrete providing protection and stability), but concrete or steel containers, measuring 80 x 90 x 120 cm, are also used.

In 1970 it was decided to bury waste drums (210 litres) that at that point were located at IFE Kjeller's site.

The drums were buried at a depth of four metres. The drums were placed in an array that consisted of two layers. The array of drums was then capped with a two metre thick layer of clay.

In 1999 retrieval of these drums began (*Anon.* 1999). The waste retrieved from the shallow clay disposal site was repacked and transported to the long-term storage facility at Himdalen. The drums consisted of the original drum grouted into a larger drum. The original drums were not opened. At Himdalen the waste drums were placed in underground vaults, the vaults were backfilled as soon as they reached waste capacity (NRPA 2003). This process can be regarded as a special type of overpacking, as it involves the placement of grout in the space between the waste drums and the larger (overpack) drum.

A1.4.5 El Cabril Repository (Spain)

The El Cabril Estate was used for uranium production in the 1950s and later it was a waste storage facility. The operations to store wastes at the mine (Mina Beta) were carried out during the 1960s and 1970s until it was filled. In order to provide additional storage capacity, three storage modules, consisting of industrial sheds with a metallic structure and concrete walls, were constructed. These provide a storage capacity for a total of 15,000 drums (each drum having a volume of 220 litres).

When the National Radioactive Waste Company, Empresa Nacional de Residuos Radiactivos (ENRESA), took over the El Cabril installations in 1985, a decision was taken to move the drums from the Beta mine to modules located on the surface.

The package transfer and reconditioning operations were carried out between May 1987 and January 1988, and culminated with the closure of the Beta mine. Since then, the mine has been unoccupied. The mine is clean and is no longer qualified as a storage facility.

Since 1992, Spain has disposed of low-level radioactive wastes in concrete-lined structures at the near-surface El Cabril disposal facility (Yucca Mountain project 2001: Spain's radioactive waste management program factsheet 2001).

At the surface facility, waste drums (both historic and current arisings) are placed in large concrete overpacks with 18 drums to an overpack. The overpacks are then lidded and grout is injected to fill the drum interspaces (Asi Sera 2004). The original drums were not opened. This process may be regarded as a special type of overpacking, involving the placement of grout in the space between the waste drums and overpack.

The present policy for spent nuclear fuel and high-level radioactive waste management is continued interim storage followed by direct disposal into deep geologic formations. The 5th Radioactive Waste Management Plan, approved by the Spanish government in 1999, outlined that no decision on the final disposal of high-level radioactive waste be made before 2010. Deep disposal study will continue, but new technologies, such as partitioning and transmutation, may also be considered.

A1.4.6 Waste Isolation Pilot Plant

The Waste Isolation Pilot Plant (WIPP) is the world's first underground repository licensed to dispose of transuranic (TRU) radioactive waste left from the research and production of nuclear weapons. WIPP began operations on March 26, 1999 after more than 20 years of scientific study, public input, and regulatory dialogue (Washington TRU Solutions LLC 2005).

WIPP is located in the remote Chihuahuan Desert of south-eastern New Mexico. Facilities include disposal rooms mined 2,150 feet underground in a 2,000-foot thick salt formation that has been stable for more than 200 million years. TRU waste is currently stored at various sites across the United States and projects are underway at these sites to repackage waste into a form suitable for transport to and disposal at WIPP.

To dispose of waste to WIPP it must be treated so that it is chemically inactive and non-flammable. Many of the donor sites do not have appropriate facilities to condition waste to be suitable for disposal at WIPP. A need was identified for a mobile plant with the capability to unpack waste drums, condition the waste to be passively safe and finally repack the conditioned waste into disposal containers suitable for WIPP (Triay *et al.* 2001).

The sections below give descriptions of ongoing work at some United States' sites that are consigning waste to WIPP.

A1.4.7.1 Fluor Hanford site

Residues from Fluor Hanford Site have been repacked to meet the conditions for acceptance for WIPP. The residues compromised a collection of diverse waste types: ash, Mixed Oxide Fuel (MOX) scrap, sand slag and plutonium bearing scrap. These residues were already chemically stable but required repacking into sturdy containers to meet WIPP standards for disposal. The repacking process involved the sorting, processing and transferring of waste solids into 2.7 litre slip lid cans. These in turn were placed into vented plastic bags and finally into 55 gallon (200 litre) drums known as pipe overpack containers. Pipe overpack containers are stainless steel lined and can hold up to four slip lid cans. Other overpacks used for WIPP are 10 drum overpacks, 12 drum overpacks and 85 gallon overpacks.

A1.4.7.2 Advanced Mixed Waste Treatment Plant (AMWTP)

A contract for AMWTP was let to BNFL Inc. in December of 1996 (Holmes and Robbins 2001). The contract was to retrieve, characterise and treat a quantity of waste, 54,000 m^3, from beneath an earthen berm (or mound) together with a stored volume of about 11,000 m^3 located at the Radioactive Waste Management Complex at the Idaho National Engineering and Environmental Laboratory, for shipment to WIPP.

The USDOE commenced shipping waste, from the 65,000 m^3 of material, to WIPP in March 2004 (WIPP newsletter, 25/05/2004). The contract also contained provision for up to 120,000 m3 of additional waste to be processed providing suitable waste could be identified.

The waste is contained in two generic container types, boxes and drums. The boxes are of a variety of types (e.g. fibreglass reinforced plywood boxes and metal boxes), whilst the drums are predominantly 55-gallon drums although some of these drums have been overpacked in 83-gallon drums. A relatively small number of drums are contained in boxes or bins.

The waste consists of a variety of materials, typically contaminated rubbish or scrap (metal, paper, rags, plastic, rubber etc.) together with immobilized or stored process liquors and contaminated solvents. This latter category is referred to as sludge or non-debris whilst the former is referred to and defined as debris under the US Toxic Substances Control Act.

Retrieved waste is/will be characterised to build up inventory data for the feed to the facility. The characterisation steps are:

- real time radiography to establish the nature of the waste or to confirm the contents of the container;
- assay of drums and boxes by passive and active neutron interrogation, coupled with high-resolution gamma spectroscopy to establish the fissile content of the waste;
- head-gas sampling to identify drums containing volatile organic compounds and those that have generated significant levels of radiolytic hydrogen. It was assumed that boxes would not sustain significant concentration of volatiles;
- coring and sampling 'sludge' drums to establish their contents.

Characterised containers are stored until they can be sequenced through the facilities for shipment. Characterised drums are/will be consigned to the "supercompactor" for size reduction, although a proportion of the drums will be sent to the facility for inspection to confirm the waste type ascribed to the drum. Debris waste drums that have been overpacked (because the integrity of the primary drum is suspect) will be introduced into the facility to prepare the waste for supercompaction (either by removing the 83-gallon drum or repacking the waste in a 55-gallon compaction drum).

Boxes will be introduced to the facility for the contents to be transferred to 55-gallon drums for supercompaction. The empty boxes will be packaged for disposal as low-level waste. The compacted waste will be placed in 100-gallon puck drums. The pucks will be placed in these drums such that the volume and weight capacity of the puck drums is maximized and the puck drum meets the definition of TRU waste (>37.0 MBq/g).

Waste that cannot currently be treated will be stored awaiting an appropriate treatment route. The remainder of the sludge, or non-debris, will be placed in intact drums, into primary containers called ten drum overpacks. These containers accept 10 x 55-gallon drums or 6 x 83-gallon drums. A "TRUPACT II" transport flask, used to transport the drums to WIPP, can accept a single ten-drum overpack.

Containers with proscribed items or items requiring special treatment (liquid mercury, poly-chlorinated biphenyl containing ballast for electric lights, gas cylinders, aerosol cans, free liquids, etc.) will be opened and their contents transferred to storage (proscribed items) or to a jobbing box (Special Case Waste) for treatment.

All free liquids will be absorbed in 55-gallon drums and maintenance waste or protective clothing in 55-gallon drums will be treated as non-debris or debris respectively.

A1.4.7.3 Savannah River

Retrieval of drummed legacy TRU waste from shallow burial for repackaging (segregation and supercompaction) is performed at this site.

The retrieved drums are opened in a glovebox environment. The waste is removed, sorted and repacked into drums to meet the WIPP acceptance criteria.

A1.4.7.5 Oak Ridge

Legacy alpha wastes are reworked here. This is done by hand, removing waste from legacy drums and then sorting/segregating the waste for repacking into drums for consignment to WIPP. This differs from UK Sellafield strategy where legacy PCM drums are monitored, compacted and grouted into 500 litre Nirex specification drums at the Waste Treatment Complex (WTC).

The difference between the UK approach of compacting drums and the US approach of repacking drums lies in operator dose uptake. The UK approach of compaction of the legacy PCM drums avoids the need for the operator to handle the waste and therefore results in lower dose to operators than the US approach. Both methods however, generate effluents. The drum containment is broken with repacking the waste, discharges are mitigated by performing repacking operations in a glovebox environment. With supercompaction, effluents arise from dust and liquid expulsion from the waste as it is compressed.

A1.4.8 Yucca Mountain

Waste packages will be placed on rails in horizontal tunnels, called drifts, about 300 metres underground. The tunnels would remain open for 100 years to permit monitoring and to allow for retrieval if a problem is discovered, or if some use is found for the spent fuel. After that period, the tunnels would be filled and sealed (Lawrence Livermore Laboratory 1996). The Yucca Mountain project will dispose of spent fuel directly in overpacks. During the operational period, defects to fuel packages will be repaired using remote welding apparatus, which may be regarded as a type of reworking. Research is currently underway into suitable welding technologies for package reworking.

A1.4.9 Karlsruhe Research Centre (Germany)

A long-term disposal option in Germany is not likely to be available for 30 years. In the interim period, drums containing radioactive waste are stored in surface facilities. As part of the interim storage management, old drums are inspected (visually and radiologically) for integrity. Damaged drums are taken for reconditioning (Graf *et al.* 2002).

All waste drums are opened and the waste is inspected for characterisation purposes. If the waste container is judged to be suitable for long term storage, the waste is placed back into its original container. All repacked containers are loaded into KONRAD containers that are large, box containers. These containers are then filled with grout before being placed into interim storage (Graf and Merx 2004).

A1.4.10 Jülich Research (Germany)

Radioactive waste produced since 1962 has been kept in interim storage at the Jülich Research Centre in Germany (Krumbach 2005).

Most of the waste has been stored in 200 litre straining ring type drums. The drums were fabricated from 1.5 mm steel which was coated on both inside and outside with several layers of paint.

The waste within the drums was cemented. The historic immobilisation process however, damaged the internal coating of the drums through abrasion and scraping. Residual moisture remaining in the waste following cementation caused corrosion of the drums. Damage also occurred to some drums as a result of package handling. In some cases where higher quality drums were used for immobilisation, corrosion was less evident, although still noticeable. The extent of corrosion of the drums is limited by virtue of the drums being interim stored in a facility with conditioned air atmosphere.

The packages are to be conditioned by using a drying process, since the presence of moisture (from water ingress to drums during storage) was found to be the primary cause of container corrosion. The dried waste packages will then be given a high quality protective coating to the outside of the drum, 3 mm thick to prevent future water ingress. The use of a polyurethane based coating has been tested on inactive packages with encouraging results.

Following treatment the drums will be loaded into KONRAD containers (which are large box containers) for further interim storage. A decision was made not to grout the drums into the KONRAD containers as this was considered to foreclose future waste treatment options.

This form of reworking of waste packages both corrected a problem with the wasteform (removal of moisture by a drying process) and used measures to prevent ingress of water to the wasteform by applying a protective coating to the outside surface of the waste container.

During the reworking of these packages discharge would arise from the drying process although the level of radionuclides in these discharges is likely to be low as radionuclides would remain immobilised in the grouted wasteform.

A1.4.11 Chernobyl

The Chernobyl accident resulted in a wide area being contaminated. Areas close to the stricken reactor were strewn with radioactive debris. Work will be undertaken to recover loose debris and package this in a form suitable for long term storage and/or disposal (Constable *et al.* 2001). Maintenance and repair of the reactor protective cover (the sarcophagus) is necessary.

Despite the temporary steps taken to manage the radioactive inventory, primarily by the construction of the sarcophagus, no waste packaging has been carried out. Hence, there are no examples of reworking. However, because of the unique nature of the situation at Chernobyl, it is considered that a watching brief should be kept on the clean-up operations as some of the waste retrieval and packaging processes may have factors of relevance to reworking.

A1.5 Management of spent sealed sources

The IAEA definition (Vilmos and Gera 2000) of a sealed source is as follows:

> "A sealed source is a radioactive material that is (a) permanently sealed in a capsule, or (b) closely bound within a solid matrix."

A source can be declared spent if:

- its use is superseded by a different technique;
- its activity has become too weak;
- its associated equipment malfunctions or is obsolete; or
- the source is damaged or leaking.

In B459 at UKAEA Harwell the processing and repackaging of National Disposal Service (NDS) sources (UKAEA 2004a) will take place. NDS radioactive sources will be posted into the active cell line where they are separated from their self-shielded containers then 'bulked' into drums.

Beginning in the late 1990s, the United States Department of Energy (USDOE) greatly expanded its sealed radioactive sources handling capacity at Los Alamos National Laboratory to accommodate thousands of excess sealed radioactive sources from the commercial sector. Initially, neutron sources were chemically processed to eliminate neutron generation. However, this was determined to be unnecessary. Instead, excess and unwanted sealed radioactive sources are simply stored as radioactive waste at government nuclear facilities. This strategy required the development of new nuclear material containers specifically designed for long lived neutron sources. The first of these is a special-form overpack capsule for individual sources. The second is a multi-function container capable of providing safe storage, transportation, and ultimately disposal (IAEA 2005).

A1.6 Non-nuclear industry

Within the chemical industry, the goal of waste reworking is to ensure containment. Many waste disposal firms, including Shanks of Fawley (Shanks 2005), offer waste repacking services for damaged chemical waste drums. Overpacks are typically used for the movement of damaged or suspect containers holding hazardous materials. Although it is now a requirement to consign hazardous materials to special landfills in a conditioned form, the chemical industry is not faced with operational constraints such as the need for remote handling. Furthermore, many non-radioactive chemical wastes can be destroyed or converted to non-hazardous chemical forms by treatment processes. There will be the need however, to protect workers from the hazardous chemical materials during any package remedial work.

With chemically hazardous wastes, there may be a future need for reworking of wastes packages to ensure compliance with the hazardous waste regulations which will require some materials to be immobilised prior to disposal in special landfills.

Appendix A2 Workshop Study– Scope, Methodology and Outputs

A2.1 Scope and Objectives

The workshop study was divided into four planned sessions. The first two sessions were intended as high-level sessions to identify the reasons for reworking and the strategies to facilitate reworking. The last two sessions were intended to focus in detail on identifying specific reworking methods and the implications of applying them.

A2.1.1 Objectives

The objectives of the four sessions were as follows:

Session 1
This was planned as a brainstorming session to prompt ideas and to identify the potential reasons for waste conditioning and reworking. The intention was also to discuss the scope of reworking. The guidewords listed below were used as a starting point:

- wasteform expansion;
- impact damage;
- corrosion;
- weld;
- seal;
- leak;
- bacteria;
- cracking;
- gas generation;
- matrix composition;
- package inventory;
- capping;
- repository design;
- programme change;
- government policy;
- safety standards.

However, part of the remit of this session was also to generate further guidewords.

Session 2
The aim of this session was to identify strategies for facilitating reworking for each of the reasons identified in Session 1. It was intended that the strategies should aim to minimise environmental impact, secondary wastes, doses and costs.

Session 3
The aim of this session was to identify appropriate reworking methods for different wasteforms and containers, for each strategy identified in Session 2.

Session 4
The aim of this session was to qualitatively assess the implications and effects of each reworking method or strategy combination identified. It was intended that the following factors should be considered for each reworking method/strategy:

- environmental impact;
- production of secondary wastes;
- safety and costs.

A2.1.2 Scope

The wasteforms of interest within the context of the workshop were those in use or of potential use in the UK, namely:

- in-drum mixed (sludges, floc, ion-exchange materials);
- pucked wastes (PCM);
- encapsulated solids (OPC-based, polymers);
- non-monolithic fillers (sand, clay);
- other novel wasteforms/approaches.

The container designs of interest within the context of the workshop were:

- 500 litre drum (and variants);
- $3m^3$ box and drum;
- 4m ILW Box; and
- non-standard packages, e.g. WAGR Box.

The examples of reworking which had been considered in the literature review and which formed the basis of the workshop were:

- Amersham sea disposal drums at Harwell;
- PCM sea disposal drums stored at Drigg;
- solid remote-handled $(\alpha)\beta\gamma$ ILW stored in B462.2/.9/.26 at Harwell;
- 200 litre drums containing legacy PCM stored at Drigg;
- post-destructive testing of waste packages;
- removal of drums from Nirex Reference Vault Backfill;
- waste packages at the Lanyu facility in Taiwan;
- Chernobyl;
- near surface repository at Różan, Poland;
- stabilised hazardous non-radioactive wastes, e.g. cement encapsulated sludges containing heavy metals from industries such as electroplating, electronics, paint, non-ferrous metal and battery production.

The examples of operational conditioning and packaging plants which had been considered in the literature review, and which formed the basis of the workshop were the following BNFL and UKAEA plants:

- Magnox Encapsulation Plant (Sellafield);
- Waste Encapsulation Plant (Sellafield);
- Waste Packaging and Encapsulation Plant (Sellafield);
- Waste Treatment Complex (Sellafield);
- WAGR Encapsulation Plant (Windscale);
- Dounreay Cementation Plant;
- Transportable ILW Solidification Plant (Magnox station decommissioning).

Experiences of dealing with “out-of-specification” packages from these or other plants were also considered within the context of the workshop. This was to ascertain their relevance to this study, and other ongoing studies into the stability of conditioned radioactive wastes, using inactive simulants to ascertain the feasibility for reworking.

A2.2 Methodology

The sessions were held at the Environment Agency’s offices in Warrington on 21 June 2005. Session 3 was not held as planned, for reasons discussed below.

Representatives from the following organisations attended the workshop study: Environment Agency (EA); Nuclear Installations Inspectorate (NII); Scottish Environment Protection Agency (SEPA); Nuclear Decommissioning Authority (NDA); UK Nirex Ltd; British Nuclear Group, Nexia Solutions, Magnox Electric, Atomic Weapons Establishment (AWE); UKAEA; British Energy; Ministry of Defence (MOD) and RM Consultants Ltd. The complete list of attendees was as follows:

Name	Job Title	Organisation
Mike Gardiner	AWE Acceptance Review Team Leader - ILW Project	AWE
Stephen Harrison	Project Manager	AWE
Colin Rhodes	Engineering and Technical Products Representative	British Nuclear Group Sellafield
Roddy Anderson	Radioactive Waste Management and Decommissioning Engineer	British Energy
Christina Alexander	Radioactive Waste Management and Decommissioning Engineer	British Energy

Name	Job Title	Organisation
Mark Tearle	Nuclear Waste Assessor – ILW Conditioning	Environment Agency
Paul Abraitis	Nuclear Waste Assessor – Nirex Programme	Environment Agency
David Copplestone	Principal Scientist – Chemicals & Radioactive Substances	Environment Agency
Kulvinder McDonald	HM Principal Inspector Nuclear Installations	HSE/NII
Glyn Davies	HM Principal Inspector Nuclear Installations – Radioactive Waste and Decommissioning	HSE/NII
Roger Streatfield	Waste Management Consultant	Magnox Electric Limited
Peter Cave	Waste Management & Decommissioning Manager	MOD
Bill Harris	Waste Management Manager	MOD
Phil Davies	Head of Waste and Nuclear Materials Strategy	NDA
Kevin Newland	Senior Technology Manager	Nexia Solutions
Richard Baxter	Safety and Environmental Systems Manager	Nirex
Simon Wisbey	Packaging Assessment Team Manager	Nirex
Iain Gray	Group Manager – Project Manager	RM Consultants Ltd
James Fitzpatrick	Director - Project Director	RM Consultants Ltd
Daniel McHugh	Senior Consultant	RM Consultants Ltd
Alan Purcell	Principal Consultant	RM Consultants Ltd
Richard McLeod	Principal Policy Officer	SEPA
Andrew Whittall	Principal Policy Officer	SEPA
Michelle Wise	Head, Technical Services Group	UKAEA

The results of each of the sessions were recorded on pro-formas, which are provided as Table A2.1, Table A2.2 and Table A2.3 in this appendix.

A2.3 Description of Workshop Sessions

A2.3.1 Session 1

The definition of the term "reworking" was discussed using the following description derived from the literature review as a basis: *in the Environment Agency's Guidance on the conditioning of ILW the term "reworking" is used to cover repackaging of waste that has already been packaged in a waste container*.

Based on the definition above, reworking was considered to potentially consist of:

- use of an overpack (e.g. for cases where only the waste container had deteriorated);
- stabilisation of the matrix (e.g. pressure injection of a stabilising matrix); and
- the retrieval and reconstitution of the wasteform.

However as a result of discussion, the definition of reworking was broadened and re-defined as:

A process involving physical intervention to packaged waste arising from deviation from the planned, storage, treatment or intended disposal process for that packaged waste.

Based on this broader definition, overpacking, stabilisation of waste and retrieval and reconstitution of the wasteform would still be classed as reworking. In addition, invasive processes such as coring or assay of the waste would also be regarded as reworking. However, monitoring of the surface of a contaminated waste package, say by means of a wipe would not be regarded as part of the reworking process.

As a result of the brainstorming session, the following guidewords were added to the original list:

- transport;
- moisture ingress;
- excess voidage;
- stakeholder demonstration – demonstration to stakeholders of acceptability of present packaging and requirement for subsequent repair;
- thermal damage;
- non-compliant package;
- breakdown of store condition;
- incomplete records;
- disposal route;
- proscribed items (records).

A series of detailed reasons were identified as to why reworking might be required (Table A2.1). These were then grouped into a series of more generic reasons for consideration in Session 2. The reasons for reworking fell into several broad categories that were:

- damage or deterioration resulting in loss of shielding or containment, generation of hazardous substances, or damage to external handling features;
- package out-of-specification;
- external policy, economic or other pressures.

The outputs from Session 1 of the workshop are discussed further in the main text of the report (Section 4).

A2.3.2 Session 2

A list of potential strategies and reworking methods for dealing with out-of-specification packages were identified against each of the generic reasons identified in Session 1. Where appropriate, this was achieved by using the list of guidewords used in Session 1. The results of this process are shown in Table A2.2. Various strategies/methods were identified.

All of the strategies/methods were carried over for further consideration in the workshop process. The outputs from Session 2 of the workshop are discussed in the main text of the report (Section 4).

A2.3.3 Session 3

The intended aim of Session 3 of the workshop study was to identify appropriate detailed reworking methods for the different wasteforms and containers for each strategy identified in Session 2. However, it became apparent from discussions during Sessions 1 and 2 that this could not be achieved because it was not practical to identify what constituted best practice, given that there is a wide range of potential problems. Instead, it was agreed to proceed to Session 4.

A2.3.4 Session 4

The intended aim of Session 4 of the workshop study was to assess the implications of the reworking strategies/methods that had been identified from previous sessions. The original intention was to attempt to achieve this by scoring each strategy/reworking method taking account of the following assessment criteria:

- environmental impact;
- secondary waste production arising from use of the strategy/method;
- safety; and
- costs.

The intention was to have a maximum score of 5 for each of the assessment criteria, giving a maximum possible score of 20 for each strategy/method.

However, it was decided instead to perform the assessment qualitatively. For each of the assessment criteria in turn, a low, medium or high (“L”, “M” or “H”) impact was assigned for each of the strategies. In this study, no account was taken of the relative importance of each of criteria. The results are shown in Table A2.3, and these are discussed in the main text of the report (Section 4).

The specific issues associated with each product type considered meant no common viewpoint was reached in Session 3 on what constitutes best practice, in terms of reworking method/strategy for a given out-of-specification waste package and wasteform. This was because of a lack of data on reworking methods and strategies, and the diversity of options that were judged to be available. Thus, it was decided to explore alternative approaches as part of Session 4.

It was agreed that there would be value in trying to define a process which would comprise a series of generic logical steps that could be followed to decide on the most appropriate action to take for any given out-of-specification waste package and wasteform. A series of logical steps was developed as the result of workshop discussions. These are presented and discussed in the main text of the report (Sections 4 and 5).

Table A2.1 Potential reasons for reworking

Guideword	Potential Reasons for Reworking[1]
Wasteform expansion	Outside of waste package spec caused by: • breakdown of package matrix; • changes in the matrix; • phase changes in the cement; • poor characterisation; • physical expansion of waste container; • springback of compacted waste.
Impact damage	• gross breach of container; • minor breach of container; • distortion of container; • damage to matrix; • loss of shielding effectiveness; • damage to handling features; • damage to raw waste.
Corrosion	• wasteform expansion; • deterioration of container; • perforation of container; • internal corrosion; • external corrosion; • external salt corrosion; • generation of hazardous material; • unacceptable appearance; • loss of identification marks; • degradation of handling features.
Weld	• cracking of weld; • failure of weld identified by NDT.
Seal	• failure of seal, especially certain types • bolt deterioration.
Leak	• unacceptable release of radioactive material; • contamination of external surface of packages.
Bacteria	• microbial induced corrosion; • Excessive gas generation.
Cracking	• stress corrosion cracking of container; • breakdown of matrix leading to powder; • cracking of concrete shielding in package.
Gas generation	• excessive radioactive gas generation; • excessive toxic or flammable gas generation; • disruption to wasteform caused by sudden significant gas generation; • outside store or transport safety case limits.

Guideword	Potential Reasons for Reworking[1]
Matrix composition	• poor quality cement; • wrong matrix or formulation; • changes in matrix; • fault in package production; • changes in waste.
Package inventory	• re-evaluation leading to conclusion that a limit, e.g. fissile, heat output, has been breached.
Capping	• missing cap; • faulty cap.
Repository design	• change in acceptance criteria.
Programme change	• extended storage leading to package deterioration.
Government policy	• indefinite or long-term storage as the national strategy; • waste becomes an asset leading to requirement for recovery; • changes to requirement for early conditioning; • LLW becoming ILW (or vice versa).
Safety standards	• out-of-specification package at point of production; • tightening of safety standards; • tightening of environmental standards; • tightening of security standards.
Transport	• tightening of safety standards; • increased requirements from stakeholder interest; • reworking of waste packages involved in transport accident.
Moisture ingress	• free liquids remaining in package; • water ingress into waste package leading to corrosion.
Excess voidage	• non-monolithic wasteform.
Intrusive sampling	• need to repair after intrusion; • need to rework other packages based on results from intrusive sampling.
Stakeholder demonstration	• need to repair after demonstration; • need to rework other packages based on results from demonstration.
Thermal damage	• package involved in fire; • package exposed to extreme low and high temperatures; • package exposed to extreme temperature cycling.

Guideword	Potential Reasons for Reworking[1]
Non-compliant packages	• plant only produces non-compliant packages; • new knowledge and understanding casting doubt.
Breakdown of store conditions	• package deterioration, e.g. salt on surface, moisture ingress, condensation, algal growth.
Incomplete records	• loss of or incomplete or unintelligible records for a specific package, preventing demonstration case for transport or disposal.
Disposal route	• change of acceptance criteria caused by different disposal route.
Proscribed items in package	• records show that a package contains something inappropriate.

Notes: [1] Based on discussion of the above, the following generic reasons for reworking were carried forward for consideration in Session 2 of the workshop

1. Loss of package containment – minor
2. Loss of package containment – major
3. Weakened Container Structure
4. Loss of package shielding
5. Surface contamination of packages
6. Deterioration of matrix structure – no breach of containment
7. Excessive gas generation above safety limits
8. Generation of hazardous material within package
9. Unacceptable appearance
10. Loss of package ID marks
11. Damage to package handling features
12. Failure of package mechanism to close
13. Package outside Waste Product Specification
14. Package outside acceptance criteria e.g. radiation levels, heat output etc.
15. Waste items become an asset
16. Changes to requirement for early conditioning
17. Incomplete records for a package
18. Change of national policy standards or disposal route requires repackaging
19. Proscribed item in package
20. Outside dimensional specification

Table A2.2 Potential strategies for out-of-specification packages

Reason	Potential Strategies[1]
Loss of package containment – minor	4, 7
Loss of package containment – major	3, 4, 5, 6, 10, 12
Weakened container structure	3, 4, 5, 6, 10, 12
Loss of package shielding	3, 4, 5, 6, 10
Surface contamination of packages	3, 7
Deterioration of matrix structure - no breach of container	1, 3, 8, 11, 2
Excessive gas generation above safety limits	8 Insert plug for transport
Generation of hazardous material within package	5, Intrusive sampling
Unacceptable appearance	4, 7
Loss of package identification marks	4, 7, 9
Damage to package handling features	4, 6
Failure of package closure mechanism	1, 4, 6
Package outside Waste Product Specification	1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 15
Package outside acceptance criteria, e.g. radiation, heat output	1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 15
Package exceeds design life	1, 3, 5, 6, 10, 12 Feeds into some of above
Waste items become an asset	5, 12
Changes to requirement for early conditioning	1
Incomplete records for a package	1, 9 Intrusive investigation
Change of national policy standards or disposal route requires repackaging	5, 6, 10, 12,15, 13
Proscribed item in package	15, 13, 5, 1,2
Outside dimensional spec	5, 6, 4, 15,

Notes: [1] The potential strategies were as follows:

1. No intervention on package
2. Intervention on operation of plant/store
3. Ongoing observation and/or Segregation of package
4. Repair container
5. Disassemble package
6. Overpack
7. External treatment
8. Non-intrusive treatment
9. Reassay
10. High temperature process
11. Injection of stabilising material
12. Dissolve package
13. Change disposal route
14. Feedback of lessons learnt (applies generally)
15. Special arrangements for disposal

All of these potential strategies were carried forward for consideration in Sessions 3 and 4 of the workshop.

Table A2.3 Predicted impacts and effects of strategies for out-of-specification packages

Strategy/Assessment criterion	Environmental Impact[1]	Secondary Wastes[1]	Hazard[1]	Cost[1]
No intervention on package	L	L	L	L
Intervention on operation of plant/store	L	L	L	L
Ongoing observation and/or Segregation of package	L	L	L	L
Repair container	L	L	M	M
Disassemble package	H	H	M	H
Overpack	M	L[2]	L	M
External treatment	L	M	L	L
Non-intrusive treatment	L	L	L	L
Intrusive examination	M	M	M	M
Reassay	L	L	L	L
High temperature process	H	H	H	H
Injection of stabilising material	M	M	M	M
Dissolve package	H	H	H	H
Change disposal route	3	3	3	3
Special arrangements for disposal	3	3	3	3
Insert plug for transport[4]	L	L	M	M

Notes: [1]L = Low Impact; M = Medium Impact; H=High Impact. Ranking has been undertaken vertically for each assessment criterion and strategy.
[2] This will result in an increase in the total volume of primary waste.
[3] Impacts will be decided on a case-by-case basis.
[4] See Table A2.2.

Glossary of terms

ALARP	As Low As Reasonably Practicable. ALARP means that all measures that are not unreasonably costly should be taken to reduce risk. This is usually achieved by the establishment and/or use of relevant good practices and standards.
Authorisation	Permit granted by the environment agencies for the disposal of radioactive waste.
BPM	Best Practical Means is a term used by the environment agencies in authorisations issued under the Radioactive Substances Act. Essentially, it requires operators to take all reasonably practicable measures in the design and operational management of their facilities to minimise discharges and disposals of radioactive waste, so as to achieve a high standard of protection for the public and the environment. BPM is applied to such aspects as minimising waste creation, abating discharges and monitoring plant, discharges and the environment. It takes account of such factors as the availability and cost of relevant measures, operator safety and the benefits of reduced discharges and disposals. If the operator is using BPM, radiation risks to the public and the environment will be as low as reasonably achievable.
Conditioning	The processing of radioactive waste to achieve passive safety for interim storage and prepare it for eventual disposal. Such processing can be considered to involve treatment, conditioning and packaging stages. For brevity "conditioning" is used in this document to include all stages of the process, except where it is necessary to refer to one of the stages specifically.
CoRWM	The Committee on Radioactive Waste Management, which is reviewing the UK's options to manage solid wastes for which no long term strategy currently exists. It is expected that CoRWM will make its recommendations to Government during summer 2006.
Decommissioning	The process whereby a nuclear facility, at the end of its economic life, is taken permanently out of service and its site made available for other purposes. In the case of a nuclear power station, this normally involves three stages. Immediately after the final closure, radioactive material such as nuclear fuel and operational waste is removed; then the buildings surrounding the reactor

	shield are dismantled; and finally the reactor itself is dismantled.
Discharge	The release of aerial or liquid waste to the environment.
Disposability	The degree to which conditioned waste meets the standards and specifications for final disposal.
Disposal	The emplacement of waste in an authorised, specialised facility constructed for its long-term management and for which the primary expectation is not one of retrieval.
Environment Agencies	The Environment Agency or the Scottish Environment Protection Agency. (Note that for the purposes of this document the Environment and Heritage Service, who have regulatory responsibility for RSA 93 matters in Northern Ireland, are not included in this definition because there are no nuclear licensed sites in Northern Ireland.)
ILW	This has radioactivity levels which exceed the upper boundary for low level waste (LLW), but which does not generate significant amounts of heat.
Letter of Comfort (LoC)[1]	Under its Letter of Comfort system, in the context of a phased approach to disposal, Nirex provides guidance to the nuclear industry on its requirements for the packaging and transport of ILW. Nirex issues LoCs in three stages, which successively assess the suitability of proposals against the requirements for safe disposal against Nirex's phased disposal concept.
Licensee	The legal entity which has the responsibility for operating a UK nuclear industry facility under the terms and conditions of the nuclear site licence.
Low-level waste	LLW, which contains radioactive materials that together do not exceed 4 GigaBecquerels per tonne alpha or 12 GigaBecquerels per tonne beta/gamma activity.
Nuclear Licensed Site	Any site which is the subject of a licence granted by the HSE (under the Nuclear Installations Act 1965) to the licensee for the purposes of installing or operating a nuclear installation on that site.
Packaging	The operation of producing a container filled with the waste or wasteform.

Passive Safety	Passive safety requires radioactive waste and materials to be immobilised in a form that is physically and chemically stable and stored in a manner that minimises the need for control and safety systems, maintenance, monitoring and human intervention.
Phased Disposal Concept	Nirex's preferred option for a deep geological disposal facility for ILW (developed by Nirex).
Regulators	The Health and Safety Executive, the Environment Agency and the Scottish Environment Protection Agency. (Note that other regulatory bodies are involved in the management of UK radioactive waste but, in this document, this definition is limited to those listed).
Repository	A nuclear facility where waste is emplaced for disposal.
Safety Case	A collection of arguments and evidence to demonstrate the safety of a facility or activity.
Secondary Waste	Waste that results from applying treatment, handling or storage technology to a waste or product stream of a process.
Segregation	The physical separation of wastes according to type and/or characteristics.
Storage	Placement of waste in any facility with the intent to retrieve it at a later time.
Sustainable Development	This is commonly defined as "Development that meets the needs of the present generation without comprising the ability of future generations to meet their own needs".
Treatment.	Any operation that changes the chemical or physical characteristics of the waste.
Waste Container	The packaging material containing the waste form.
Wasteform	The physical and chemical form of the waste after treatment and/or conditioning (resulting in a solid product). The waste form is a component of the waste package.
Waste Management	All administrative and operational activities involved in the handling, pre-treatment, treatment, conditioning, transport, storage and disposal of radioactive waste.

Waste Package	The package of material destined for disposal including the waste container and wasteform.

[1] Change in terminology: At the time of writing, Nirex were in the process of changing the terminology “Letter of Comfort” such that LoC will stand for “Letter of Compliance” as from January 2005. To avoid confusion and to maintain consistency with quoted reference material, the term “Letter of Comfort” is used throughout this document: as such, the terms “Letter of Comfort” and “Letter of Compliance” are interchangeable in this guidance. Nirex will produce separate guidance on the application of its Letter of Compliance process, which will include details of the new terminology.

List of abbreviations

ALARP	As Low As Reasonably Practicable ALARP (see Glossary)
AMWTP	Advanced Mixed Waste Pilot Plant
AWE	Atomic Weapons Establishment
AWRP	Active Waste Retrieval Programme
BNFL	British Nuclear Fuels plc
BPM	Best Practicable Means:
CoRWM	Committee of Radioactive Waste Management (see Glossary)
EA	Environment Agency
ENRESA	Empresa Nacional de Residuos Radiactivos
HHISO	Half Height ISO container
HMNII	Her Majesty's Nuclear Installations Inspectorate
HSE	Health and Safety Executive
LLW	Low Level Waste (see Glossary)
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste (see Glossary)
ISS	Interim Safe Storage
LLW	Low Level Waste
LoC	Letter of Comfort/Letter of Compliance
MOX	Mixed Oxide Fuel
NDS	National Disposal Service
NDT	Non-destructive testing
NEA	Nuclear Energy Agency
NII	Nuclear Installations Inspectorate
NRVB	Nirex Reference Vault Backfill
NuSAC	Nuclear Safety Advisory Committee
NWAT	Nuclear Waste Assessment Team
PCM	Plutonium Contaminated Material
RWMAC	Radioactive Waste Management Advisory Committee
RWPG	Radioactive Waste Policy Group
SEPA	Scottish Environment Protection Agency
TRU	Transuranic
UKAEA	United Kingdom Atomic Energy Authority
USDOE	United States Department of Energy
WAMAC	Waste Monitoring and Compaction
WETP	Waste Encapsulation and Treatment Plant
WIPP	Waste Isolation Pilot Plant
WRATS	Wastes Requiring Additional Treatment
WTC	Waste Treatment Complex
WQCL	Waste Quality Checking Laboratory

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