National Waste Programme

Management of Waste Failing the Discrete Item Limit

Feasibility Study

NWP-REP-139 – Issue 1 – Dec 2016
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Document history

<table>
<thead>
<tr>
<th>Issue</th>
<th>Date</th>
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</thead>
<tbody>
<tr>
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This document has been produced by Amec Foster Wheeler on behalf of the National Waste Programme Office with involvement from Magnox Ltd, Sellafield Ltd, AWE, Radioactive Waste Management Ltd and the Nuclear Decommissioning Authority.
Executive Summary

Low Level Waste (LLW) Repository Ltd established and leads a UK-wide integrated National Waste Programme (NWP) on behalf of the Nuclear Decommissioning Authority (NDA) to implement the National LLW Strategy for the nuclear industry; extend the life of the repository; obtain overall cost savings for LLW management; and enable hazard and risk reduction across the nuclear industry.

A growing area of interest for the nuclear sector is the management of problematic wastes. These are wastes for which there is no defined or available waste treatment or management route, or those for which the available route is significantly sub-optimal. One waste type of significant concern to the Lower Activity Waste (LAW) management community is waste which conforms to the definition of a discrete item and exceeds the relevant numerical discrete item limits, as laid out in the LLW Repository Ltd Waste Acceptance Criteria (WAC).

A distinct item, as defined in the WAC documentation, is “a distinct item of waste that, by its characteristics, is recognisable as unusual or not of natural origin and could be a focus of interest, out of curiosity or potential for recovery and recycling / re-use of materials, should the waste item be exposed after repository closure”.

As discrete items which do not meet the activity limits specified in the WAC cannot be managed via the LLW Repository, they can result in management as intermediate level waste (ILW), either because there are limited alternative options available, or because of the waste producers’ perception that this is the case.

This study develops a list of credible options which might be used for the effective management of these items, and forms the basis for more detailed assessments at a later stage, if this is deemed appropriate.

An inventory was provided based on information from waste producers. The inventory has been divided into three main waste groups:

1. Metals with simple geometries and predominantly accessible surfaces;
2. Metals with complex geometries and inaccessible surfaces;
3. Cemented drums.

Discrete items that fail to conform to the WAC may be managed either by modifying the physical form (e.g. shape) of the object so that it no longer qualifies as a discrete item of waste, or reducing the total activity of the item so that it is within the relevant discrete item activity limits.¹

¹ The cutting or dismantling of a waste item with the sole intention of reducing its weight or specific activity to meet the discrete item limits in the WAC is prohibited by the WAC. Physical modification in the context of this report is that which makes the item no longer unusual or a focus of interest, rather than changing its radioactive properties.
Having this in mind, a long list of seventeen potential technologies and management approaches was developed and grouped into four main categories (size reduction, decontamination, thermal treatment and other approaches), as presented in Table ES-1.

Table ES-1: The 17 identified technologies

<table>
<thead>
<tr>
<th>Technology type</th>
<th>Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size reduction – shredding/crushing</td>
<td>Shredding, Jaw crusher, Supercompaction</td>
</tr>
<tr>
<td>Size reduction – mechanical cutting</td>
<td>Circular saw, Wire saw, Reciprocating saw</td>
</tr>
<tr>
<td>Size reduction – thermal cutting</td>
<td>Torch cutting, Plasma cutting, Laser cutting</td>
</tr>
<tr>
<td>Decontamination</td>
<td>Chemical decontamination, Physical decontamination</td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>Metal melting, Incineration, Plasma arc processing, Vitrification</td>
</tr>
<tr>
<td>Other approaches</td>
<td>Disposal elsewhere, Decay storage</td>
</tr>
</tbody>
</table>

The long list of options has been subjected to an initial screening assessment process using the following criteria:

1. Effectiveness (waste group-specific);
2. Nature and disposability of resulting product;
3. Impact on worker and environmental safety from technology use;
5. Preliminary technology readiness; and
6. Availability to the UK industry.

The assessment process was carried out at an expert workshop attended by key representatives of the waste producers, the NDA, Radioactive Waste Management (RWM) and LLW Repository Ltd. The process allowed for a number of options to be screened out, leaving those that offer a credible treatment to be carried forward for further study.

The screening process was performed using a Red, Amber, and Green (RAG) scoring system, to assess each technology against each waste group. Where a technology scored red against any one criterion, it was screened out. Technologies scoring green and amber were all carried forward as credible options.

As shown in Table ES-2, the assessment identified a number of credible options for each waste group, with the cemented drums waste group having the lowest number of credible options. A number of options were assessed as being credible for all three waste groups, namely shredding, wire saw, plasma arc processing, vitrification, disposal elsewhere, and decay storage.
## Table ES-2: Summary of the assessment of credible options

<table>
<thead>
<tr>
<th>Technology</th>
<th>Metals: simple geometries</th>
<th>Metals: complex geometries</th>
<th>Cemented drums</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shredding</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Jaw crusher</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Supercompaction</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Circular saw</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Wire saw</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Reciprocating saw</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Torch cutting</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Plasma cutting</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Laser cutting</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Chemical</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Physical</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Metal melting</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Incineration</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Plasma arc processing</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Vitrification</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Disposal elsewhere</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Decay storage</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

✓ technology credibly applicable to a specific waste group

X technology not credibly applicable to a specific waste group

Following the assessment, a gap analysis was carried out to identify gaps or research and development needs that may preclude or impact on the applicability of the technologies to the waste groups. This analysis identified that some credible technologies (e.g. shredding, plasma arc, vitrification) can be used against all identified waste groups but would require further trials and testing against the identified waste groups.
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1. Introduction

Low Level Waste (LLW) Repository Ltd established and leads a UK-wide integrated National Waste Programme (NWP) on behalf of the Nuclear Decommissioning Authority (NDA) to:

- Implement the National LLW Strategy for the UK nuclear industry;
- Extend the life of the repository;
- Obtain overall cost savings for LLW management;
- Enable hazard and risk reduction.

A growing area of interest for the nuclear sector is the management of problematic wastes. These are wastes for which there is no defined or available waste treatment or management route, or those for which the available route is significantly sub-optimal. One waste type of significant concern to the lower activity waste (LAW) management community is waste which fails to conform to the *discrete item* criteria specified in the LLW Repository Ltd Waste Acceptance Criteria (WAC) [1].

Wastes breaching the *discrete item limit* were also identified by waste producers as the highest priority problematic waste in 2015/2016 and, recognising the limitations in granularity of the inventory data available for such wastes, as such a *discrete items* inventory, separate from the problematic waste inventory, was compiled[2]. LLW Repository Ltd produced a summary of this inventory in 2016 [2]. This is discussed further in Section 2.

LLW Repository Ltd’s Environmental Safety Case (ESC) presents scenarios in which, in the long term, due to the coastal erosion or excavation of items during human intrusion, a person can encounter a discrete item of radioactive waste which has been disposed at the LLW Repository (LLWR). The results from the assessment made in the ESC provide the basis for WAC for disposal of discrete waste items to the LLWR’s engineered vaults.

The potential radiation doses to persons who encounter *discrete items* of radioactive waste disposed in the LLWR were assessed by LLW Repository Ltd in 2013 [3]. The results from the assessment were used to provide a basis for the WAC for disposal of discrete waste items to the

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1 In this report the use of italics for the term *discrete item* or *discrete item limits* indicates that the item (object or waste) referred to cannot currently be disposed at LLWR without some form of treatment owing to its physical and radiological properties. These are laid out in the WAC.

2 It is recognised that a transition between the fourth and fifth issues of the LLWR WAC occurred between prioritisation of problematic waste in FY15/16 and this study. The April 2016 iteration of the LLWR WAC changed a number of the radionuclide groupings in the discrete item definition which has enabled a wider range of waste, which previously would have failed the discrete item limits, to be safely accepted for disposal at the LLWR.
LLW Repository’s engineered vaults. Section L3.2.3 of LLWR’s WAC for Low Level Waste (LLW) disposal [1] concerns discrete items.

As these types of wastes cannot be managed via disposal to the LLW Repository (LLWR), they may be managed as intermediate level waste (ILW), either because there are limited alternative options available, or because of the waste producers’ perception that this is the case. This can result in significant additional cost and the need for long-term storage pending the availability of disposal facilities. This study develops a list of credible options which might be used for the effective management of these items, and forms the basis for more detailed assessments at a later stage if this is deemed appropriate. These credible options are based on the definition of discrete items in the WAC and which result in the waste being rendered into a less recognisable form.

1.1. Background

The *discrete item*, as defined in the WAC documentation, means “a distinct item of waste that, by its characteristics, is recognisable as unusual or not of natural origin and could be a focus of interest, out of curiosity or potential for recovery and recycling / re-use of materials, should the waste item be exposed after repository closure”.

The WAC also defines radioactivity limits for *discrete items*: the activities and specific activities of individual discrete items must comply with the following sum of fractions:

\[
\frac{Q_A}{DIL_A} + \frac{Q_{B1}}{DIL_{B1}} + \frac{Q_{B2}}{DIL_{B2}} + \frac{Q_C}{DIL_C} \leq 1,
\]

where \(Q_A\) is the total activity or specific activity of group N radionuclides and \(DIL_N\) is the Discrete Item Limit for that group, depending on the mass of the *Discrete Item*.

The groups of radionuclides are presented in Table 1 and the *discrete items limits* for these are presented in Table 2 [1].

<table>
<thead>
<tr>
<th>Table 1: Radionuclide groups for limiting discrete items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
</tr>
<tr>
<td><strong>Group B1</strong></td>
</tr>
<tr>
<td><strong>Group B2</strong></td>
</tr>
<tr>
<td><strong>Group C</strong></td>
</tr>
</tbody>
</table>
Table 2: Discrete item limits

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Mass 1 kg or less</th>
<th>Mass between 1 and 100 kg</th>
<th>Mass 100 kg or greater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>0.001 GBq</td>
<td>1 GBq/t</td>
<td>0.1 GBq</td>
</tr>
<tr>
<td>Group B1</td>
<td>0.01 GBq</td>
<td>10 GBq/t</td>
<td>1 GBq</td>
</tr>
<tr>
<td>Group B2</td>
<td>0.3 GBq</td>
<td>300 GBq/t</td>
<td>30 GBq</td>
</tr>
<tr>
<td>Group C</td>
<td>1 GBq</td>
<td>1000 GBq/t</td>
<td>100 GBq</td>
</tr>
</tbody>
</table>

Some examples of discrete items are given in the WAC documentation, and they can vary from smaller-sized waste (hand tools, engineered items and equipment of durable materials) to larger items such as grouted drums of waste or even large metal items (steel beams and plates, pipework, shielding, heavy equipment and flasks).
2. Waste inventory

The LAW inventory that would be expected to breach the discrete item limits was provided by LLW Repository Ltd. This inventory was constructed based on information provided by the waste producers and comprises 74 waste streams. More detail is presented in Appendix 1 of this report. An Inventory Summary Report [2] has also been developed by LLW Repository Ltd and was also used as a starting point for this study.

The inventory has been developed and divided into four main groups, based upon their characteristics (waste form, weight and size, radiological characteristics). The four groups were developed to cover all types of materials in the inventory. This way, the emphasis is on the main physical characteristics and the assignment of individual items into one group or another will not have a significant impact on the assessment.

Evaluation of the inventory data, specifically generated for this study, has shown that there is a lack of characterisation for many of the items in the inventory that have been defined as discrete items. It is likely that when these items are more adequately characterised, a significant proportion may be found to be outside the definition of wastes failing the discrete item limits and therefore to be suitable for disposal without further treatment. Conversely, it is possible that ongoing characterisation of wastes will identify other waste items, and different populations of different waste types, that do not comply with the discrete item limit.

The identified waste groups are as follows:

1. Metals – simple geometries and predominantly accessible surfaces

These are metallic wastes that can be characterised by having a simple geometry where all the items' surfaces are accessible (without inner voids). Many of the items present in the inventory are heavy duty metallic wastes.

Some examples of the wastes within this group are: framework, bars, plates, containers, skips, trolleys, rams and bogies, and magazine bodies.

2. Metals – complex geometries and inaccessible surfaces

These are more durable and physically robust metallic objects with complex geometries, usually formed from multiple parts joined together, which results in many of the items having inaccessible surfaces or internal voids.

Some examples of the wastes within this group are: pipework, pumps, flowmakers, crane parts, filters, and heat exchangers.

3. Drums containing cemented waste

These are metallic (mild steel) drums that contain cement-encapsulated waste, such as water treatment sludges. Another type of waste within this category would be metallic drums that
contain cement-encapsulated items of waste, such as metallic filters. These wastes were not identified within the inventory itself, but from discussions held with waste consigners and with LLW Repository Ltd. These types of waste were included in the assessment for this group, with any differences from drums containing cemented sludges highlighted as necessary.

4. Sources

This group contains radioactive sources that are either encapsulated within a metallic structure and those that are identified within the inventory as including cement, sand, paper and/or plastic, rather than metal.

During the assessment workshop it was acknowledged that as lower activity sources have their specific criteria and limits in LLWR’s WAC, they will have to comply with those limits. Should they breach the source limits in the WAC, they would not be accepted at the LLWR, irrespective of the discrete item limits. Because of this, it was agreed that this waste group should not be carried forward to the assessment. It was noted that some waste routes for lower activity sources exist – either for re-use or management – and that some sources remain problematic waste as these routes are not suitable. Issues relating to the management of problematic sources, and work to identify and support implementation of waste management solutions for these wastes, will be coordinated through the work of the ongoing Problematic Waste Integrated Project Team being led by RWM and LLW Repository Ltd on behalf of NDA.
3. Identification of technologies and management approaches

This section identifies a number of proposed technologies and approaches for the treatment of LAW that fail to conform to the LLWR discrete item criteria.

Discrete items that breach the WAC limits may be managed either by modifying the physical form (e.g. shape) of the object so that it no longer qualifies as a distinct item of waste, or reducing the total activity of the item so that it is within the discrete item activity limits. Having this in mind, a long list of proposed approaches was developed and is presented below, with a detailed description of each presented in Appendix 2 as separate datasheets.

To facilitate the assessment process, technologies were grouped into one of four main categories:

- Size reduction technologies: these involve techniques such as cutting, compressing or shredding the item of waste so that it is no longer ‘discrete’ as is defined in the WAC (i.e. is no longer an item that could be a focus of interest).

- Decontamination technologies: these reduce the activity of the waste item so that it is below the relevant WAC limits.

- Thermal treatment technologies: these aim to modify the physical shape of the item of waste and also reduce its activity so that the item is no longer ‘discrete’ as defined in the WAC.

- Other approaches: these approaches may also be effective in managing the challenges presented by the discrete items.

3.1. Size reduction technologies

These technologies reduce the size of items of waste, by shredding, crushing, cutting or otherwise segmenting a large body into smaller items. Depending on the type of waste and the precise method used, size reducing these wastes is intended to change the waste into a less recognisable form that would not be classed as a ‘discrete item’ as defined in the WAC documentation (i.e. is no longer an item that could be a focus of interest).

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3 The technical datasheets were developed and researched ahead of the stakeholder workshop used to assess the technologies, using specialist contractor resource, to provide underpinning background technical information on the different technologies and approaches.

4 The use of size reduction technologies for the sole intent of reducing the specific activity of the item to conform to the radioactivity limits for discrete items is prohibited by the LLWR WAC. The use of size reduction techniques in this context is to transform items that fail the discrete item limit into wastes which are no longer deemed to be unusual or with the potential to be a focus of interest.
The range of size reduction techniques may be categorised further by method used: shredding/crushing, mechanical cutting, and thermal cutting.

Size reduction – Shredding / crushing techniques

- **Shredding** – This uses mechanical equipment to reduce the size of individual items waste. Cutter wheels intermesh and are used to tear apart the waste which is trapped between the wheels. The capacity of the shredder will be determined by the feeding and cutting systems.

- **Jaw crusher** – These use considerable compressive force to break up hard, brittle and tough materials. The mechanical pressure required to crush the material is achieved by two jaws in a “V” alignment, of which one is fixed while the other moves back and forth.

- **Supercompaction** – In this case a vertical compaction unit is employed into which drums are fed from a roller conveyor. Within the compaction chamber, a hydraulic ram exerts a high compressive force to crush the drums into ‘pucks’.

![Figure 1: From left to right, a shredder [4], a jaw crusher [5] and a supercompactor [6]](image)

Size reduction – Mechanical cutting techniques

- **Circular saw** – This uses a round, toothed blade which rotates at high speed to cut through materials, leaving a straight and accurate cut.

- **Wire saw** – A length of wire is bound either around (‘pull cutting’) or against (‘push cutting’) the material being cut. The wire cuts through the material as the result of abrasion due to the wire moving at a high speed.

- **Reciprocating saw** – This uses a mechanical method to achieve cutting through a push and pull movement of a saw blade.
Size reduction – Thermal cutting techniques

- **Torch cutting** – A flame is used to heat the metal being cut to its ‘ignition’ temperature (below its melting point), before an oxygen jet is turned on to instigate a vigorous exothermic reaction that results in the formation of slag. The oxygen jet blows the slag away, allowing the jet to pierce through the metal and continue cutting.

- **Plasma cutting** – A direct current arc between an electrode and the conducting metal to be cut is established. The arc is established in a plasma gas and as the flow of this gas through the nozzle is increased, the penetrating plasma jet cuts through the metal.

- **Laser cutting** – This uses a focused laser beam to melt material from a localised area and cause it to flow away. Once the material is completely pierced, the cutting process can start. A gas jet is used to eject the molten material from the cut.

3.2. Decontamination technologies

Decontamination technologies remove radioactive contaminants from the waste. In this way a *discrete item’s* activity can be reduced sufficiently for it to be within the WAC activity limits for disposal at the LLWR, and possibly even be suitable for disposal as “Out-of-Scope” material (or VLLW or low-activity LLW).

These technologies may be grouped into chemical/electrochemical and physical/mechanical methods:
Chemical/electrochemical techniques – These are effective in removing radioactive contaminants from waste by means of one or more chemical agents, such as a detergent, oxidising agent or acid. The category includes electrochemical decontamination in which the chemical processes are assisted by an electrical field. In both cases, considerable volumes of secondary wastes will be produced and will require treatment.

The use of complexing agents during the process of chemical decontamination of wastes may introduce challenges as such materials can have a negative impact on the disposability of the resulting product or secondary wastes. This is because the presence of complexants in wastes is severely limited by the LLWR WAC.

Acid digestion was also considered as a separate chemical method which is used to completely dissolve wastes. Even if this method could be used for treating metals, it was not considered practicable for metallic waste items of any significant size. In operation, the technique would generate substantial volumes of secondary acidic waste that would need to be treated. Accordingly, the decision was made not to carry forward acid digestion to the assessment.

Physical/mechanical techniques – These work by removing the radioactive contaminants from waste by means of a physical process, such as scrubbing, abrasive blasting or water jetting. As for chemical decontamination, considerable volumes of secondary wastes will be produced.

3.3. Thermal treatment technologies

Thermal techniques use high temperatures to melt, burn, vitrify, or vaporise wastes. Many of the radioactive contaminants that would be released are then captured in the treatment plant off-gas systems and become secondary wastes. Depending on the technology, the typical products from thermal processes should be capable of being disposed without any significant further treatment.
The thermal technologies considered in this study were metal melting, incineration, plasma arc processing, and vitrification.

- **Metal melting** – This works on the principle that when metal is melted, different radionuclides will migrate to the slag, to metal ingots or off-gases, depending on the properties of the element. This partitioning effect, potentially when combined with the co-treatment of higher activity (*discrete item*) metal with lower activity metal, would give rise to metal ingots that can be re-used or could be disposable.

- **Incineration** – This involves an exothermic reaction process which uses heat and oxygen to destroy or transform waste through combustion. The process produces ash containing the radionuclides that cannot be treated in the off-gas system.

- **Plasma arc processing** – This uses an electric arc to generate temperatures in excess of 20,000 °C. This causes the molecular structure of the wastes to break down and form a granular slag. Glass frit can be added to the feedstock to produce a vitrified wasteform.

- **Vitrification** – In this case the feedstock is combined with glass forming compounds at a high temperature to produce a solution of radionuclides within a molten glass matrix. This would then be poured into a container to form a monolithic block.

![Figure 5: A metal melting facility (left) [15] and an incineration facility (right) [16]](image)

![Figure 6: Plasma arc processing (left) [17] and in-container vitrification (right) [18]](image)
3.4. Other management approaches

This subsection covers a range of other, more operational approaches for the management of discrete items. These comprise diverting the wastes that would conform with the definition of a discrete item, or breach discrete item numerical limits to another disposal facility or to a decay store.

- **Disposal elsewhere** – In this case the discrete items would be taken either for near-surface disposal in a purpose-built disposal facility\(^5\) or for disposal in a Geological Disposal Facility (GDF), as currently planned in England and Wales for the disposal of higher activity wastes.

- **Decay storage** – Here the discrete items would be taken for storage in a suitable facility, with the intention that they would be retrieved at a later date, when their activity levels have decayed sufficiently, so that they conform with the discrete item limits or if other management routes that are available.

![Figure 7: A geological disposal facility (left) [19] and a decay storage facility (right) [20]](image)

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\(^5\) The disposal facility at Dounreay does not specify limits for discrete items, so it could, in theory, accept these types of waste as long as they conform to the other WAC for this facility. However, it is recognised that the use of the Dounreay facility is strictly limited by Scottish Government policy and the Environmental Authorisation for the Dounreay facility to wastes arising from Dounreay or MoD Vulcan; and as such there is no latitude to the use of this facility for such wastes arising elsewhere in the nuclear industry.
4. Assessment criteria and methodology

The aim of this study was to identify technologies or management approaches that would provide a credible means of treating LAW items that arise for disposal, that breach the physical form criteria of a discrete item and/or exceed the numerical discrete items limits. Hence, the assessment performed in this study evaluated whether an identified potential solution ‘could’ be used for treating at least one of the identified waste groups.

Having identified a long list of potential treatment or management solutions, screening criteria were applied to eliminate the options that were unlikely to be feasible against a certain waste group. The identified assessment criteria were:

1. Effectiveness (waste group-specific)

   This criterion evaluated how effective an identified treatment technology was likely to be against each of the waste groups that have been defined in Section 2. This was a high level (or preliminary) screening criterion such that, if a technology was found to be ineffective against discrete items within a specific waste group, it was assigned a score of red and therefore no further assessment of that technology against that waste group was required.

2. Nature and disposability of resulting product

   This criterion provided a measure of the disposability of the product arising from the treatment of discrete items within a waste group, using a specific technology. The governing issue here was whether the product remained a discrete item after processing and/or would require further treatment prior to disposal.

3. Impact on worker and environmental safety from technology use

   This criterion provided a measure of whether a technology could be operated safely within a specific waste group, in the context of both workers and the environment. This highlighted any safety concerns that were judged to be too challenging to manage satisfactorily, e.g. as to whether there were ALARP issues.

4. Nature and disposability of secondary wastes

   This criterion provided a measure of the quantity of secondary wastes that may arise when the technology was applied against a certain waste group, and also the challenges that would need to be overcome to treat any secondary waste produced, before it could be safely managed or disposed.

5. Preliminary technology readiness

   This criterion provided a measure of the stage of development of a given technology, and whether it has developed sufficiently to be employed at an industrial scale for nuclear decommissioning or in another regulated industry.
6. **Availability to the UK industry**

The criterion reflected whether a given technology for the purpose of treating items of radioactive waste is available to the UK nuclear industry now or will be available in the very near future (within 5 years).

The assessment to identify credible options for treating *discrete items* was carried out using a Red, Amber, and Green (RAG) scoring system. How these colours were defined for this assessment against each criterion is presented in Table 3.

The assessment was carried out by evaluating the performance of each technology against each waste group for each criterion in turn. The logic adopted was that a technology would be retained for the next stage of the evaluation unless it was assigned a red score against any criterion (for any waste group), in which case it was screened out entirely and not considered further. Technologies that were assigned green or amber scores were carried forward as credible options, but at this stage no ranking assessment of the options themselves was undertaken.

In order to provide background and to facilitate the main assessment of the options, which was undertaken within a workshop attended by relevant topic experts, the project team undertook and presented the outcome of a preliminary assessment, which was intended to be provisional in nature. Participants at the main assessment workshop included representatives from waste producers, LLW Repository Ltd, NDA and RWM. This allowed for different aspects, opinions and experiences, (reflecting technical, programmatic and strategic issues), to be captured within the assessment.
Table 3: Assessment criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Green</th>
<th>Amber</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness against waste groups</td>
<td>The technology is effective against the waste group.</td>
<td>There are some uncertainties or concerns regarding the effectiveness of the technology against the waste group.</td>
<td>The technology is not effective against the waste group.</td>
</tr>
<tr>
<td>Nature and disposability of resulting product</td>
<td>The product is no longer a discrete item. The product can be directly disposed at the LLWR without further processing.</td>
<td>The product may be disposed at the LLWR if some further treatment is carried out and this is an established route or process for disposal.</td>
<td>The product fails LLWR’s WAC and cannot be disposed. The product would require extensive further treatment prior to disposal and/or the treatment method cannot be used routinely.</td>
</tr>
<tr>
<td>Impact on worker and environmental safety from technology use</td>
<td>There are no safety concerns with this technology, and its use is consistent with the ALARP principle.</td>
<td>There are some safety concerns regarding the use or operation of the technology, but these could potentially be resolved without requiring disproportional effort to do so. The technology is consistent with the ALARP principle.</td>
<td>There are major safety concerns regarding the use or operation of the technology that are not possible to resolve without requiring disproportional effort to do so. The technology is not consistent with the ALARP principle.</td>
</tr>
<tr>
<td>Nature and disposability of secondary wastes</td>
<td>Trivial quantities of secondary wastes would be produced by the technology, which are easy to manage.</td>
<td>Non-trivial quantities of secondary wastes would be generated by the technology, which can be managed in an appropriate manner.</td>
<td>Considerable quantities of secondary wastes would be produced, and/or would be difficult to manage.</td>
</tr>
<tr>
<td>Preliminary technology readiness</td>
<td>The waste treatment technology is in use in the nuclear industry.</td>
<td>The waste treatment technology has been used outside the nuclear industry and therefore may need some R&amp;D to adapt it for use within it.</td>
<td>No operational experience with the technology for waste treatment inside or outside the nuclear industry.</td>
</tr>
<tr>
<td>Availability to the UK</td>
<td>The waste treatment technology is available within the UK on an industrial scale.</td>
<td>The waste treatment technology is not yet available within the UK on an industrial scale but could be easily transferable or otherwise implemented.</td>
<td>The technology is not available within the UK and for a period of time that is regarded as unacceptable to the waste producer.</td>
</tr>
</tbody>
</table>
5. **Assumptions**

A number of assumptions were made in order to identify credible options for the treatment of wastes failing the *discrete item limits*. These are listed as follows:

- For the purposes of the assessment exercise, it was assumed that the waste being evaluated had been adequately characterised and that it falls within the definition of a *discrete item* as laid out in the relevant sections of the WAC documentation; and

- It was assumed that there are no other WAC which may preclude disposal of a *discrete item* after treatment (for example, shredding a cemented drum of waste with hazardous properties might allow it to meet the discrete item WAC but it might still breach a hazardous materials WAC).

6. **Credible options assessment**

A summary of the assessment of credible options is presented in Table 4. Sections 6.1 to 6.3 describe the findings of the assessments by waste group. Appendix 3 contains the full assessment tables.

<table>
<thead>
<tr>
<th>Technology group</th>
<th>Technique</th>
<th>Waste group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Metals: simple geometries</td>
</tr>
<tr>
<td>Size reduction: Shredding</td>
<td>Shredding</td>
<td>retain</td>
</tr>
<tr>
<td></td>
<td>Jaw crusher</td>
<td>eliminate</td>
</tr>
<tr>
<td></td>
<td>Supercompaction</td>
<td>eliminate</td>
</tr>
<tr>
<td>Size reduction: Mechanical cutting</td>
<td>Circular saw</td>
<td>eliminate</td>
</tr>
<tr>
<td></td>
<td>Wire saw</td>
<td>retain</td>
</tr>
<tr>
<td></td>
<td>Reciprocating saw</td>
<td>retain</td>
</tr>
<tr>
<td>Size reduction: Thermal cutting</td>
<td>Torch cutting</td>
<td>retain</td>
</tr>
<tr>
<td></td>
<td>Plasma cutting</td>
<td>retain</td>
</tr>
<tr>
<td></td>
<td>Laser cutting</td>
<td>retain</td>
</tr>
<tr>
<td>Decontamination</td>
<td>Chemical</td>
<td>retain</td>
</tr>
<tr>
<td></td>
<td>Physical</td>
<td>retain</td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>Metal melting</td>
<td>retain</td>
</tr>
<tr>
<td></td>
<td>Incineration</td>
<td>eliminate</td>
</tr>
<tr>
<td></td>
<td>Plasma arc processing</td>
<td>retain</td>
</tr>
<tr>
<td></td>
<td>In-container vitrification</td>
<td>retain</td>
</tr>
<tr>
<td>Other</td>
<td>Disposal elsewhere</td>
<td>retain</td>
</tr>
<tr>
<td></td>
<td>Decay storage</td>
<td>retain</td>
</tr>
</tbody>
</table>
### 6.1. Metals with simple geometries

Table 5 provides highlights from the assessment for Waste group 1: Metallic waste objects with simple geometries and accessible surfaces.

Table 5: Highlights from the assessment for Waste group 1: Metals with simple geometries

<table>
<thead>
<tr>
<th>Waste group 1: Metals – simple geometries, accessible surfaces</th>
<th>Technique</th>
<th>Assessment highlights</th>
</tr>
</thead>
</table>
|                                                               | Shredding | • Widely used to reduce large metal items to metallic scrap, a variety of designs being available.  
• Can be operated remotely using automatic feeding systems, reducing the risk, but the maintenance may be complex. |
|                                                               | Jaw crusher | • Will not be effective against metallic waste with simple geometries as the waste could merely become distorted (thus retaining its properties as a *discrete item*) or if small enough, to fall through the exit opening of the crusher. |
|                                                               | Supercompaction | • Unable to compress items of the size and thickness considered in this waste group. |
|                                                               | Circular saw | • Cannot cut metallic components of significant thickness (i.e. above 0.6 cm), so it is not expected to be effective for this waste group. |
|                                                               | Wire saw | • Can be used to cut metals of substantial thickness (has been used to cut metal/concrete building structures, submarines and shipwrecks).  
• Requires cooling fluid (gas or water) which will become contaminated and will pose containment challenges.  
• Contaminated coolant and used wires will have to be managed as secondary wastes. |
|                                                               | Reciprocating saw | • Capable of cutting metallic items of significant thickness (*i.e.* up to ~13 cm).  
• Small quantities of secondary wastes.  
• Usually used as hand-held equipment. This may expose the operator to additional safety risks (contamination, conventional risks). |
|                                                               | Torch cutting | • Can only be used to cut ferrous metals, mild and low-alloy steels up to 6 cm thick. Cannot usually cut stainless steel or aluminium as they will not readily oxidise.  
• Can be easily used on site because the equipment is light and it doesn’t need a power source.  
• If hand-held, workers are exposed to contaminated items and at risk of conventional injury.  
• Small quantities of secondary wastes. |
|                                                               | Plasma cutting | • Can cut electrically-conductive metals with thicknesses up to 5 cm.  
• If hand-held, workers are exposed to contaminated items and at risk of conventional injury.  
• Produces large quantities of contaminated aerosols and sparks and suitable containment could be required. |
### Waste group 1: Metals – simple geometries, accessible surfaces

<table>
<thead>
<tr>
<th>Technique</th>
<th>Assessment highlights</th>
</tr>
</thead>
</table>
| Laser cutting                    | • Can cut metals with thicknesses up to 2 cm.  
• Light equipment that can be easily used on site.  
• If hand-held, workers are exposed to contaminated items and at risk of conventional injury.  
• Small quantities of secondary wastes. | |
| Chemical decontamination         | • Can be used for the reduction of radioactive contamination from the surface or surface layers of the metal.  
• The process should result in surface-decontaminated metal which would no longer breach the *discrete item* radioactivity limits.  
• Gives rise to acids or other liquids containing radioactive contaminants. | |
| Physical decontamination         | • Effective for decontaminating the surface of the metal waste.  
• Secondary wastes may include metal swarf, crud and any contaminated cooling liquids used. Waste generated could be in category of ILW. | |
| Metal melting                    | • May require that the metal waste is size-reduced, segregated and/or decontaminated before melting.  
• Will result in metal ingots with reduced activity which may be suitable for free release or recycling into nuclear industry products.  
• Secondary wastes include contaminated slag and spent filters and scrubbers from the treatment plant off-gas system. | |
| Incineration                     | • Not effective for the treatment of these type of metals as they are non-combustible. | |
| Plasma arc processing            | • Can only treat scrap and not bulk metal.  
• The molten metal will form a distinct layer which will have to be assessed against the *discrete items limits* when disposed.  
• Although proven in the nuclear industry overseas, facilities are not available in the UK. | |
| Vitrification                    | • Can only treat scrap and not bulk metal.  
• The waste will need to be size reduced to fit in the sacrificial box and after treatment it will melt into a separated layer.  
• Secondary wastes include spent filters and scrubbers from the treatment plant off-gas system. | |
| Disposal elsewhere               | • Waste would need to comply with the facility requirements, including packaging.  
• A disposal facility for wastes not suitable for near-surface disposal is not currently available in the UK. | |
| Decay storage                    | • May be suitable for reducing activity of metals, but may require a long storage period.  
• May be suitable for reducing the activity of metals to within *discrete item limits*, but may require a long storage period.  
• Decay stores are used in other countries, and although a specifically designed decay store does not exist in the UK, waste is currently stored on sites. | |
6.2. Metals with complex geometries

Table 6 presents highlights from the assessment for Waste group 2: Generally, these are larger and more robust metallic objects than those in Waste group 1 with complex geometries and inaccessible surfaces.

Table 6: Highlights from the assessment for Waste group 2: Metals with complex geometries

<table>
<thead>
<tr>
<th>Waste group 2: Metals – complex geometries, inaccessible surfaces</th>
<th>Assessment highlights</th>
</tr>
</thead>
</table>
| Shredding | • Can effectively shred metal waste with more complex geometries to metal scrap.  
• Requires appropriate containment and characterisation of internals.  
• Maintenance may be complex.  
• Potential for non-trivial quantities of secondary wastes. |
| Jaw crusher | • Incapable of size-reducing more resilient metallic objects with complex geometries. |
| Supercompaction | • Unable to compress items of the size and thickness considered in this waste group. |
| Circular saw | • Suitable for thin metals only, not items identified in this waste group. |
| Wire saw | • Can be used to cut metals of significant thickness and geometries into segments, which should no longer constitute discrete items.  
• Requires adequate characterisation of internals, otherwise making ALARP case would be difficult.  
• Secondary wastes include used cutting wires, filters from containment and potentially coolant if used. |
| Reciprocating saw | • Capable of cutting metals of thickness up to 13 cm.  
• Requires adequate characterisation of internals, otherwise making ALARP case is difficult. |
| Torch cutting | • Can cut ferrous metals, mild and low-alloy steels up to 6 cm thick. Cannot usually cut stainless steel or aluminium.  
• Requires adequate characterisation of internals, otherwise making ALARP case would be difficult.  
• Flexible technology as the equipment is relatively lightweight and doesn’t require a power source. |
| Plasma cutting | • Can cut metals of thicknesses up to 5 cm.  
• Requires adequate characterisation of internals, otherwise making ALARP case would be difficult.  
• The technology permits great accuracy on where to position the cuts, so a cutting plan can be made for an efficient cutting of items with complex geometries.  
• It would produce larger quantities of secondary waste than the other thermal cutting technologies discussed here. |
| Laser cutting | • Can cut metals with thicknesses up to 2 cm.  
• Also requires adequate characterisation of internals, otherwise making ALARP case would be difficult.  
• Flexible technology that allows cutting on site as the equipment is light and easy to use. |
## Waste group 2: Metals – complex geometries, inaccessible surfaces

<table>
<thead>
<tr>
<th>Technique</th>
<th>Assessment highlights</th>
</tr>
</thead>
</table>
| Chemical decontamination | • Proving the degree of decontamination of the internal surfaces may be difficult for complex geometries.  
• Risks to workers will depend on the chemical agents used.  
• Secondary wastes include contaminated agents, acids, etc. |
| Physical decontamination | • Cannot decontaminate internal inaccessible surfaces.                                                                                                                                                                   |
| Metal melting          | • May require that the item is size reduced, segregated and/or decontaminated before the main treatment step and to make sure that any internal voids are accessed.  
• The resulting products are metal ingots that could be recycled.  
• Internal voids present a safety risk but managed through pre-treatment such as size reduction.  
• Secondary wastes include contaminated slag and spent filters / scrubbers. |
| Incineration           | • Not effective for the treatment of bulk metal waste.                                                                                                                                                                   |
| Plasma arc processing  | • Can only treat scrap metal, so the waste would need to be size reduced first.  
• The metal will melt and form a distinct layer which has to be assessed against the discrete items limits prior to disposal.  
• Internal voids present a safety risk but managed through pre-treatment such as size reduction. |
| Vitrification          | • Can only treat scrap metal. Waste will need to be size reduced to fit into the sacrificial box.  
• Molten metal will form a distinct layer within the sacrificial box which has to be assessed against the discrete items limits prior to disposal.  
• Secondary wastes include spent filters and scrubbers from treatment plant off-gas system. |
| Disposal elsewhere     | • May require size reduction first, depending on the disposal container and the facility requirements.  
• A disposal facility for wastes not suitable for near surface disposal is not currently available in the UK. |
| Decay storage          | • May be suitable for reducing activity of metals, but may require a long storage period.  
• May be suitable for reducing the activity of metals to within discrete item limits, but may require a long storage period.  
• Decay stores are used in other countries, and although a specifically designed decay store does not exist in the UK, waste is currently stored on sites. |
### 6.3. Cemented drums

Table 7 presents highlights from the assessment for Waste group 3: Cemented drums.

#### Table 7: Highlights from the assessment for Waste group 3: Cemented drums

<table>
<thead>
<tr>
<th>Waste group 3: Cemented drums</th>
<th>Assessment highlights</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technique</strong></td>
<td><strong>Assessment highlights</strong></td>
</tr>
</tbody>
</table>
| **Shredding** | • Can be effective for cemented drums.  
• Rubble would be produced from the cement and scrap metal from the drum.  
• Filters from the containment system would probably arise as secondary waste, along with worn cutting wheels and other contaminated equipment parts.  
• Available in the UK, but not routinely used for cemented drums. |
| **Jaw crusher** | • Expected to be effective for crushing cemented drums. If there are cemented items inside the drum, they are expected to become exposed when the drum gets crushed.  
• Filters from the containment system would probably arise as secondary waste, as well as jaw plates and other contaminated equipment parts.  
• Used in the mining industry but not in nuclear decommissioning. |
| **Supercompaction** | • Not effective for compacting cemented drums. |
| **Circular saw** | • Not effective for cutting cemented drums, as the drum thickness is too great. |
| **Wire saw** | • Effective for cutting cemented drums as the technique can be used to cut very thick metal and concrete.  
• Would produce segments of cemented drums and depending on the sizes of the segments, the waste could become loose waste.  
• If there are cemented items inside the drum, the waste would need to be suitably characterised. |
| **Reciprocating saw** | • Not effective for cutting cemented drums, as the drum thickness is too great. |
| **Torch cutting** | • Not effective for cutting cemented drums, as the technique is designed for cutting metals. |
| **Plasma cutting** | • Not effective for cutting cemented drums, as the technique is designed for cutting metals. |
| **Laser cutting** | • Not effective for cutting cemented drums, as the technique is designed for cutting metals. |
| **Chemical decontamination** | • Not effective for decontaminating cemented drums as this is a surface only decontamination method. |
| **Physical decontamination** | • Not effective for decontaminating cemented drums as this method is only applicable for treatment of surfaces. |
| **Metal melting** | • Not effective for cemented drums, as the technique is designed for metals. |
| **Incineration** | • Incineration is not effective for treatment of cemented drums. |
## Waste group 3: Cemented drums

<table>
<thead>
<tr>
<th>Technique</th>
<th>Assessment highlights</th>
</tr>
</thead>
</table>
| Plasma arc processing | • The technique should work in principle, as it is used to treat drums of waste.  
• Internal voids would present a safety risk.  
• Secondary wastes include filters and scrubber solutions. |
| Vitrification         | • The technique should work in principle, as it is used to treat concrete and drums of waste.  
• Secondary wastes include filters and scrubber effluents.  
• Inactive and active commissioning has been completed at Sellafield. Small-scale trials have been carried out on cemented drums. |
| Disposal elsewhere    | • May require size reduction as a pre-treatment, depending on the disposal container and the facility requirements.  
• A disposal facility for wastes arising from the general nuclear industry not suitable for disposal at the LLWR is not currently available in the UK. A new facility (whether centralised, near-site or on-site) would be required. |
| Decay storage         | • May be suitable for reducing activity of cemented drums, but may require a long storage period.  
• Reductions in the activity levels within materials would need to be monitored.  
• Decay stores for wastes in the region of the boundary between the UK-defined categories of ILW and LLW exist elsewhere in Continental Europe. Waste producers in the UK currently store wastes on site. |
7. Gap analysis

This section is intended to identify any gaps or research and development needs that became apparent during the assessment that may preclude or impact on the applicability of the technologies for the waste groups. Six of the options were assessed as being credible options for all three waste groups, namely shredding, wire saw cutting, plasma arc processing, vitrification, disposal elsewhere, and decay storage. These technologies and methods can be used to treat all waste identified in the inventory, but some uncertainties regarding their applicability were uncovered during the course of the work so further trials, as described below, may need to be performed before the conclusions can be confirmed.

Shredding is a technique that is being widely used outside the nuclear industry for the management of metallic waste of different sizes and geometries. It has also been used in the nuclear industry for treating soft LLW. In the nuclear industry, its suitability for the treatment of thicker metallic waste or waste with complex geometries has yet to be established with certainty, so further trials are considered to be appropriate.

Wire saw cutting can be used to segment metal and concrete waste of any thickness. However, there are some uncertainties regarding the resulting product. If the resulting product is in the form of ‘slices’ of concrete these could still be considered discrete items, but it is expected that a cutting plan could be prepared to avoid the issue, basically by size reducing the generated segments further, via additional cutting or shredding.

Plasma arc processing and vitrification both emerged as potentially promising technologies. However, as these technologies have only been used previously for scrap metal, so further research and development would need to be carried out to prove their suitability for bulk metal and cemented drums.

Decay storage is another promising option for all three waste groups, which could be used to reduce the activity of discrete items to within the relevant limits or until ‘other’ (unspecified) management routes become available. Although a purpose-built decay store does not currently exist in the UK, current waste stores could potentially be used to reduce the activity of short-lived wastes to meet the discrete item limits.

The Disposal elsewhere option (other than to the LLWR) also performed favourably in the assessment. However, this is significantly disadvantaged by the fact that no reliable date is currently available for when a GDF or alternative near-surface disposal facility may be expected to become available within the UK.

Another concern that would require further analysis to resolve satisfactorily is that some technologies could merely lead to the production of waste in a form that would still qualify as a discrete item. For example, the glass ‘block’ produced from vitrification could be considered a discrete item. If these products breach the discrete item limits, it would be necessary to subject them to further treatment such as size reduction (e.g. shredding) before they could be accepted for final disposal at the LLWR.
8. Conclusions

This study develops a list of credible options which might be used for the management of items of waste that would be categorised as a discrete item in the LLW Repository Ltd WAC, or exceed the relevant numerical limits specified for such items. It is intended to form the basis for more detailed assessments at a later stage if this is deemed appropriate.

For this study an inventory was provided based on information from waste producers. The inventory has been divided into three main waste groups:

1. Metals with simple geometries and predominantly accessible surfaces;
2. Metals with complex geometries and inaccessible surfaces;
3. Cemented drums.

Evaluation of the inventory data, specifically generated for this study, has shown that there is a lack of characterisation for many of the items in the inventory that have been defined as discrete items. It is likely that when these items are more adequately characterised, a significant proportion may be found to be outside the definition of wastes failing the discrete item limits and therefore to be suitable for disposal without further treatment. Conversely, it is possible that ongoing characterisation of wastes will identify other waste items, and different populations of different waste types, that do not comply with the discrete item limit.

As shown in Table 8 below, there are a number of credible options identified for each waste group.

For the treatment of the items of metallic waste in the inventory that would qualify as wastes failing the discrete item limits, a number of treatment options have been identified, with physical decontamination emerging as only applicable to metallic items that have simple geometries.

The assessment has showed that metallic items with more complex geometries and internal voids would be more challenging to treat. If some form of size reduction is to be considered for treating such items, the balance between the detriments and benefits of doing so would need to be understood as part of an ALARP assessment. Such an assessment would in turn need to be informed by characterisation information on such items that is more reliable than currently available. A similar caveat would also hold for thermal treatments if applied to such items. In this case size reduction would also be required to ensure that features such as internal voids would be breached and any surface activity within them characterised before the application of high temperatures as a failure to do so could lead to additional safety risks.

For the cemented drums group, fewer technologies were identified as being credible. From the assessment, these wastes could be size-reduced by shredding, jaw crushing and wire saw cutting. In theory, plasma arc and vitrification have potential of treating these types of waste but further trials would be necessary in order to establish if these treatment techniques are practical. Another credible management approach for cemented drums that could facilitate their eventual disposal at the LLWR would be to decay store them until an ‘other’ option of treatment or
alternative disposal route is available. Disposal to a facility other than the LLWR remains a potentially credible option for all wastes that qualify as *discrete items*, recognising that such a facility does not exist in the UK at present.

Six of the treatment options are able to treat all of the waste types identified in the inventory, namely shredding, cutting with a wire saw, plasma arc processing, vitrification, disposal to a non-LLWR facility, and decay storage pending final disposal at the LLWR.

Three technologies were not found to be effective against any of the waste groups: supercompaction, cutting with a circular saw and incineration. Accordingly, these were eliminated from further consideration at the next stage of the options assessment within which the positive and negative aspects of each of the options will be compared to identify the optimal approach for treating each waste type.

**Table 8: Summary of assessment of credible options**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Metals: simple geometries</th>
<th>Metals: complex geometries</th>
<th>Cemented drums</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shredding</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Jaw crusher</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Supercompaction</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Circular saw</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Wire saw</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Reciprocating saw</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Torch cutting</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Plasma cutting</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Laser cutting</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Chemical</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Physical</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Metal melting</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Incineration</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Plasma arc processing</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Vitrification</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Disposal elsewhere</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Decay storage</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

✓ technology credibly applicable to a specific waste group

X technology not credibly applicable to a specific waste group
9. Next Steps

The report will be submitted to the NDA and published on the LLW Repository website. It will be used to provide supporting information for discussions and meetings held by the National Programme and the Problematic Waste Integrated Project Team as part of its governance arrangements.

To ensure that progress is maintained on the identification and implementation of approaches for the management of waste which fails the discrete item limit, additional workscope is required by the Problematic Waste IPT, the National Waste Programme and relevant stakeholders:

- Work be undertaken to ascertain whether other populations of potential waste failing the discrete item limit (such as durable hard plastics) identified during the stakeholder workshop pose a waste management challenge for waste producers. If so, the credible options for the management of these additional waste populations should be identified.

- Optioneering be undertaken to identify the preferred option(s) for the management of the waste failing the discrete item limit populations covered by the credible options studies.

- The wastestreams be included in ongoing work by the Near-Surface Disposal Integrated Project Team as a potential population of interest.

- A watching brief on the industry is required by the Problematic Waste IPT and the National Waste Programme to keep abreast of the changes in the inventory of this wastestream, and to ensure that any overarching optioneering remains current and relevant.
10. References


11. [http://guelphweddingshop.blogspot.co.uk/](http://guelphweddingshop.blogspot.co.uk/) accessed 04/11/16


Appendix 1: Inventory

Inventory data on *discrete items* were provided to Amec Foster Wheeler by LLW Repository Ltd. The inventory contained data on 74 waste streams and presented some information regarding the waste stream, waste description, volumes, current or future arisings, proposed management routes, and why the waste is believed to be a *discrete item*. However, detailed information was lacking in many of the areas and it was clear that many of the wastes have, to date, not been fully characterised. Further characterisation would be required before any technology could be identified for a number of the wastes in the inventory. It is possible that adequate characterisation would demonstrate that a significant proportion of the inventory would no longer be considered to be a *discrete item*.

To facilitate the assessments undertaken here, the inventory was divided into three distinct waste groups. These are presented in Table A1-1. Note that 12 of the 74 streams were initially categorised into a fourth group: Sources. It was decided at a project workshop held on 20 October 2016 that these are outside the scope of this study as LLW Repository Ltd has separate waste acceptance criteria for sources. Table A1-2 indicates the number of waste streams falling into each of the groups and their quantities.

### Table A1-1: Discrete item waste groups

<table>
<thead>
<tr>
<th>No.</th>
<th>Waste group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Metals – simple geometries</td>
<td>Framework, bars, plates, containers, skips, trolleys, rams and bogies, magazine bodies</td>
</tr>
<tr>
<td>2</td>
<td>Metals – complex geometries</td>
<td>Pipework, pumps, flowmakers, crane parts, filters, heat exchangers</td>
</tr>
<tr>
<td>3</td>
<td>Drums containing cemented waste</td>
<td>Cement-encapsulated water treatment sludges and filters encapsulated in concrete</td>
</tr>
</tbody>
</table>

### Table A1-2: Waste group quantity data (to the nearest tonne or cubic metre)

<table>
<thead>
<tr>
<th>No.</th>
<th>Waste group</th>
<th>No. of streams</th>
<th>Total weight (t)</th>
<th>Total volume (m³)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Metals – simple geometries</td>
<td>40</td>
<td>259</td>
<td>185</td>
</tr>
<tr>
<td>2</td>
<td>Metals – complex geometries</td>
<td>19</td>
<td>47</td>
<td>34</td>
</tr>
<tr>
<td>3</td>
<td>Drums containing cemented waste</td>
<td>3</td>
<td>310</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>62</strong></td>
<td><strong>616</strong></td>
<td><strong>421</strong></td>
</tr>
</tbody>
</table>

* Metal volumes were calculated assuming a metal density of 1.4 t/m³

Figure A1-1, Figure A1-2
Figure A1-3A1-3 give key summary information on the volume distribution, weight distribution and source organisations of the waste groups.

The group with the largest volume is Group 3, ‘Drums containing cemented waste’, which are primarily cement-encapsulated water treatment sludges in nominal 230-litre mild-steel drums from AWE. This group also includes metal gauge filters encapsulated in concrete from Sellafield.

The significant number of metal waste streams was split into two sub-groups, based on their physical differences:

- Group 1: Simple geometries; and
- Group 2: Complex geometries.

A description of the materials that make up each metal group is provided in Table 1. All metals arise from Sellafield, with Group 1, ‘Metals – Simple geometries’, being the largest in number, weight and volume.

![Volume distribution by waste group (in cubic metres)](image)
Figure A1-2: Weight distribution by waste group (in tonnes)

Figure A1-3: Discrete items by source organisation
Shredding

Shredding is a technique that involves the use of mechanical equipment to reduce the size of a range of materials, including metals [1].

The shredding process is well proven in non-nuclear industries, especially in the recycling industry. Shredders are used to reduce the size of metals, plastics, aluminium, scrap cars as well as waste materials such as municipal solid wastes.

In the nuclear industry, shredding is a widely applied technology for volume reduction of LLW, and is typically used as a pre-treatment technique before incineration [2], compaction or disposal. With the development of the shredding technology for larger items such as cars, opportunities may be present for application to larger metallic items.

Shredders come in many different variations and sizes. The capacity of the shredder is defined by the feeding system and the cutting system. The cutter wheels intermesh and tear apart the waste which is trapped between the wheels and cut to the size of the clearance between the wheels. Large capacity shredders often use hammer-mills for size reduction.

The shredder’s feeding system can be manual (waste is fed by hand into the shredder) or automatic (waste is fed by a conveyer). The waste does not need any pre-treatment before being shredded.

The shredders can be equipped with different types of cutting systems (horizontal shaft, vertical shaft, single-shaft, two-shaft, three-shaft and four-shaft cutting systems). The advantage of multi-shaft systems is that secondary shredding can take place in one step as the input material circulates around the interlocking wheels, further reducing the size of the waste.

The discharged material then drops into a container. Between the shafts/cutting wheels and the container, a mesh can be placed to provide a screen and limit the size of items produced as an output. In multi-shaft systems, the material that is not permitted through the mesh can re-circulate in the

cutting wheels and be further reduced in size.

Shredders can reduce the size of a variety of materials depending on the cutting system:

- A single cutter system is recommended for wood, paper, hard plastics, and brittle materials where small, uniform particle size is vital.
- A two-cutter system is recommended for metals, soft plastics, tyres, product destruction, or any diverse and contaminated materials where particle size variation is allowed.
- Three/four-cutter systems are specially suited for applications such as electronic scrap, tyres, big items, and other materials where a uniform, small to medium particle size is desired.
- Smaller-capacity shredders have a limited opening for feeding waste material and are not amenable to the feeding of boxed or bulky wastes. These are usually mobile shredders.

A high-capacity shredder is ideal for reducing the size of bulky waste containing metal and abrasives, for example steel drums (with or without contents), and engine blocks. These are usually fixed, low-speed, high-torque, multi-material shredders. Some materials that do not have angular features (such as drums), tend to float on the cutting wheels rather than pass through the shredder. For these items, a ram can be installed to help the shredder engage the material.

In some cases, the outputs of shredding are transported by conveyor directly to a secondary separation or sorting process. In a nuclear industry setting, this may allow for monitoring using mounted detectors, and potential for segregation systems if required.

Low speed shredders can reduce waste down to ~25-300 mm in size (depending on the shredder and the material), whereas high speed shredders can achieve 25 mm or less.

**Type of waste material that can be processed (input):**

- Dry solids such as rubber, plastics, wood, metal, concrete.
- Can process bulky items depending on the feeding and cutting systems.
- Can process heterogeneous items.

**Type of material produced by the process (output):**

- Size reduced waste with the size depending on the cutting system.
- Replacement parts for shredders become a secondary waste. Following decommissioning the cutting wheels will become secondary waste, as well as other parts that come into contact with the waste (e.g. feed conveyor belt, output container).

**Current practices in the UK or other countries:**

Shredding is a technique which has been used in the nuclear sector for LLW. Shredders can be purchased or leased for campaigns.

**Other comments:**

The cost of the process will depend on the size of the shredder and its speed (high-speed shredders are more costly).
Jaw crusher

A jaw crusher uses compressive force to break up rock, stone and other hard, brittle and tough materials. The mechanical pressure (compression) required to crush the rock is achieved by the two jaws of the crusher of which one is fixed while the other reciprocates.

A jaw crusher consists of a set of vertical jaws mounted in a “V” alignment; one jaw is kept stationary and is called the fixed jaw while the other jaw, the swing jaw, moves back and forth relative to it by a cam mechanism, acting essentially like a nutcracker. The volume or cavity between the two jaws is called the crushing chamber. The movement of the swing jaw can be quite small, since complete crushing is not performed in one stroke. The inertia required to crush the material is provided by a weighted flywheel that moves a shaft creating an eccentric motion that causes the closing of the gap. The rock remains in the jaws until it is small enough to pass through the gap at the bottom of the jaws [3]. Figure A2-2 shows a cross-sectional diagram of a jaw crusher.


Jaw crushers are run on belt drives driven by an electric motor or diesel engine. Jaw crushers are used extensively throughout the aggregate and mineral processing industry, for example, a jaw crusher is one of the primary crushers used in a mine or ore processing plant [4]. Fixed and mobile jaw crushers are available [5], as shown in Figure A2-3.

The size and capacity of a jaw crusher is determined by the feed opening. Jaw crushers can have a rectangular or square feed opening at the top of the jaws. Primary jaw crushers are typically of the square opening design, while secondary jaw crushers are of the rectangular opening design. However, there are exemptions to this [6].

Figure A2-3: Examples of mobile (left) and stationary (right) jaw crushers

Jaw crushers are heavy duty machines and hence need to be robustly constructed. The outer frame is generally made of cast iron or steel. The jaws themselves are usually constructed from cast steel. They are fitted with replaceable liners which are made of manganese steel, or Ni-hard (a Ni-Cr alloyed cast iron).

In many cases, the size-reduced rock/stone produced by a jaw crusher is transported by conveyor directly to a secondary separation or sorting process. In a nuclear industry setting, this may allow for monitoring using mounted detectors, and potential for segregation systems if required.

The main advantages of jaw crushers are [4]:
- A heavy duty design;
- Long-life;
- Cost-effective;
- High productivity; and
- Standard replacement parts.

Type of waste material that can be processed (input):
- Rock, stone, rubble, blocks of concrete.
- Can process bulky solid items depending on the feed opening and adjustment setting.

Type of material produced by the process (output):
- Size reduced items with the size depending on the feed opening and adjustment setting.
- Replacement parts for jaw crushers would become a secondary waste. Following decommissioning, any parts that have come into contact with the waste could become secondary wastes.

Current practices in the UK or other countries:
Jaw crushers are routinely used in mining and ore processing plants. Jaw crushers can be purchased or leased for campaigns.

Other comments:
The cost of the process will depend on the size/capacity of the jaw crushe.
Supercompaction

Supercompactors are large, sophisticated systems (as shown by Figure A2-4). Larger systems are usually fixed (within a building) although smaller, mobile supercompactors are available in skid or trailer mounted configurations. Although they are available from suppliers, larger supercompactors are not generally bought 'off the shelf' because they may need to be configured for the particular type of waste requiring treatment.

Typically, a supercompactor consists of a vertical compaction unit with associated controls, and feed and removal systems for waste drums. The drums are fed from a roller conveyor to the compaction chamber below a hydraulic ram that exerts a compressive force typically in the range of 750–2200 t. Unlike a low-force compactor, in a supercompactor entire drums containing waste are crushed under a high force and turned into 'pucks'.

The pucks are removed from the supercompaction cell on a roller conveyor and then monitored, measured and wrapped if required. After this, the pucks are usually repackaged in large containers or boxes for transport/disposal.

![Figure A2-4: A high force compactor used for compacting drums of waste](image)

Elastic and brittle materials behave differently under compression. Elastic materials undergo plastic deformation and when the compressive force is released, they tend to expand again. This is referred to as 'spring back' and can reduce the overall efficiency. If there is a large amount of spring back, then the lid of a drum can be pushed open by the expanding waste. In contrast, brittle materials break into smaller pieces when compacted, filling the interstitial spaces between larger objects, and leading to a greater reduction in sizes. There is no 'spring back' from brittle materials. Hard, solid objects are not compactable and therefore need to be sorted from wastes in advance to avoid damaging the equipment.

Anti-spring back devices are required for drums to hold the material in its new configuration once it has been compressed. The choice of anti-spring back material is important because it must be able to withstand the force of the compactor.

Due to the high force used, large supercompactors are usually remotely operated and contained within buildings (or cells) fitted with high efficiency particle air (HEPA) filtration to avoid spreading any dust or vapour that may be expelled from the waste. Although wastes should nominally be dry (i.e. not sludges), residual water may be squeezed out of the wastes, and so the containment system will also need to provide for water collection.

Supercompaction can be used for a range of different solid wastes, such as paper, plastic, personal protective equipment (PPE), smaller metal objects (that may have already been size reduced), etc. It can also be used for some solid materials that would not be suitable for a low-force compactor, such as building rubble.

**Type of waste material that can be processed (input):**
- Solid wastes, such as paper, plastic, PPE and smaller metal objects.
- Can also process higher-density materials such as metal objects, bricks and rubble.

**Type of material produced by the process (output):**
- Pucks formed from the compressed steel drum and its contents.
- Secondary wastes include dust collected in HEPA filters and any liquids squeezed from the waste.

**Current practices in the UK or other countries:**
A commonly used and well developed technology. Many different designs of supercompactors are commercially available from a range of suppliers to suit different types and quantities of waste.

**Other comments:**
Compacted wastes, especially those with a high organic content, are likely to require further treatment (e.g. encapsulation in cement) to meet waste acceptance criteria for disposal.
Circular saws

Circular saws, also known as cold saws, use a round, toothed blade which rotates at high speed to cut materials (as shown in Figure A2-5 and A2-6). Different blades are available for different materials, including metals. The equipment can vary in scale from hand-held, to bench-mounted, to machine operated. The machinery is usually self-propelled, and can be powered pneumatically, hydraulically, or electrically. Small circular saws are used in a range of industries, including nuclear decommissioning, and are relatively inexpensive. The blade of the circular saw results in a straight and accurate cut. It is commonplace for circular saws, like other segmenting equipment, to be converted for use remotely. Variations of the circular saw design have also been developed to enable it to be used underwater, and there is some experience of deploying the saws into highly active fuel storage ponds on nuclear sites [8].

Figure A2-5: Example of a hand-held circular saw (Bosch GKS190 190mm) [9].

The circular saw is commonly applied in conjunction with a band saw for segmentation of metallic waste. The circular saw is used for removing the large items from their location and the band saw is used for further cutting. Circular saws use a flood coolant system to keep the saw blade teeth cooled and lubricated.

As a result of cutting metal, swarf is produced as secondary waste. It is paramount that this is collected to control contamination. Collection typically involves vacuuming the chips from the cut and collecting, filtering and recycling lubricants if they are used. During the size reduction of the Belgian Reactor 3, a suction system was used to remove swarf while cutting. However, due to blockages, it was found that placing a funnel and basket under the work area followed by suction to remove the swarf after cutting was effective.

The use of circular saws is commonplace and well understood. Blades for circular saws are available for cutting metal; however, compatibility with the circular saw machine is vital. When considering the blade for use in a circular saw, the following considerations should be taken:

- The size (diameter) of the blade;
- Material;
- Compatibility of waste material with saw;
- Tooth count;
- Tooth design and configuration;
- Environment of use (dry or wet cutting).

Additionally, some blades may be suitable for wet cutting only. In reference to the material that a saw blade can be applied to, thin walled materials typically refer to <6 mm, and thick walled materials typically refer to >6 mm, however this will vary between suppliers. The portable circular saws can typically cut 6 mm thick metal and use an aluminium catcher for collecting swarf.

**Type of waste material that can be processed (input):**

- Commonly, hand-held circular saws can cut steels, aluminium and non-ferrous metals of <6 mm thickness.
- Bench-mounted or machine operated saws can cut metals with thicknesses greater than 6 mm.

Type of material produced by the process (output):
- Size reduced metal items that are roughly cut.
- Secondary wastes include dust and metal swarf/flecks. The machine itself will become secondary waste.

Current practices in the UK or other countries:
- The technology is readily available and used extensively inside and outside of the nuclear industry.
- The use of remotely operated circular saws has been developed for nuclear power plant decommissioning (see Figure A2-6).

Other comments:
Hand-held circular saws are manual labour intensive and therefore require consideration of safety, noise, and vibration. However, the safety and performance aspects are well understood.
Wire saws

There are two variations of wire saws; continuous and oscillating. Continuous wire saws, also known as endless or loop wire saws, are forced around the system at a very high speed (~20m/s). Oscillating wire saws, also known as reciprocating or open end wire saws, use a continuous length of wire which is wound on to a cylinder. The cutting is the result of abrasion between the wire and the material rather than through teeth as would happen for saw blades. In comparison to saw blades, the kerf (the width of the saw cut) is small. The wires are often cooled using water and lubricated through addition of water or oil. Similarly, more advanced systems are able to incorporate liquefied gases such as CO₂ for cooling and cleaning of the wire during use. Cooling prevents wire breakage and promotes efficient cutting. The wire can be a single strand or could be several braided together, known as a cable.

The diamond wire saw

The diamond wire cutting process was originally developed for rock cutting in mining operations, and has been developed in this industry for over 30 years. A diamond wire saw typically uses a metal wire, impregnated with diamonds, or diamond impregnated beads [11], fitted to a continuous strand of string or rubber encapsulated steel wire, looped into the wire sawing machine and driven at high speed. The efficiency of the bead type of saw is defined by the bead density on the wire. The highest specification wires have ~53 beads per metre. Technology development has led to the application of this technique to underwater cutting of piping, concrete and metal structures. Diamond wire saws are typically powered by two hydraulic or electric motors. The support system can be free-standing or affixed to the structure that is being cut. Tension on the wire can be controlled by a torsion control and braking system. Pulleys can be attached to upward and downward support arms to facilitate different cutting angles, and to allow for effective ‘push’ or ‘pull’ cuts to be made. The ‘push’ and ‘pull’ approaches are illustrated in the Figure A2-7 below.

Figure A2-7: The ‘Pull’ (left) and ‘Push’ (right) cutting configurations.

In some cases, such as cutting through thick concrete structures which may include reinforcement bars, wire saws may be preferable due to the low vibration that is produced [12]. Diamond wire saws do not produce dust when water-cooled. It is common for a diamond wire saw to be bespoke. The

Simple design means that the saw can be compact and remotely operated. This can be used where access is restricted due to tight spaces, underwater, or in highly active areas.

Diamond wire saws have been used in the nuclear industry in the US and the UK on various decommissioning tasks. In the US, the technology was developed and deployed for use on several cutting tasks involving concrete and metal structures. The positive results of this work led to it being used for the decommissioning of the Tokomak Fusion Test Reactor (TFTR) for segmentation of the TFTR vacuum vessel [13]. In this work, the ‘pull’ cut approach was used to begin cutting operations and was typically used for 60% of the cutting area. The ‘push’ cut approach was used to complete the cutting and the final severing of the vessel.

Containment and contamination control is a key consideration in the use of wire saw cutting if producing dust or if liquid cooled. In the TFTR segmentation [13], these factors were addressed through the infill of the vessel with a low density concrete. This fixed contaminants, preventing the release of tritium from graphite tiles inside the vessel, and contributed to additional shielding from gamma radiation, as well as removing voids from the waste – a requirement for disposal.

A further relevant example of the deployment of diamond wire sawing is a contract under the Design Services Alliance to support development of an innovative solution to the disposal of skips from the First Generation Magnox Storage Pond at Sellafield. Due to the extremely high dose levels, this is required to be done semi-remotely. As part of this work, a cutting jig was designed and tested to section pond skips for flat packing [14], as well as a remotely operated system also being installed at Sellafield [15].

The guillotine saw

The guillotine saw involves a cutting jig that houses a reciprocating saw. Due to the restrictions of the cutting frame, the guillotine saw lends itself to cutting sections of long lengths of material such as pipes or bars. Its compact design means that it is mobile and used for the in situ cutting of pipes.

Although guillotine saws can cut a range of materials and are transportable, the limitation of the geometries that can be cut restricts their potential for application to the size reduction of large metallic items.

Type of waste material that can be processed (input):
Large items can be size-reduced including metals, concrete and stone.

Type of material produced by the process (output):
- Segmented input material.
- Secondary wastes include dust, contaminated water or gas, and contaminated wires.

Current practices in the UK and other countries:
The use of a cryogenically-cooled diamond wire saw has been demonstrated for the segmentation of

a large metallic vessel [13], and has been tested on the size reduction of nuclear fuel skips [14, 15].

**Other comments:**
There are advantages to the use of water for effective cooling, cleaning of the wires, and dust suppression, however, the control of the spray of water and collection of the waste water can be challenging. Liquefied gas is more expensive and does not contribute to dust control, but provides cooler cutting temperatures which may improve the performance of the wire and diamond beads. In the case of the TFTR decommissioning, a cryogenic gas was selected [13].
Reciprocating saws

Reciprocating saws achieve cutting through a push and pull movement (reciprocating) of a saw blade. The saws are capable of being applied to a range of materials, including metals, and are typically used for quick and rough cutting of thin pipes and frames. Figure A2-8 shows a hand-held reciprocating saw being used to cut a square steel tube.

![Figure A2-8: Image of a reciprocating saw being used to cut a square steel tube](image)

The reciprocating saw is commonly applied for the segmentation of metallic waste. It is a relatively inexpensive and common industrial tool used to cut all types of metal pieces with a hardened steel reciprocating saw blade [16]. Since the reciprocating saw uses a mechanical method to cut the metal, fire hazards are reduced and contamination control is easier. Reciprocating saws have low operating costs and high cutting speeds and can be used as either portable or stationary units. Some types can also be operated remotely. Air or electric motors may be used and the set-up time is relatively short.

![Figure A2-9: Example of a reciprocating saw (DeWalt DW311K-LX) [17]](image)

Designs range widely in power, speed, and features, from less powerful portable, handheld models that are usually shaped like a cordless drill, to high-power, high-speed, corded models designed for heavy construction and demolition work (see Figure A1-12). Modern reciprocating saws almost all

have variable speed, either through trigger sensitivity or through a dial. Variants and accessories are available for specialized uses, such as clamps and long blades for cutting large pipe.

Blades are available for a variety of materials and uses. Common types include metal cutting blades, wood cutting blades, blades for composites, for drywall, and other materials. Many of these blade types have a variety of tooth designs intended for special purposes, such as tree-limb cutting, demolition work, clean cutting, or contaminated materials. Abrasive coated blades are also available for hard materials like tile and stone.

As a result of cutting metal, swarf is produced as secondary waste. It is paramount that this is collected to control contamination. Collection typically involves vacuuming the chips from the cut and collecting, filtering and recycling lubricants if they are used.

Rolls-Royce has been involved in several nuclear decommissioning projects. In one such project, they developed an underwater reciprocating saw, which allowed the controlled cutting of components, by means of a system of automatically activated interlocks, on a stainless steel machine bed [18].

**Type of waste material that can be processed (input):**
Reciprocating saws can cut steels, aluminium and non-ferrous metals of <130 mm thickness.

**Type of material produced by the process (output):**
- Size reduced waste items that are roughly cut.
- Secondary wastes include dust and metal swarf/flecks. The machine itself will become secondary waste.

**Current practices in the UK or other countries:**
The technology is readily available and used extensively inside and outside of the nuclear decommissioning industry.

**Other comments:**
Usually, reciprocating saws are manual labour intensive and therefore require consideration of safety, noise, and vibration. However, the safety and performance aspects are well understood.

Torch cutting

Torch cutting is the most widely applied industrial thermal cutting process. The technique uses a torch assembly carrying a flowing mixture of fuel gas and oxygen which is ignited at the nozzle of the torch. The torch cutting equipment is low cost and can be used manually or adapted for remote (mechanised) use. There are several fuel gas and nozzle design options that can significantly enhance performance in terms of cut quality and cutting speed. The process can efficiently cut a variety of thicknesses up to 600 mm [19]. The cutting process is illustrated in Figure A2-10, with examples in Figure A2-11.

The cutting tip of the torch consists of a main oxygen jet orifice surrounded by a ring of pre-heater jets used to heat the metal to its ‘ignition’ temperature but below its melting point. When the metal reaches the ‘ignition’ temperature, the main oxygen jet is turned on, directed into the preheated area instigating a vigorous exothermic chemical reaction between the oxygen and the metal to form iron oxide or slag. The oxygen jet blows away the slag enabling the jet to pierce through the material and continue to cut through the material.

![Torch Cutting Process Diagram](image)

Only ferrous metals which oxidise readily can be cut using this process as oxidation of the metal being cut is required for the technique to work. Stainless steel, aluminium and other non-ferrous metals cannot usually be cut. However, iron or iron-aluminium powder in a flowing mixture can be introduced at the torch nozzle to increase the flame temperature sufficient to cut through non-ferrous metals [20].

This technique is often used underwater where safety controls are required to ensure no waste gas build up under nearby obstructions that then have the potential to explode.

Since the process gives rise to dust and aerosols, suitable ventilation, filtering and operator protection are required. Oxygen cutting is widely used in industry, and therefore skilled operators and good standard, inexpensive equipment is readily available. The equipment is also straightforward to set up.

**Type of waste material that can be processed (input):**
- Ferrous (iron-containing) metals, mild and low-alloy steels. Not aluminium or stainless steel.
- Types of ferrous metals that can be cut include simple geometries such as bars, plates, pipes with a bigger diameter, drums and tanks.

**Type of material produced by the process (output):**
- Smaller-sized metal pieces (the physicochemical characteristics of the metal are not affected).
- Secondary wastes include dust, aerosols, gases and sparks.

**Current practices in the UK and other countries:**
Torch cutting has been widely used as a cutting method outside the nuclear industry. It has also been used in nuclear decommissioning projects (e.g. the cutting of the reactor vessel of unit 2 of Zion nuclear power plant in the USA [21]).

**Other comments:**
If a HEPA filter ventilation system is used, metal ducting and a spark arrestor is required to draw smoke and sparks away, otherwise a fire could occur in the ventilation system due to the sparks.

Plasma cutting

Plasma arc cutting is a thermal cutting technique which is capable of cutting through electrically conductive materials and is an alternative to torch cutting. The process cuts any electrically-conductive metal (steel, aluminium, copper, stainless steel, etc.) of varying thicknesses (from <9 mm up to 50 mm [22]).

A direct current arc between an electrode and the conducting metal to be cut is established. The arc is established in a plasma gas that flows through an orifice in the torch nozzle. When used for cutting, the plasma gas flow is increased so that the deeply penetrating plasma jet cuts through the material. The molten material is removed in the efflux plasma. The technology requires a power supply. Although the operating voltage to sustain the plasma is typically 50 to 60 V, the open circuit voltage needed to initiate the arc can be up to 400 V DC [23].

The process is illustrated in Figure A2-12.

The process differs from torch cutting in that the plasma process operates by using the arc to melt the metal, whereas the torch cutting process uses oxygen to oxidise the metal and the heat from the oxidation reaction melts the metal. The plasma arc process can be applied to metals such as stainless steel, aluminum, cast iron and non-ferrous alloys.

The plasma arc equipment can be used manually or adapted for remote (additional specialised equipment is required) or even underwater operations. Process variants have been designed to improve the cut quality, cutting speed, arc stability, noise and fume reduction.

The advantages of using the plasma cutting process underwater are a reduced noise level, absorption of smoke and dust into the water, and metal cooling. However, a contaminated slag/sludge will accumulate as a secondary waste in the water tank.

The process generates large quantities of aerosols, smoke and dust with a large number of small size particles (less than 3 μm) [24]. As a result, when the process is applied in the nuclear industry, extensive containment is required to reduce the spread of particulate. Off-gas systems must also be considered. Prior to cutting, all surfaces should be decontaminated or cleaned to reduce the amount of airborne debris. If the process is operated manually, workers are required to wear protective equipment and an air-fed hood or an air-supplied respirator with a reserve bottle. If the process is being used underwater, the water should be filtered for better visibility.

**Type of waste material that can be processed (input):**
- Cuts any electrically-conductive metal such as steel, aluminium, copper, stainless steel, etc.
- It is suitable for smaller thicknesses.

**Type of material produced by the process (output):**
- Smaller-sized metal pieces (the physicochemical characteristics of the metal are not affected).
- Secondary wastes include radioactive airborne particulates, liquids and gases (depending on mode of use).

**Current practices in the UK and other countries:**
- Plasma cutting is widely used in fabrication and welding, automotive repair and restoration, industrial construction, salvage and scrapping operations.
- The process has been applied in the nuclear industry. For example, at the German Nuclear Power Plant (NPP) Gundremminge, a 5 mm thick stainless steel construction was cut using plasma arc underwater (at a water depth of 4 m) [25]. The thermal shield of NPP Rheinsberg, Germany was also cut using plasma arc underwater (water depth of 0.8 m).

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Laser cutting

Laser (Light Amplification by Stimulated Emission of Radiation) cutting is a widely used cutting process. It is typically used for industrial manufacturing applications. Laser cutting uses a focused laser beam to melt material in a localised area. When the laser beam strikes the work piece, it will heat it up to such an extreme temperature that it melts or even vaporises. Once the work piece is completely pierced, the cutting process can start. The laser beam is moved along the work piece melting the material as it goes. A gas jet is used to eject the molten material from the cut and leave a clean edge, as illustrated in Figure 2-14. Dross is the residue that is formed at the bottom of the cut work piece and is a form of re-solidified melt material.

![Illustration of the laser cutting process](image)

Laser cutting can be used on a variety of different materials such as acrylic, wood, paper, carbon steel and stainless steel (see Figure 2-15). The technique can cut the following metals at certain thicknesses: carbon manganese steels (up to 20 mm), stainless steel (up to 12 mm), aluminium (up to 10 mm), brass and titanium. Cutting aluminium and copper alloys requires a more powerful laser due to their high heat conductivity and light reflective properties.

The process is not generally considered suitable for use underwater, as the water would diffuse the laser beam.

Advantages of the process are that it produces a clean and fast cut. The process can also be easily automated or carried out remotely.

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[27] http://engineerstudent.co.uk/laser_cutting.html accessed 08/09/16
Type of waste material that can be processed (input):
- Solid metals such as mild steel, aluminium and stainless steel.
- It can be applied to sheets of materials, pipework or framework.
- It can cut complex geometries, but only with flexibility in where and how to cut the components.
- It can cut other materials such as titanium, paper, plastics, wood, fabrics, ceramics and concrete.

Type of material produced by the process (output):
- Smaller-sized pieces of waste.
- Secondary waste can include radioactive airborne particulate, with cutting waste mainly in the form of dust requiring vacuum extraction and filtering.

Current practices in the UK and other countries:
- Laser cutting is widely used in fabrication and welding shops, automotive repair and restoration, industrial construction, salvage and scrapping operations.
- Laser cutting technology is being used in the nuclear industry including decommissioning [28]. An automated laser cutting technique has been used at Hinkley Point A for dismantling steel Magnox pond skips in order to store the material more effectively [29].

Chemical decontamination

Chemical decontamination is the removal or reduction of radioactive contamination through a chemical process. It could potentially be used to divert wastes from LLW routes to VLLW routes. Secondary wastes will be produced with any method of decontamination, but these wastes should be easier to treat than the original waste depending on the nature of the process (it is recognised that the use of certain complexing and chelating agents may preclude disposability of such secondary waste to LLWR or GDF).

A wide variety of chemicals are used for decontamination of the various materials/surfaces found in nuclear facilities [30]. Decontamination agents range from nitric and hydrofluoric acids to a variety of organic complexing agents, such as citric acid, ethylenediaminetetraacetic acid, etc.

Mild chemical decontamination (e.g. detergents, creams, foams, dilute acids/alkalis) is used to decontaminate large flat pieces of metal on site, e.g. doors, pools, liners, reactor containment. It is easy to do and inexpensive but only removes loose contamination and has high secondary waste generation (reagents tend not to be reusable) [31]. It has generally been used for items where the main purpose is to remove contamination without attacking the base material.

Aggressive chemical decontamination (e.g. concentrated acids/alkalis, oxidising/reducing agents) is used to remove thin layers of metal surfaces and to decontaminate relatively complex components and geometries. It can remove highly contaminated surfaces, possibly to release limits, and is commercially available with low secondary waste production (if the reagent can be reused). Limitations are that dismantling/segmentation is required and there may be higher exposure to workers than from mild chemical decontamination. Figure A2-16 shows before and after images of stainless steel being decontaminated in an acid bath.

Electrochemical decontamination (electropolishing) is used for the decontamination of disassembled components, regular surfaces and localised ‘hot spots’. In principle, these are chemical processes assisted by the use of an electrical field. Electropolishing is a process widely used in different industrial applications to remove the surface layer and to produce a smooth, polished surface on metals and alloys. It can be considered to be the opposite of electroplating, as metal layers are removed from a surface rather than being added as a coating. It is a fast process with low volume of secondary waste production. However, it may not be effective for hidden surfaces having poor electrolyte contact and may lead to higher dose to workers.

[30] IAEA, Management of low and intermediate level radioactive wastes with regard to their chemical toxicity, IAEA-TECDOC-1325, 2002
Surface cleaning techniques (i.e. mild chemical decontamination) are used when contamination is limited to near surface material. Surface removal (i.e. aggressive chemical and electrochemical decontamination) is used when the contamination goes beyond the near surface and into the profile of the material.

**Type of waste material that can be processed (input):**
Inorganic solids, metals, concrete, equipment and components.

**Type of material produced by the process (output):**
- Decontaminated materials, potentially suitable for diversion to disposal routes for VLLW.
- Secondary wastes include liquids/acids containing radioactive contaminants from chemical decontamination.

**Current practices in the UK or other countries:**
- Decontamination techniques are widely used worldwide in the nuclear decommissioning industry.
- There are many chemical decontamination techniques available. Some techniques require more complex application procedures or require more development in order to allow their application.

**Other comments:**
There will only be a benefit from decontamination if it results in improved safety conditions or if the waste is moved from a higher category to a lower category: (i) conversion of ILW to LLW, (ii) decontamination for unrestricted release, or (iii) decontamination for reuse within the industry [33].

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accessed 12/09/16

Physical / mechanical decontamination

Physical decontamination is the removal or reduction of radioactive contamination by a physical process. Decontamination is carried out during nuclear decommissioning in several stages: before dismantling, after dismantling, and during decontamination of buildings.

Decontamination could potentially be used to divert wastes from LLW routes to VLLW routes. Secondary wastes will be produced with any method of decontamination.

Physical or mechanical decontamination methods can be classified as either surface cleaning or surface removal:

- Surface cleaning techniques are used when contamination is limited to near surface material;
- Surface removal is used when the contamination goes beyond the near surface and into the profile of the material.

Mechanical decontamination may be used as an alternative, employed simultaneously or sequentially with chemical decontamination. When dealing with porous surfaces, mechanical methods may be the only option. As with chemical decontamination, the selection of the most effective technique depends on many variables, such as the contaminants involved, surface material and cost. Figure A2-17 shows a trolley mounted floor decontamination system which uses a high pressure water jet for the mechanical cleaning of plant floors, walls and components, among other things.

![Image of a trolley mounted floor (mechanical) decontamination system](image)

Physical decontamination methods for metal and concrete include vacuum cleaning; brushing, washing and scrubbing; high pressure water/steam lance; abrasive blasting; ultrasonic cleaning; shaving/grinding; drilling and spalling; high pressure jet spalling; and hydraulic hammering [35].

Mobile mechanical decontamination systems include CO₂ blasting, grit or sand blasting, plastic or glass bead blasting, water blasters and water jetting [34].

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[34] IAEA, Mobile Processing Systems for Radioactive Waste Management, Nuclear Energy Series NW-T-1.8, 2014
As these techniques are so versatile, it may be advantageous to locate a centralised decontamination facility on site in which one or more of these techniques may be used. Such a facility could then be used to decontaminate dismantled or segmented components.

Disadvantages of mechanical methods are that (i) they require that the surface is accessible, and (ii) if the necessary precautions are not taken, many methods produce airborne dust. Containment may therefore be required for worker safety and to prevent the spread of contamination.

**Abrasive blasting decontamination systems**

A wet abrasive blasting system is a closed loop, liquid abrasive decontamination technique. The system uses a combination of water, abrasive media and compressed air and is normally applied in a self-contained, leakproof, stainless-steel enclosure. There is no danger of airborne contamination as a self-contained air ventilation system with an absolute filter maintains negative pressure inside the cabinet. Radioactive waste is mechanically separated from the cleaning media, e.g. by cyclone/centrifuge separation, sieving. Water can be filtered and recycled; no soluble or hazardous chemicals being required. Wet abrasive cleaning is being used in many nuclear facilities to remove smearable and fixed contamination from metal surfaces such as structural steel, scaffolding, components, hand tools and machine parts. The equipment can be used on components such as turbine blades or valves where the removal of metal is not desired, or it can be adjusted to remove high levels of corrosion and paint by varying the air pressure and the amount of abrasive media.

The dry abrasive blasting technique, commonly termed sand blasting and abrasive jetting, has been commonly used in non-nuclear industries. This technique, which uses abrasive materials suspended in a medium that is propelled onto the surface being treated, results in the uniform removal of surface contamination. Compressed air or blasting turbines are normally used to carry the abrasive. Removed surface material and abrasive are collected and placed in appropriate containers for treatment and/or disposal. Recirculation of abrasives allows the generation of secondary wastes to be minimised. Dry abrasive blasting is applicable to most surface materials except those that might be shattered by the abrasive, such as glass or Plexiglas. Its use on aluminium or magnesium should also be avoided owing to the risk of dust explosions. It is most effective on flat surfaces, and because the abrasive is sprayed, it can also be used on ‘hard to reach’ areas.

**Type of waste material that can be processed (input):**
Inorganic solids, metals, concrete, equipment and components.

**Type of material produced by the process (output):**
- Decontaminated materials, potentially suitable for diversion to routes for VLLW.
- Secondary wastes from mechanical decontamination include liquids/water containing radioactive contaminants and swarf/crud/fines.

**Current practices in the UK or other countries:**
- Decontamination techniques are widely used worldwide in the nuclear decommissioning industry.
- There are many decontamination techniques available. Some techniques require more complex application procedures or require more development in order to allow their industrial application.

**Other comments:**
There will only be a benefit from decontamination if it results in improved safety conditions or if the waste is moved from a higher category to a lower category: (i) conversion of ILW to LLW, (ii) decontamination for unrestricted release, or (iii) decontamination for reuse within the industry [36].

Metal melting is a means of reducing the size and overall volume of the metal prior to disposal. Melting can be used to decontaminate metal so that the clearance and exemption limit of the processed metals is achieved and the metal can be considered to be ‘non-radioactive’. This means it does not need to be disposed of in a radioactive waste repository [37].

Metal melting (as illustrated in Figure A2-18) works on the principle that when metals are melted, the radioactive isotopes are re-distributed to either the slag, the metal ingots, or the off-gases, depending on the properties of the element. Cs-137, H-3 and I-129 are removed to the off-gas due to their volatility and are trapped in filters. Transuranic elements are typically transferred to the slag. Metallic elements (and their radioisotopes) remain in the melt, for example Co-60. The metallic radioisotopes are typically distributed homogenously throughout the ingots that are produced from the metal melt. The slag is separated from the molten metal before it cools and solidifies, allowing it to be segregated [38].

After cooling, the ingots are monitored to ensure their radioactivity content is below clearance levels before being released for reuse in the conventional (non-nuclear) scrap metal market. The separated slag containing the radioactivity, is also cooled and solidified, and kept separate for further management as radioactive waste.

Figure A2-18: Example of metal melting facility [39]

Metal melting tends to be used for steels, but it can also be applied to other metals such as aluminium, copper, brass and lead.

Metal melting facilities tend to be commercially operated as they are large and expensive. They require a large throughput of metal to provide the economies of scale to be profitable. Use of the facilities may require exporting the radioactive slag metal back to the consignor.

Metal melting can be used to process large items. For example, whole steam generators from decommissioned Magnox reactors in the UK have been exported to Sweden as complete units for

[37] IAEA, Innovative waste treatment and conditioning technologies at nuclear power plants, IAEA-TECDOC-1504, 2006
[39] Studsvik Waste Treatment Facility, 26th March 2008,
melting. They are transported whole because the unit provided containment during transport. These were then size reduced by cutting (for example wire saw or mechanical nibbler) before melting. For large items such as pipework and some furniture, melting would be suitable where another size reduction process such as cutting is used first to create a transportable unit before being melted.

The metal melting process is commonly used for LLW. However, metal melting facilities can be licensed for ILW processing. Facilities designed to process ILW metals require substantially greater investment in off-gas systems to filter and abate atmospheric discharges.

The primary benefit of metal melting comes from achieving the clearance and exemption limits so the processed metal can be deemed 'non-radioactive'. This product can then be re-used.

If it were found that significant activity from the relevant inventory could not be removed by metal melting, there may be the potential to couple the process with another pre-treatment process such as milling (where the surface layer is removed) prior to melting. This is particularly applicable as the activation of steel in skips is expected to be within ~1.5 mm of the metal surface [40].

However, there may be benefits to melting even if the result was a product which was still considered to be radioactive and required disposal. The removal of voidage and production of a manageable shape would make disposal in standard containers potentially more practical.

**Type of waste material that can be processed (input):**
Stainless steel, carbon steel, aluminium, lead, copper, brass and other metals. LLW and ILW metals. Metals that are either contaminated or activated.

**Type of material produced by the process (output):**
- Cleared 'non-radioactive' metal.
- Contaminated slag.
- Secondary wastes include spent filters and scrubbers, etc.

**Current practices in the UK or other countries:**
- Metal melting is a proven technology, and several commercially operated facilities are available to nuclear operators in Europe and the USA.
- The viability of the process depends on the quantity of metal to be processed, the cost-benefit and ALARP arguments from coupling with another process if the necessary levels of activity could not be removed by metal melting.

**Other comments:**
All metals may potentially be treated by melting but the advantage comes when the metal can meet the clearance and exemption limits and be considered 'non-radioactive' but this depends on the initial radioactivity content. This would need to be evaluated on a case-by-case basis before the method is adopted, and application of another technology would need to be assessed, both in terms of ALARP and cost-benefit.

Incineration

Incineration is the most commonly used thermal treatment process. In simple terms, it involves burning combustible waste in an enclosed chamber (furnace) in the presence of air at a temperature in the range 800-1000 °C. Some incinerators also introduce gas or oil fuel to enhance combustion [41].

In theory, incineration can be used to volume and weight reduce any combustible materials, both solid and liquid (e.g., oils), and can be used for LLW and ILW, although ILW treatment is complex due to the need for remote handling and shielding. Incineration also destroys hazardous organic compounds and flammable solvents in the waste [42].

Incineration is widely used on an industrial scale for non-radioactive municipal and industrial wastes. The main components of an incinerator, as illustrated in Figure A2-19, are:

- a waste receipt and storage area, with capabilities to sort and blend materials;
- the combustion chamber;
- an off-gas filter system; and
- an ash removal system.

![Figure A2-19: Incineration system block diagram [41]](image)

Incinerators are available in a range of sizes, from large industrial units to small, mobile units that can be taken to a site for temporary use. A number of commercial incinerators are licensed to burn limited amounts of radioactive wastes in some countries (e.g., the UK). Small-scale incinerators specifically for burning radioactive wastes have been installed on some nuclear sites.

Incinerators licensed for radioactive wastes use an enclosed main (primary) combustion chamber and a secondary combustion chamber to complete destruction of the organic compounds in the off-gases from the primary chamber. The system is usually operated at a slight negative pressure to induce airflow. Off-gas systems are required to filter and scrub any radioactive and hazardous combustion

gases, and entrained particulates (e.g. HCl, HF, SO₂, NOₓ, heavy metals). Typical off-gas treatment systems are the combination of a scrubber, electrostatic precipitator and HEPA filters. Monitoring and treatment of the off-gas will be required.

The efficiency of an incinerator depends largely on the calorific value of the waste. To achieve complete combustion of the organic portion of the waste, the main requirements are adequate reaction temperature, sufficient air supply and an adequate combustion time.

The main solid by-product of incineration is ash. This comprises the non-combustible components of the waste. The amount of ash produced depends on the waste material and how heterogeneous it is. The ash is collected and can be immobilised, usually by mixing with cement, to produce a solid wasteform. If the waste contains any fissile material, care must be taken to maintain containment of particulates and ensure criticality control.

**High temperature incineration**

A conventional incinerator is a self-sustaining process, because only combustible wastes are treated and at temperatures of around 1000 °C. With high temperature incineration (HTI), a powerful burner is installed which employs fuel and mostly pure oxygen as a combustion gas. Operating temperatures can exceed 1500 °C; therefore, the waste feed can contain some proportion of non-combustible material, such as metal, air filters and insulation material.

**Type of waste material that can be processed (input):**
- Dry solid wastes, ion exchange resins, organic liquids (e.g. oils and solvents) and aqueous liquids.
- The HTI waste feed can contain some proportion of non-combustible material, such as metal, air filters and insulation material.

**Type of material produced by the process (output):**
- The primary output is flue ash and bottom ash that collects in the base of the incinerator. This ash is often more compatible with downstream management steps (e.g. immobilisation) than the original waste.
- HTI produces a glass-like granulate.
- Secondary wastes include used filters and scrubber materials from the off-gas systems. Central components of the incinerator are likely to become waste when the facility is decommissioned.

**Current practices in the UK or other countries:**
Incineration is a well-proven technology with incinerators being used in the UK and overseas to treat radioactive waste.

**Other comments:**
- Ash can be compacted as solid waste or melted, alone or together with other residues, and stored as solid waste.
- Scrubbers can be cemented and stored as solid waste or dried in a fluidizing bed reactor and the resulting granulate melted together with the ashes or other incineration residues.
- The installation costs for HTI are relatively high, and HTI can also be seen as a precursor to plasma technology systems. The higher temperature plume of a plasma torch (of 5000 °C or more) eliminates the waste feed limitations for HTI.
Plasma arc processing

Plasma arc processing is a technique that uses an electric arc to generate temperatures in excess of 20,000 °C. This extreme temperature causes the molecular structure of materials to be broken into their constituent atoms [43].

The electric arc can be generated by a conventional plasma torch (used in many industrial processes, e.g. metal cutting, metallurgical application, vitrification of fly ash from municipal incinerators) or by one or more graphite electrodes. Plasma sources provide deep thermal conversion to produce an end product in the melted state. The off-gases contain increased concentrations of radioactive particles and nitrogen oxides compared to lower temperature thermal methods and hence require more advanced off-gas systems. There are two main plasma torch types [44]:

- **Transferred torches**, where the plasma torch transfers electrical energy from the anode to the molten slag which serves as the cathode. By this principle, the energy is transferred directly into the waste material to be heated (for example as illustrated in Figure A2-20).
- **Non-transferred torches**, which contain two metallic tubular electrodes separated by a gas injection chamber. An electrical arc flows between the negative and positive electrodes and hence the gas flow injected into the downstream electrode is ionised. The result is a high temperature gas flow coming from the downstream electrode in a plasma jet.

![Figure A2-20: Illustration of the plasma plant at the ZWILAG Facility, Switzerland](image)

The waste feed can include not only solid organic waste, such as paper, wood, plastics and rubber, but also inorganic and mixed/metallic materials such as debris, soil, scrap metal, thermal insulating materials and glass. The percentage of inorganic materials in the total waste volume can be as high as

100% depending on the waste origin and composition. The vaporisation conditions can be changed by using a reducing plasma gas instead of an oxidising one [45].

The resulting vapour phase is passed through an afterburner or catalytic converter for complete oxidation, followed by appropriate treatment of the off-gas. The molten residues (metal and/or slag) which contain most of radioactivity are transferred into an external vessel and cooled. In general, they form solid phases which are deemed to be directly suitable for storage and disposal. Direct vitrification of the slag by the addition of glass frit into the crucible during treatment may yield a wasteform with enhanced properties (such as reduced radionuclide leaching rates).

Depending on the nature of the off-gas treatment system, the process will lead to the production of some secondary waste, such as HEPA filters or aqueous solutions, which might require subsequent treatment.

The technique has been applied in various forms for the destruction of problematic chemical waste and extended to LLW. The first full-scale plasma plant for processing LLW, at the ZWILAG facility in Switzerland, became operational in 2004 and has operated successfully since then [46]. It runs two 10-week campaigns per year (this is due to the limited waste generation volume and is not a technology restriction). The process permits both the processing of combustible materials and the melting of metallic parts, concrete and other solid matter. It can also be used to vitrify organic and inorganic matter.

Another full-scale plasma facility is ordered for the Kozloduy NPP site in Bulgaria [47]. The facility consists of a tilting plasma furnace equipped with a 500 kW non-transferrable torch as the heat source and it will treat 250 tonnes of waste per year, spread over 40 operational weeks. The waste types to be treated include: organic waste in bags, pre-compacted waste (mixture of organic/inorganic in 200 L steel drums), supercompacted waste (organic, wood, concrete), liquids such as oils, spent resins, and intermediate level waste (Category 2a).

**Type of waste material that can be processed (input):**
- Inorganic and mixed solid wastes such as debris, soil, scrap metal, thermal insulating materials and glass.
- Organic solid wastes such as paper, wood, plastics and rubber.
- Organic liquid wastes may also be treated by injection into the stream of plasma gas or simultaneously with solid waste in the primary reaction chamber.

**Type of material produced by the process (output):**
- The end product is a solid, glass-like material packed in metal or ceramic containers and suitable for direct disposal without any further treatment.
- The radioactive materials are immobilised.
- The end product has a very high mechanical and chemical durability exceeding the equivalent properties of the glass matrices.

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Current practices in the UK or other countries:
Plasma arc processing plants are currently in operation in Europe, including the ZWILAG facility in Switzerland, the Pluton industrial-scale plant in Russia [48], and the Plasma Melting Facility (PMF) at the Kozloduy NPP site in Bulgaria (under construction).

Other comments:
- Volume reduction factors range from 6 (typical ZWILAG results) for waste containing mostly metals and debris to 10 for treatment of mixed waste (typical Pluton results) and to more than 100 for primarily organic waste [49].
- Lifecycle costs are high for plasma technology compared to other thermal methods.
- As it is a complex technology, the preference would be to have a fixed installation, as mobile operations are not currently considered to be feasible.

In-container vitrification

The GeoMelt® system solidifies wastes into a glass matrix batch-by-batch. This provides flexibility in terms of the waste feed and also lowers the total lifecycle cost for waste treatment [50].

GeoMelt® uses electric current to melt glass former to produce glass, as illustrated in Figure A2-21. During the melt, hazardous wastes are destroyed from exposure to high temperatures, and radioactive isotopes are captured into a glass matrix (as shown in Figure ). The GeoMelt® container is selected so that, after the melt, the glass within the container can be directly stored or disposed.

Unlike conventional vitrification technology, which requires a homogeneous waste feed, GeoMelt® can process various forms of waste simultaneously, and can use liabilities such as contaminated soils and inorganic ion exchange media as glass formers. It can also treat radioactively-contaminated asbestos.

GeoMelt’s® batch-treatment process delivers the following benefits:

- Ability to customise the glass formulation and melting temperatures for a specific waste.
- Reduction in the amount of pre-treatment.
- An increase in waste loading capacity.
- Large volume reductions.
- Significant reduction of maintenance costs.

Kurion partnered with the UK’s National Nuclear Laboratory (NNL) to install a GeoMelt® plant at the Sellafield site to evaluate the technology for problematic waste streams that currently have no path to disposal. Cold and active commissioning of the full-scale demonstration GeoMelt® ICV plant was recently completed at Sellafield, with the first commercial vitrification of radioactive waste being performed in July 2016 [51].

GeoMelt® vitrification technology has also been applied for the bulk vitrification of LLW at Hanford site, USA (a full-scale GeoMelt® plant) [52], and at a hazardous and toxic waste treatment facility in Mie Prefecture, Japan [53].

**Type of waste material that can be processed (input):**
- Can simultaneously process mixed organic, inorganic and radioactive contaminants.
- Can accommodate a wide range of mixed wastes, including drums, scrap metal, concrete, boulders, asphalt, wood, plastic, asbestos-contaminated material, soils and sludges [54].
- Effective for a wide range of contaminants such as pesticides, herbicides, PCBs, dioxins, asbestos, arsenic, mercury, lead, and mixed transuranic wastes.

**Type of material produced by the process (output):**
A glass matrix containing the radionuclides.

**Current practices in the UK or other countries:**
- Cold and active commissioning has been completed for the GeoMelt® ICV plant at Sellafield.
- GeoMelt® has also been deployed at sites in the USA, Australia and Japan.

**Other comments:**
GeoMelt® has produced 26,000 tons of glass in the USA, UK, Japan and Australia since the 1990s.

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Disposal elsewhere

The IAEA defines disposal as [55]:

*The emplacement of waste in an appropriate facility (e.g. near surface or geological repository) without the intention of retrieval.*

The primary distinction between disposal and storage is the phrase “without the intention of retrieval”. If waste retrieval is intended, then it is “long-term storage” or “interim storage”.

The approvals required for the disposal of radioactive wastes are granted by regulatory authorities and/or government agencies in individual countries. There are currently a number of organisations around the world which operate licensed disposal facilities for radioactive wastes. There are also a number of national and/or regional organisations that are actively seeking to develop disposal facilities [56].

**Geological disposal**

UK Government policy is to manage higher activity radioactive waste in the long-term through geological disposal. This is to be implemented alongside ongoing interim storage and supporting research [57].

A GDF, as illustrated in Figure A2-23, is a highly-engineered facility capable of isolating radioactive waste within multiple protective barriers, deep underground, to mitigate the threat of human intrusion and to manage the environmental impact of the waste. It will provide a permanent solution to the UK’s existing higher activity radioactive waste (including anticipated waste from a new build programme).

![Figure A2-23: Illustration of a GDF][57]

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Near-surface disposal

The Scottish Government policy is that the long-term management of higher activity radioactive waste should be in near-surface facilities. Facilities will be located as near to the sites where the waste is produced as possible [57].

Near-surface facilities could include earthen trenches for the disposal of solid waste, above-ground engineered structures, engineered structures just below the ground surface and rock caverns, silos and tunnels excavated at depths of up to a few tens of metres underground. It is generally accepted that near-surface facilities such as these are suitable for the disposal of VLLW, LLW and some ILW, but not ILW that will not decay to safe levels over a period of a few hundred years, or HLW, as both are deemed unsuitable for near-surface disposal [58].

![Image](https://www.sckcen.be/en/Technology_future/Radioactive_waste/Surface_disposal)

Figure A2.24: Illustration of a near-surface disposal facility for short-lived ILW being developed by ONDRAF/NIRAS [59]

Type of waste material that can be processed (input):
LAW and HAW packaged for disposal.

Type of material produced by the process (output):
Dispositioned wastes.

Current practices in the UK or other countries:
- The only GDF currently in operation for HAW is the Waste Isolation Pilot Plant (WIPP) in New Mexico, USA.
- Near-surface disposal facilities are located in Scotland, France, Finland, Sweden, Spain, Japan, Hungary, Belgium, Slovenia and the USA [60].

Decay storage

The IAEA defines storage as [61]:

The placement of waste in a facility where isolation, environmental protection and monitoring are provided. It is an interim activity with the intent that the waste will be retrieved at a later date for release from regulatory control or processing and/or disposal.

The primary distinction between storage and disposal is the phrase "with the intent that the waste will be retrieved at a later time". If waste retrieval is not intended, then it is disposal.

Radioactive wastes are typically stored for varying periods of time for one or more of the following reasons [62]:

- To allow for the decay of short-lived radionuclides to a level at which the radioactive waste can be released from regulatory control (clearance) or authorised for discharge, or recycling and reuse.
- To collect and accumulate a sufficient amount of radioactive waste prior to its transfer to another facility for treatment and conditioning (or until a processing method has been developed).
- To collect and accumulate a sufficient amount of radioactive waste prior to its disposal (or until a disposal facility has been constructed).
- To reduce the heat generation rate of HAW prior to its disposal and, in some cases, prior to steps in its predisposal management.
- To provide long-term storage of waste in those countries lacking a suitable disposal facility.

In this case, a decay store could be an option to reduce the radioactivity of an item of waste to below the discrete item limits, depending on whether the item is contaminated with activation products (short-lived) or fission products (long-lived). For example, an item contaminated with long-lived actinides may not be suitable for decay storage, but an item contaminated with short-lived radionuclides could be suitable for decay storage.

Figure A2-25 shows the storage building for ILW at the ZWILAG facility in Switzerland. The storage containers are filled with conditioned waste ready for final storage and are stacked one on top of the other in the storage shafts by remote control. The solid concrete lids covering the individual storage shafts are visible in the figure. The reception, unloading and storage areas are separate. There is a centralised inventory and careful inventories are also kept for each location and of the contents of each individual container. The condition of the stored casks and containers is also checked regularly.

Decay storage is a cost-effective way to manage short-lived LLW. Radioactivity reduces with time, and after 10 half-lives the level of radioactivity has reduced by a factor of 1,024, typically to near background levels. For the short-lived radioisotopes typically used in medicine and research, this storage period for complete decay may be only a few weeks to a few months. After this time, the waste is no longer radioactive and can be disposed of as conventional waste (taking into account any other hazards that the waste might pose, such as biological hazards). For other wastes, such as spent nuclear fuel, the decay storage period may be many hundreds of thousands of years, making decay storage unfeasible.

**Type of waste material that can be processed (input):**
Any wastes containing or contaminated with, activation products or short-lived radionuclides.

**Type of material produced by the process (output):**
Wastes that meet the discrete item limits.

**Current practices in the UK or other countries:**
There are storage facilities for LLW/ILW in a number of countries, including Germany, Switzerland, the Netherlands, Slovenia and Canada.

**Other comments:**
Decay storage is practiced in the international nuclear industry.

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Appendix 3: Assessment tables

WASTE GROUP 1: Metals – simple geometries and predominantly accessible surfaces (framework, boxes, plates, skips, trolleys, magazine bodies, rams and bogies)

<table>
<thead>
<tr>
<th>WASTE GROUP 1 Metals – simple, accessible</th>
<th>Effectiveness</th>
<th>Resulting product</th>
<th>Worker and environmental safety</th>
<th>Secondary wastes</th>
<th>Technology readiness</th>
<th>Availability to UK industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shredding</td>
<td>Three and four cutter systems can shred metal items effectively.</td>
<td>Metal scrap which will no longer constitute a <em>discrete item</em>.</td>
<td>Can be remotely operated with automatic feed systems. Appropriate containment would be required to ensure contamination control. Maintenance activities may be complex and demanding.</td>
<td>Filters from the containment system would probably be generated, along with secondary wastes from decontaminating the equipment after use. Possibly there would be a need to dispose of used cutting wheels.</td>
<td>Although widely used outside the nuclear industry for the management of metallic scrap it has not been deployed for the management of radioactive metals.</td>
<td>Technique is used in UK for the management of soft wastes.</td>
</tr>
<tr>
<td>Jaw crusher</td>
<td>Incapable of size reducing the generally smaller metallic objects within this category</td>
<td>Input items would probably undergo significant deformation, but would remain <em>discrete items</em>.</td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## WASTE GROUP 1

### Metals – simple, accessible

<table>
<thead>
<tr>
<th>Effective</th>
<th>Resulting product</th>
<th>Worker and environmental safety</th>
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<th>Technology readiness</th>
<th>Availability to UK industry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supercompaction</strong></td>
<td>Unable to compress items of the size and thickness considered in the inventory.</td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Circular saw</strong></td>
<td>Hand-held saws maximum cut depth in metal ca 0.6cm. Suitable for thin plate only, not items identified in inventory.</td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wire saw</strong></td>
<td>Can be used to segment materials of almost any thickness.</td>
<td>Metal scrap which will not constitute a discrete item, provided that an appropriate cutting plan can be developed.</td>
<td>Can be operated remotely, therefore conventional risks are low. If gas or water cooling is used for the cutting wire, containment may be more challenging than for dry cutting techniques.</td>
<td>Filters from the containment system would probably be generated, along with the need to manage contaminated coolant. Used cutting wires will require disposal.</td>
<td>Method used in nuclear decommissioning.</td>
</tr>
</tbody>
</table>
### WASTE GROUP 1
**Metals – simple, accessible**

<table>
<thead>
<tr>
<th>Effectiveness</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Reciprocating saw</strong></td>
<td>Capable of cutting steel, aluminium and non-ferrous metals of thickness up to 13 cm. May not be effective for largest items in the inventory.</td>
<td>Metal scrap which will not constitute a <em>discrete item</em> provided that an appropriate cutting plan can be developed.</td>
<td>Usually a hand-held technique, so operator would be exposed to contaminated items and be subject to risk of conventional injury.</td>
<td>Some dust and metal swarf produced, but quantities likely to be relatively small and straightforward to manage. Used blades will require disposal.</td>
<td>Method used in nuclear decommissioning.</td>
</tr>
<tr>
<td><strong>Torch cutting</strong></td>
<td>Can be used for cutting only ferrous metals, mild and low-alloy steels, up to 6 cm. Cannot be used to cut stainless steel or aluminium.</td>
<td>Metal scrap which will not constitute a <em>discrete item</em> provided that an appropriate cutting plan can be developed.</td>
<td>Produces sparks and aerosols so appropriate containment would be required. If used as hand-held, appropriate protection will be required as the operator will be exposed to risks (contaminated items, conventional injury). If cutting can be automated, risks to worker safety would be reduced.</td>
<td>Will generate dust, contaminated aerosols, gases and sparks, so the filters from the containment system together with any PPE, would become secondary waste.</td>
<td>Method has been used in nuclear decommissioning.</td>
</tr>
<tr>
<td>WASTE GROUP 1</td>
<td>Effectiveness</td>
<td>Resulting product</td>
<td>Worker and environmental safety</td>
<td>Secondary wastes</td>
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<tr>
<td>---------------</td>
<td>---------------</td>
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<td>---------------------------------</td>
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<td>-----------------------</td>
</tr>
<tr>
<td>Metals – simple, accessible</td>
<td>Can cut any electrically-conductive metals of thicknesses up to 5 cm.</td>
<td>Metal scrap which will not constitute a <em>discrete item</em> provided that an appropriate cutting plan can be developed.</td>
<td>Produces large quantities of sparks and aerosols so appropriate containment would be required. If using hand-held, appropriate protection is required (containment and ventilation system, protection equipment for the operator). If automated, the risks to the operator will be reduced.</td>
<td>Filters from the containment system would probably be generated, along with waste PPE if used.</td>
<td>Has been used in nuclear decommissioning.</td>
</tr>
<tr>
<td>Plasma cutting</td>
<td>Can cut any electrically-conductive metals of thicknesses up to 5 cm.</td>
<td>Metal scrap which will not constitute a <em>discrete item</em> provided that an appropriate cutting plan can be developed.</td>
<td>Produces large quantities of sparks and aerosols so appropriate containment would be required. If using hand-held, appropriate protection is required. If cutting is automated, reduces risk to worker safety.</td>
<td>Filters from the containment system would probably be generated, along with waste PPE if used.</td>
<td>Has been used in nuclear decommissioning.</td>
</tr>
<tr>
<td>Laser cutting</td>
<td>Can cut metals of thickness up to 2 cm.</td>
<td>Metal scrap which will not constitute a <em>discrete item</em> provided that an appropriate cutting plan can be developed.</td>
<td>Produces large quantities of sparks and aerosols so appropriate containment would be required. If using hand-held, appropriate protection is required. If cutting is automated, reduces risk to worker safety.</td>
<td>Filters from the containment system would probably be generated, along with waste PPE if used.</td>
<td>Has been used in nuclear decommissioning.</td>
</tr>
</tbody>
</table>
### WASTE GROUP 1

**Metals – simple, accessible**

<table>
<thead>
<tr>
<th>Effectiveness</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical decontamination</strong></td>
<td>Chemical decontamination can be used for reducing the activity of metallic wastes (by removal of a surface layer for surface contaminated metals).</td>
<td>The result is a surface decontaminated metal. If the activity is reduced sufficiently, the item will no longer breach the LLWR WAC discrete item limits.</td>
<td>The techniques may present some risks to worker safety, which would depend on the chemicals used and would require appropriate management.</td>
<td>Will give rise to liquids, which may be acidic, and which will contain radioactive contaminants.</td>
<td>Widely used in nuclear decommissioning industry.</td>
</tr>
<tr>
<td><strong>Physical decontamination</strong></td>
<td>The technique will decontaminate the surfaces of metallic objects. It will only be effective on accessible surfaces.</td>
<td>The result is a surface decontaminated metal. If the activity is reduced sufficiently, the item will no longer breach the LLWR WAC discrete item limits.</td>
<td>Some techniques will require cooling liquids. Airborne dust or contaminated cooling liquid may be produced with some methods. In both these cases safety precautions would be required and adequate containment may be more challenging to provide.</td>
<td>Any cooling liquids, which will become contaminated with metal swarf/crud, will form secondary waste. In some cases these may be in the category of ILW.</td>
<td>Widely used in nuclear decommissioning.</td>
</tr>
</tbody>
</table>
## WASTE GROUP 1
### Metals – simple, accessible

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Melting</td>
<td>The metal may need to be size reduced, segregated and/or decontaminated before melting.</td>
<td>Metal ingots with reduced activity content.</td>
<td>Contained system reduces worker safety risks.</td>
<td>The technology will give rise to contaminated slag, spent filters and scrubbers.</td>
<td>Melting of metallic wastes is a proven technology in the nuclear industry for LLW.</td>
</tr>
<tr>
<td>Incineration</td>
<td>Will involve very high temperatures and will only be practicable for small quantities of combustible metals.</td>
<td>Not assessed</td>
<td>Not assessed</td>
<td>Not assessed</td>
<td>Facilities are located in Continental Europe but not in the UK.</td>
</tr>
<tr>
<td>Plasma arc processing</td>
<td>Can only be used to treat scrap metal.</td>
<td>The treated metal will melt and form a separate layer.</td>
<td>Contained system reduces worker safety risks.</td>
<td>Spent HEPA filters and in some cases, aqueous solutions from off-gas system.</td>
<td>Plasma treatment is a proven technology in the nuclear industry.</td>
</tr>
<tr>
<td>Vitrification</td>
<td>Will require size reduction as a pre-treatment. Only suitable for scrap metal.</td>
<td>The waste would be vitrified into a sacrificial box. The metal melts and forms a separate layer at the base of the box.</td>
<td>Contained system reduces worker safety risks.</td>
<td>Scrub solution would be produced if wet scrubbing is used. Filters, which would be treated separately.</td>
<td>Has been deployed at nuclear sites in USA, Japan (active facility for hazardous waste) and Australia.</td>
</tr>
</tbody>
</table>
### WASTE GROUP 1
**Metals – simple, accessible**

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Disposal elsewhere</strong></td>
<td>Would be suitable if waste could not be managed in any other way. Waste items may require size reducing, depending on the disposal container.</td>
<td>Disposed metal waste, with additional packaging.</td>
<td>Disposal facilities should have high levels of worker and environmental safety.</td>
<td>Trivial in volume and nature.</td>
<td>Experience is available outside the UK.</td>
</tr>
<tr>
<td><strong>Decay storage</strong></td>
<td>May be suitable for reducing the activity of metal to below <em>discrete item limits</em>, but may require long storage period. This could involve leaving the waste materials at the site of origin.</td>
<td>Metallic waste with reduced activity.</td>
<td>Decay stores should have stringent worker safety procedures.</td>
<td>Trivial in volume and nature.</td>
<td>Decay stores for wastes in the region of the boundary between the UK-defined categories of ILW and LLW are located in countries such as Switzerland, Germany and Canada.</td>
</tr>
</tbody>
</table>
## WASTE GROUP 2: Metals – robust objects with complex geometries and inaccessible surfaces (pipework, pumps, flowmakers, crane parts, filters, heat exchangers)

<table>
<thead>
<tr>
<th>WASTE GROUP 2 Metals – complex, inaccessible</th>
<th>Effectiveness</th>
<th>Resulting product</th>
<th>Worker and environmental safety</th>
<th>Secondary wastes</th>
<th>Technology readiness</th>
<th>Availability to UK industry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shredding</strong></td>
<td>Three and four cutter systems can shred metal items effectively. For complex geometries, more powerful shredders may be required.</td>
<td>Metal scrap which will no longer constitute a <strong>discrete item</strong>.</td>
<td>Can be remotely operated with automatic feed systems. Appropriate containment would be required to ensure contamination control. Maintenance activities may be complex and demanding.</td>
<td>Filters from the containment system would probably be generated, along with, secondary wastes from decontaminating the equipment after use. Possibly there would be a need to dispose of used cutting wheels.</td>
<td>Technique is used in the UK for the management of soft wastes. Although widely used outside the nuclear industry for the management of metallic scrap, it has not been deployed for the management of radioactive metals.</td>
<td>Available in the UK.</td>
</tr>
<tr>
<td><strong>Jaw crusher</strong></td>
<td>Incapable of size reducing the more generally physically robust metallic objects within this category.</td>
<td>Input items would probably undergo some deformation, but would remain <strong>discrete items</strong>.</td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
</tr>
</tbody>
</table>

Jaw crusher

Incapable of size reducing the more generally physically robust metallic objects within this category.

Input items would probably undergo some deformation, but would remain **discrete items**.

Not assessed
### National Waste Programme

#### WASTE GROUP 2
*Metals – complex, inaccessible*

<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Supercompaction</strong></td>
<td>Unable to compress items of the size and thickness considered in the inventory.</td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Circular saw</strong></td>
<td>Hand-held saws maximum cut depth in metal ca 0.6 cm. Suitable for thin plate only, not items identified in inventory.</td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WASTE GROUP 2 Metals – complex, inaccessible</td>
<td>Effectiveness</td>
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</tr>
<tr>
<td><strong>Wire saw</strong></td>
<td>Can be used to segment materials of almost any thickness.</td>
<td>Metal scrap which will not constitute a discrete item provided that an appropriate cutting plan can be developed.</td>
<td>Can be operated remotely, therefore low conventional risks. If gas water cooling is used for the cutting wire, containment may be more challenging than for dry cutting techniques. Lack of characterisation of internals may make ALARP case difficult to establish.</td>
<td>Filters from the containment system would probably be generated, along with the need to manage contaminated coolant. Used cutting wires will require disposal.</td>
<td>Method used in nuclear decommissioning.</td>
</tr>
<tr>
<td><strong>Reciprocating saw</strong></td>
<td>Capable of cutting steel, aluminium and non-ferrous metals of thickness up to 13 cm. May not be effective for largest items in the inventory.</td>
<td>Metal scrap which will not constitute a discrete item provided that an appropriate cutting plan can be developed.</td>
<td>Usually a hand-held technique, so operator exposed to contaminated items and be subject to risk of conventional injury. Lack of characterisation of internals may make ALARP case difficult.</td>
<td>Some dust and metal swarf produced, but quantities likely to be relatively small and straightforward to manage. Used blades will require disposal.</td>
<td>Method used in nuclear decommissioning.</td>
</tr>
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## National Waste Programme

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</tr>
</thead>
<tbody>
<tr>
<td>Metals – complex, inaccessible</td>
<td>Can cut ferrous metals, mild and low-alloy steels up to 6 cm. Cannot be used to cut stainless steel or aluminium.</td>
<td>Metal scrap which will not constitute a <em>discrete item</em> provided that an appropriate cutting plan can be developed.</td>
<td>Containment for aerosols and sparks would be required. Can be operated remotely, therefore conventional risks are low. Lack of characterisation of internals may make ALARP case difficult.</td>
<td>Will generate dust, contaminated aerosols, gases and sparks, hence the filters from the containment system together with any PPE would also become secondary waste.</td>
<td>Method used in nuclear decommissioning.</td>
<td>Available in the UK.</td>
</tr>
<tr>
<td><strong>Torch cutting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasma cutting</td>
<td>Can cut electrically conductive metals of thicknesses up to 5 cm.</td>
<td>Metal scrap which will not constitute a <em>discrete item</em> provided that an appropriate cutting plan can be developed.</td>
<td>Produces large quantities of sparks and aerosols so appropriate containment would be required. Can be operated remotely, therefore conventional risks are low. Lack of characterisation of internals may make ALARP case difficult.</td>
<td>Filters from the containment system would probably be generated, along with waste PPE if used.</td>
<td>Has been used in nuclear decommissioning.</td>
<td>Available in the UK.</td>
</tr>
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</tr>
<tr>
<td>Laser cutting</td>
<td>Can cut metals of thickness up to 2 cm.</td>
<td>Metal scrap which will not constitute a discrete item provided that an appropriate cutting plan can be developed.</td>
<td>Containment system for aerosols is required. Can be operated remotely, therefore conventional risks are low. Lack of characterisation of internals may make ALARP case difficult.</td>
<td>Filters from the containment system would probably be generated, along with waste PPE if used.</td>
<td>Has been used in nuclear decommissioning.</td>
<td>Available in the UK.</td>
</tr>
<tr>
<td>Chemical decontamination</td>
<td>Achieving and demonstrating that decontamination of internal surfaces has been effective will be difficult for complex geometry metals.</td>
<td>Metals with decontaminated surfaces but potentially contaminated internals.</td>
<td>There may be risks to worker safety, depending on the chemicals/agents used.</td>
<td>Acids, liquids, etc. containing the radioactive contaminants.</td>
<td>Used in nuclear decommissioning.</td>
<td>Available in the UK.</td>
</tr>
<tr>
<td>Physical decontamination</td>
<td>Requires that surfaces are accessible and therefore hence will not be able to decontaminate internal surfaces.</td>
<td>Items with decontaminated surfaces but with internal contamination remaining untreated.</td>
<td></td>
<td></td>
<td></td>
<td>Not assessed</td>
</tr>
<tr>
<td>WASTE GROUP 2</td>
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<td>----------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Metals – complex, inaccessible</td>
<td>The metal may need to be size reduced and/or decontaminated as a first step and assurance provided that there are no internal voids that could retain activity.</td>
<td>Metal ingots with reduced activity content.</td>
<td>Metal ingots with reduced activity content.</td>
<td>Complex geometry metals with inaccessible voids present a safety risk (potential for explosion).</td>
<td>Method used in nuclear decommissioning.</td>
<td>The technology is not currently available in the UK but services overseas are available.</td>
</tr>
<tr>
<td>Melting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incineration</td>
<td>Not effective for the treatment of metals with complex geometries as it's only practicable for small quantities of combustible metals.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasma arc processing</td>
<td>Will require size reduction as a form of pre-treatment. Can only be used to treat scrap metal.</td>
<td>The molten metal will form a separate layer.</td>
<td>Lack of characterisation of internals may make ALARP case difficult.</td>
<td>Filters and aqueous solutions from off-gas system.</td>
<td>Used in nuclear decommissioning throughout Continental Europe.</td>
<td>Facilities exist in Continental Europe but not in the UK.</td>
</tr>
<tr>
<td>Vitrification</td>
<td>Will require size reduction as a pre-treatment. Only suitable for scrap metal.</td>
<td>The waste would be vitrified into a sacrificial box. The metal melts and forms a separate layer at the base of the box.</td>
<td>Lack of characterisation of internals may make ALARP case difficult.</td>
<td>Scrub solution, if wet scrubbing is used. Filters which would be treated separately.</td>
<td>Used in nuclear decommissioning in the USA, Japan and Australia.</td>
<td>Inactive and active commissioning completed at Sellafield.</td>
</tr>
</tbody>
</table>
### National Waste Programme

<table>
<thead>
<tr>
<th>WASTE GROUP 2</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Disposal elsewhere</td>
<td>May require size reduction, depending on the disposal container.</td>
<td>Disposed metal waste. Packaging requirements will need to be met.</td>
<td>Disposal facilities should have high levels of worker and environmental safety.</td>
<td>Secondary wastes are expected to be trivial and therefore not pose a problem.</td>
<td>Experience is available outside the UK.</td>
<td>No facility for waste that is unsuitable for near surface disposal currently exists in the UK.</td>
</tr>
<tr>
<td>Decay storage</td>
<td>May be suitable for reducing the activity of metal to <em>discrete item limits</em>, but may require a long storage period.</td>
<td>Metallic waste with reduced activity.</td>
<td>Decay stores should have strict safety procedures. The reduction in the activity levels in the stored materials would need to be monitored.</td>
<td>Secondary wastes are expected to be trivial and therefore not pose a problem.</td>
<td>Decay stores for wastes in the region of the boundary between the UK-defined categories of ILW and LLW exist in Switzerland, Germany and Canada.</td>
<td>Formal decay storage facilities do not currently exist in the UK. Waste producers can decay store waste on their sites subject to approvals being granted.</td>
</tr>
</tbody>
</table>
### WASTE GROUP 3: Steel drums containing cemented waste (cemented sludges and cemented metal gauge filters)

<table>
<thead>
<tr>
<th>WASTE GROUP 3 Cemented drums</th>
<th>Effectiveness</th>
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<th>Worker and environmental safety</th>
<th>Secondary wastes</th>
<th>Technology readiness</th>
<th>Availability to UK industry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shredding</strong></td>
<td>Effective for destroying cemented drums as discrete items.</td>
<td>Treatment method will generate rubble from the cement as well as scrap metal from the drum.</td>
<td>Automatic feeding systems offer safety benefits over manual feeding systems. Appropriate systems would be required to ensure contamination control. Maintenance activities may be complex and demanding.</td>
<td>Filters from the containment system would probably be generated, along with secondary wastes from decontaminating the equipment after use. Possible need to dispose of used cutting wheels as radioactive waste.</td>
<td>Although shredding issued in nuclear decommissioning, it is not routinely employed for cemented drums.</td>
<td>Available in the UK.</td>
</tr>
<tr>
<td><strong>Jaw crusher</strong></td>
<td>Expected to be suitable for crushing cemented drums. Likely to be more difficult to crush metal gauge filters in cement than cemented sludges.</td>
<td>Rubble from the cement and compressed scrap metal from the drum.</td>
<td>Automatic feeding systems offer safety benefits over manual feeding systems. Appropriate containment would be required to ensure contamination control.</td>
<td>Filters from the containment system would probably be generated, along with secondary wastes from decontaminating the equipment after use. Possibly, the used jaw plates would also need to be disposed of.</td>
<td>Jaw crushers are used in mining but not in nuclear decommissioning.</td>
<td>Available in the UK.</td>
</tr>
</tbody>
</table>
## Cemented drums

<table>
<thead>
<tr>
<th>WASTE GROUP 3</th>
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<th>Technology readiness</th>
<th>Availability to UK industry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supercompaction</strong></td>
<td>Cemented drums cannot be compacted.</td>
<td></td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
</tr>
<tr>
<td><strong>Circular saw</strong></td>
<td>Not effective for cutting cemented drums, as drum thickness too great.</td>
<td></td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
</tr>
<tr>
<td><strong>Wire saw</strong></td>
<td>Expected to be suitable for cutting cemented drums as the technology is able to cut through very large thicknesses.</td>
<td>Segments of cemented drums. However, it is uncertain whether these segments would still constitute discrete items.</td>
<td>Can be operated remotely, therefore low conventional risks. If gas or water cooling is used for the cutting wire, containment may be more challenging than for dry cutting techniques. Filters from the containment system would probably be generated, along with the need to manage contaminated coolant. Used cutting wires will require disposal.</td>
<td>Lack of characterisation of internals may make ALARP case difficult where the cemented drums contain metallic items.</td>
<td>Method used in nuclear decommissioning.</td>
<td>Available in the UK.</td>
</tr>
<tr>
<td><strong>Reciprocating saw</strong></td>
<td>Not effective for cutting cemented drums, as drum thickness too great.</td>
<td></td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
</tr>
</tbody>
</table>
### National Waste Programme

<table>
<thead>
<tr>
<th>CEMENTED DRUMS</th>
<th>EFFECTIVENESS</th>
<th>RESULTING PRODUCT</th>
<th>WORKER AND ENVIRONMENTAL SAFETY</th>
<th>SECONDARY WASTES</th>
<th>TECHNOLOGY READINESS</th>
<th>AVAILABILITY TO UK INDUSTRY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Torch cutting</strong></td>
<td>Not effective for cutting cemented drums.</td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Plasma cutting</strong></td>
<td>Not effective for cutting cemented drums.</td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Laser cutting</strong></td>
<td>Not effective for cutting cemented drums.</td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chemical decontamination</strong></td>
<td>Not effective for decontaminating cemented drums.</td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Physical decontamination</strong></td>
<td>Not effective for decontaminating cemented drums.</td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Melting</strong></td>
<td>Not effective for cemented drums.</td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Incineration</strong></td>
<td>Cemented drums cannot be incinerated.</td>
<td></td>
<td></td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Plasma arc processing</strong></td>
<td>The technology could be effective for the treatment of cemented drums as it</td>
<td>Solid granular material or glass-like material (if frit is added) suitable for</td>
<td>Contained system reduces risks to worker safety.</td>
<td>Secondary wastes would include filters and aqueous solutions from</td>
<td>Used in nuclear decommissioning in Continental Europe.</td>
<td>Facilities located in Continental Europe but not in the UK.</td>
</tr>
</tbody>
</table>
### National Waste Programme

#### WASTE GROUP 3

<table>
<thead>
<tr>
<th>Effectiveness</th>
<th>Resulting product</th>
<th>Worker and environmental safety</th>
<th>Secondary wastes</th>
<th>Technology readiness</th>
<th>Availability to UK industry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cemented drums</strong></td>
<td>can treat drums of waste. Requires further investigation.</td>
<td>direct disposal.</td>
<td>In the case of items cemented within drums, any internal voids will present a safety risk and will be more difficult to make the ALARP case.</td>
<td>the off-gas system.</td>
<td></td>
</tr>
<tr>
<td><strong>Vitrification</strong></td>
<td>In principle the technology is effective, as it can treat drums of waste and concrete, but this would require further investigation.</td>
<td>Glass matrix containing the radionuclides.</td>
<td>Contained system reduces risks to worker safety.</td>
<td>Secondary wastes include filters which may be treated separately. Also scrub solution, if wet scrubbing is used.</td>
<td>Used in nuclear decommissioning in the USA, Japan (active facility for hazardous wastes) and Australia. Small-scale trials have been carried out on cemented drums.</td>
</tr>
<tr>
<td><strong>Disposal elsewhere</strong></td>
<td>May require size reduction, depending on the disposal container to be used.</td>
<td>Packaging requirements will need to be met.</td>
<td>Disposal facilities should have strict safety procedures.</td>
<td>Secondary wastes are expected to be trivial and therefore not pose a problem.</td>
<td>Experience is available outside the UK.</td>
</tr>
</tbody>
</table>
### National Waste Programme

<table>
<thead>
<tr>
<th>WASTE GROUP 3 Cemented drums</th>
<th>Effectiveness</th>
<th>Resulting product</th>
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<th>Secondary wastes</th>
<th>Technology readiness</th>
<th>Availability to UK industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay storage</td>
<td>May be suitable for reducing the activity of cemented drums to discrete item limits, but may require a long storage period.</td>
<td>Cemented drums with reduced activity.</td>
<td>Decay stores should have strict safety procedures. The reduction in the activity level in the stored materials would need to be monitored.</td>
<td>Secondary wastes are expected to be trivial and therefore not pose a problem.</td>
<td>Decay stores for wastes in the region of the boundary between the UK-defined categories of ILW and LLW exist in Switzerland, Germany and Canada.</td>
<td>Formal decay storage facilities do not currently exist in the UK. Waste producers can decay store waste on their sites subject to approvals being granted, however.</td>
</tr>
</tbody>
</table>