

National Waste Programme

Management of Contaminated Oils

Feasibility Study

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Executive Summary

The National Low Level Waste (LLW) Programme, part of LLW Repository Ltd (LLWR Ltd), works on behalf of the Nuclear Decommissioning Authority (NDA) to lead the implementation of the UK Strategy for the Management of LLW from the Nuclear Industry (the National LLW Strategy). A key component of the remit of the National LLW Programme (NWP) is the provision of guidance on different aspects of waste management practice and to coordinate efforts on improvement of LLW management practice across the UK nuclear industry. The NWP has undertaken work over the past few years to gather and collate information on the national inventory of problematic wastes; these are defined as wastes that do not have underpinned, defined or available waste management routes. The NWP is using this collated information to support waste producers in the identification and deployment of technology solutions to manage their problematic waste inventories. One such problematic waste type is oil that is unsuitable for incineration.

Radioactively contaminated oil wastes are commonly incinerated for disposal where the characteristics of the oil make such a management route feasible. However, incineration may be difficult to achieve for a number of reasons and other treatment regimes may therefore need to be sought to allow the wastes to be disposed of through existing routes. This report considers the other technologies available for non-incinerable oils.

LLWR Ltd provided inventory information on 68 waste streams representing oils currently assumed to be unsuitable for incineration. Characterisation data for many of these waste streams was found to be sparse, with little or no firm information to justify the assessment that they are non-incinerable; it therefore seems entirely credible that adequate characterisation will allow at least some of these wastes to be routed to incineration. Nevertheless, in the absence of firm evidence to the contrary, the inventory assessment assumed that all materials deemed to be non-incinerable would require an alternative treatment. The 68 waste streams were categorised based on their composition, into five distinct groups where different treatment approaches might be necessary or desirable: oils with organically bound tritium, oils with tritiated water, oils with active solids, oily water and oil contaminated solids.

In total, 21 potential technologies for the treatment of liquid organic waste were chosen for assessment. These are categorised by process type in Table A below. Thermal processes use high temperatures to break down and destroy the organic components of the waste. Chemical processes use oxidation and highly reactive species to destroy the organic components of the waste. Physical processes, however, do not destroy the waste but either separate out the different phases of the waste or immobilise the liquid waste into a solid form.

The 21 technologies were each subjected to an initial screening process for technical effectiveness and technological readiness. This process allowed a large number of unsuitable options to be discounted, leaving those which were most credible to be taken forward for complete assessment.

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Table A: The 21 chosen technologies by process type

Thermal	Physical	Chemical
Pyrolysis	Absorption	Electrochemical treatment
Plasma treatment	Centrifugation	Wet oxidation
Vitrification	Filtration	Molten salt oxidation
Microwave treatment	Physical / mechanical decontamination	Direct chemical oxidation
	Drying and evaporation	Acid digestion
	Distillation	Advanced oxidation
	Direct immobilisation	Supercritical water oxidation
	Phase separation	Biological treatment
		Alkaline hydrolysis

Having undertaken this initial screening process, a total of eight credible options were taken forward for complete assessment. These were:

1. Pyrolysis
2. Plasma treatment
3. Absorption
4. Centrifugation
5. Filtration
6. Physical / mechanical decontamination
7. Electrochemical treatment
8. Wet oxidation

The complete assessment process used a range of criteria developed to highlight the potential advantages and limitations of the eight credible technologies. These criteria were:

- Impact of waste stream characteristics
- Nature and extent of radioactive contamination
- Technical effectiveness
- Technological readiness
- Nature and disposability of products
- Nature and disposability of secondary wastes
- Discharges
- Economic issues
- Safety issues

This process culminated in the feasibility of each of the eight credible technologies being determined for each oil group. The credible treatment technologies and their feasibility by waste group are shown in Table B below.

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The study showed that there was at least one credible technology that could be applied for each waste group identified in the inventory. However, none of the technologies identified are likely to provide a complete solution, although thermal techniques and absorption could be used to manage most of the waste groups, and all will generate products or secondary wastes that will require conditioning before disposal. Given the sensitivity of some approaches to the physicochemical nature of the feedstock, it will be necessary to improve the characterisation information available and to trial potential approaches on samples of oil from individual waste streams to ensure optimisation of conditions.

To take the findings of this study forward and to facilitate the implementation of waste management solutions, the following recommendations are made:

- A programme of characterisation is required to improve the quality and completeness of the inventory information; enabling the identification and implementation of waste management solutions.
- This study has identified that thermal treatment is a technology that could be used for the management of the range of different oil waste groups. The output of this study should be made available to the ongoing Thermal Treatment Integrated Project Team (IPT), set up by NDA, so that this potential opportunity can be recognised.
- Thermal treatment is a technology that has tolerance for a diverse range of feedstock. To enable the opportunity for the use of thermal technology for problematic waste management to be recognised, the National LLW Programme should undertake an assessment of the suitability of thermal treatment for the management of other problematic wastes, and should make the output available to the NDA Thermal Technology IPT.
- Waste producers who hold oil wastes which do not contain organically bound tritium should assess the suitability of the Oil Waste Leaching (OWL) process (or similar decontamination processes) for their wastes.
- The National LLW Programme should, in collaboration with Magnox Ltd, produce and disseminate a briefing note on the use and effectiveness of the OWL decontamination process to make learning from the ongoing Trawsfynydd oil treatment available to the wider LLW management community.
- The output of this study should be made available to Radioactive Waste Management Ltd (RWM) Upstream Optioneering team to facilitate the assessment of the Higher Activity Waste (HAW) oil inventory and the identification of common opportunities to take forward.
- Develop and deliver – seeking NDA funding as appropriate – a programme of work to undertake disposability assessments for oil absorption technologies.

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Table B: The credible treatment technologies and their feasibility by waste group

	Technology	Tritiated oils (organically bound ³ H)	Tritiated water (³ HOH) in oil	Oils with active solids	Oily water (<50% H ₂ O)	Oil contaminated solids
Th	Pyrolysis	Yes	Yes	Possible	Yes	No
	Plasma treatment	Yes	Yes	Yes	Yes	Yes
Ph	Absorption	Yes	Yes	Yes	Yes	Possible
	Centrifugation	No	Possible	Yes	Yes	No
	Filtration	No	No	Yes	No	Possible
	Decontamination	No	Yes	Yes	Yes	Yes
Ch	Electrochemical treatment	Yes	Yes	Possible	Yes	No
	Wet oxidation	Possible	Possible	No	Possible	No

Th = Thermal, Ph = Physical, Ch = Chemical

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1. Introduction

The National Low Level Waste (LLW) Programme, part of LLW Repository Ltd, works on behalf of the Nuclear Decommissioning Authority (NDA) to lead the implementation of the UK Strategy for the Management of LLW from the Nuclear Industry (the National LLW Strategy). A key component of the remit of the National LLW Programme (NWP) is the provision of guidance on different aspects of waste management practice and to coordinate efforts on improvement of LLW management practice across the UK nuclear industry. The NWP has undertaken work over the past few years to gather and collate information on the national inventory of problematic wastes; these are defined as wastes that do not have underpinned, defined or available waste management routes. The NWP is using this collated information to support waste producers in the identification and deployment of technology solutions to manage their problematic waste inventories. One such problematic waste type is oil that is unsuitable for incineration. This report considers the available technologies for managing such material.

Radioactively contaminated oils are commonly incinerated for disposal where the characteristics of the oil make such a management route feasible. However, incineration may be difficult to achieve for a number of reasons. For example, relatively high activity concentrations of tritium and carbon-14 in the oil may challenge the discharge authorisations for an incinerator, or the presence of alpha-emitting radionuclides may make acceptance at the facility and management of any incineration residues difficult. Under these circumstances, incineration of the wastes may be difficult, and other treatment regimes may need to be sought to allow the wastes to be disposed of through existing routes.

Two strategies could be applied to reach this objective. The oil could be decontaminated to the point where it can be accepted at an incinerator: for example oils contaminated with alpha active solids could be treated in some way to remove the solid phase leaving an incinerable fluid and a solid phase suitable for disposal via existing routes for solid waste. Alternatively, the oil could be solidified, perhaps by absorption on a suitable substrate, and sent directly to a solid waste disposal route.

This report is structured as follows:

Section 2 assesses information currently available on the inventory of non-incinerable oils to provide information on their origin and quantity, and their radiological and physicochemical properties to inform assessment of potential treatment techniques.

Section 3 provides an introduction to each of the 21 potential treatment technologies that have been identified. An assessment based on technological readiness and technical effectiveness was completed for each technology to determine which would be carried forward to the next stage of the assessment.

Section 4 provides a further assessment of the eight credible technologies and Section 5 presents the overall conclusions and key messages from the work.

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2. Nature and quantity of the waste

Inventory data on non-incinerable oils were provided to Amec Foster Wheeler by LLW Repository Ltd (LLWR Ltd). The inventory contained data on 68 waste streams and presented some information regarding the generic waste type, waste description, volumes, current and future arisings. However, detailed information in many areas was somewhat sparse and it is clear that many of the oil wastes have, to date, been poorly or not characterised. Further characterisation work will be required before any treatment regime could be identified for many of the wastes in the inventory. Indeed, it is possible that adequate characterisation would demonstrate that a significant proportion of the inventory could be incinerated without further treatment. However, for the purpose of this study it is assumed that all the wastes identified by LLWR Ltd for this study are non-incinerable.

A detailed description of the inventory used in this work is provided as Appendix 1. This Appendix is based upon the data provided by LLWR Ltd, supplemented where possible by information from the UKRWI [1]. However, to facilitate the assessments undertaken here, the inventory was divided into five distinct groups of material. These are presented in Table 1. Table 2 indicates the number of waste streams falling into each of these groups and the overall volume.

Table 1: Oil waste groups

No.	Group	Description
1	Oils with organically bound tritium (OBT)	Oils in which the tritium is chemically bound to carbon in the oil.
2	Oils with tritiated water (HTO)	Oils mixed with tritiated water.
3	Oils with active solids	Oil containing active solids such as swarf or activated wear products.
4	Oily water	A mixture of oils and water with water content up to 50%.
5	Oil contaminated solids	Oily rags and oil soaked wastes.
	Other oils	Waste streams where the data are too sparse to allow them to be firmly assigned to groups 1 to 5. It is expected that further data would, however, allow them to be categorised.

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Table 2: Waste group quantity data (with volumes to 2 significant figures)

No.	Group	No. of waste streams	Total volume (m ³)
1	Oils with organically bound tritium	1	100
2	Oils with tritiated water	6	140
3	Oils with active solids	35	280
4	Oily water	3	3.0
5	Oil contaminated solids	2	40
	Other oils	21	110
	Total	68	670

A detailed breakdown of the waste inventory is given in Appendix 1. Figures 1 to 3 give key summary information on the volumes, sources and times of arising of the waste groups.

The group with the largest volume is Group 3, 'Oils with active solids', which arise primarily as used lubricating oils from Sellafield. Group 2, 'Oils with tritiated water', also arise primarily from Sellafield and are included in the UKRWI [1] as stream 2D30. 'Oils with organically bound tritium' (Group 1) arise solely from the activities of the Joint European Torus fusion research facility at Culham (waste stream 5H307).

The 'Other oils' group, which represents those streams where the data are insufficient to allow assignment to one of the other groups, also arises primarily from a single waste stream at Sellafield described as 'cumulated oils' and for which there aren't enough data available to assign it to one of the main groups.

Two waste streams from the inventory, one for Heysham A and another for Hinkley Point B, are recorded as containing some problematic oil waste but their volume is uncertain. These are therefore not presented in Figures 1 or 2.

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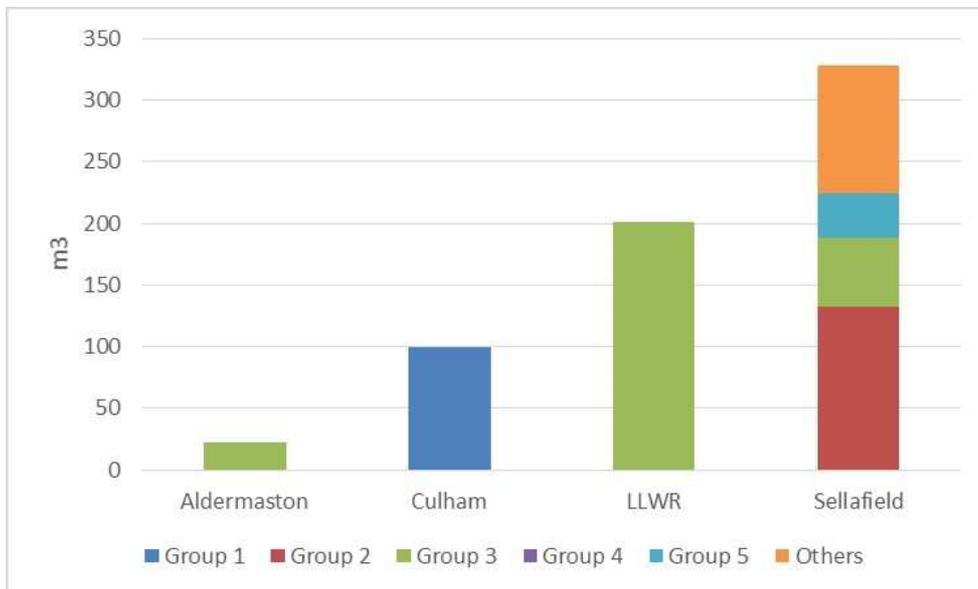


Figure 1: Problematic oil wastes by source – major contributors

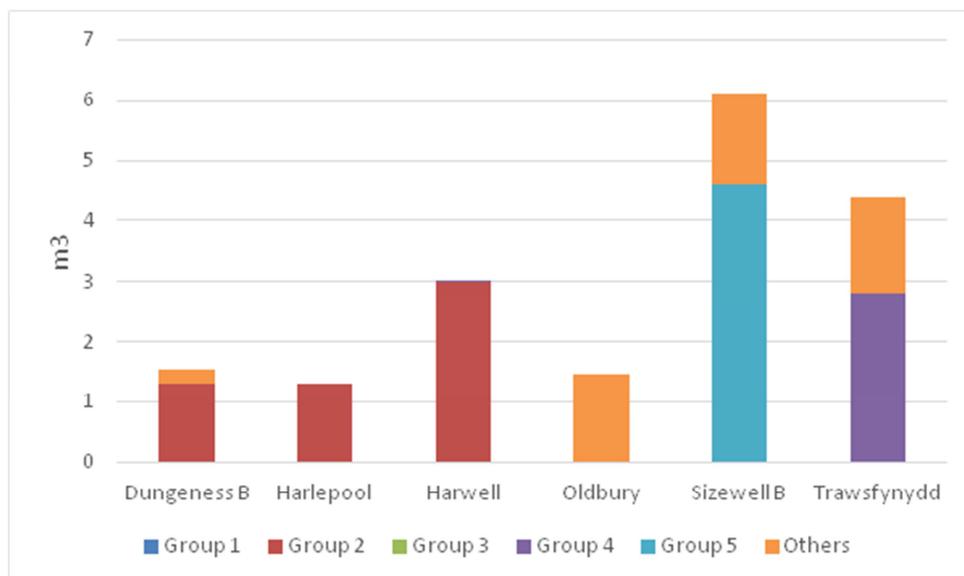


Figure 2: Problematic oil wastes by source – minor contributors

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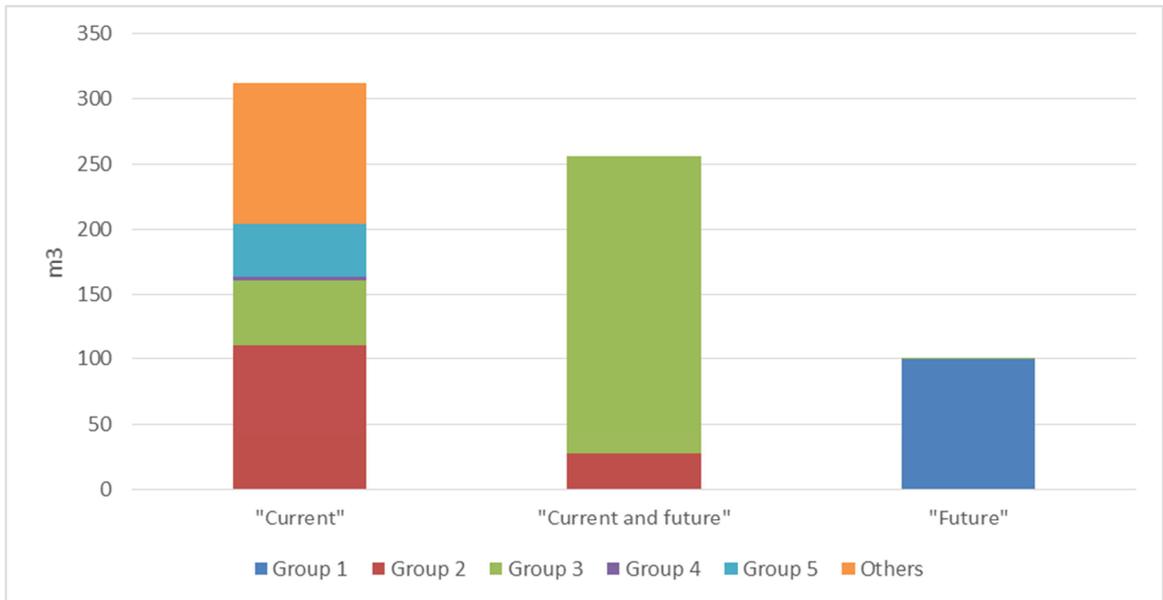


Figure 3: Stock and arising volumes (*the oils in the inventory are assigned to one of these three categories)

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3. Identification of credible treatment technologies

This section of the report identifies those technologies which have been proposed for the treatment of organic radioactive waste, and evaluates which of these treatments would be credible for use in the management of the oil inventory described in Section 2 above.

Section 3.1 lists the technologies identified. Section 3.2 outlines the criteria used for evaluating which are credible and would merit carrying forward for further evaluation, and Section 3.3 presents the assessment of the technologies identified in Section 3.1. Full references supporting the assessments are to be found in Appendix 2.

3.1 Identification of potential technologies

Reference 2 provides an overview of the technologies that can be used to process organic radioactive wastes, indicating which are potentially suitable for the management of contaminated oils. These technologies and several others identified from the literature were chosen for preliminary assessment, making an initial total of 21 technologies.

The technologies can be categorised by process type. The three process categories are physical separation/immobilisation, chemical destruction and thermal destruction. Chemical processes use oxidation and highly reactive species to destroy the organic components of the waste. Thermal processes use high temperatures to break down and destroy the organic components of the waste. Physical processes, however, do not destroy the waste but either separate out different phases of the waste or immobilise the liquid waste into a solid form. Table 3 below lists the 21 technologies within their respective categories. Brief descriptions of each technology are given in Section 3.3. More detailed descriptions are to be found as part of Appendix 2.

Table 3: The 21 technologies categorised by process type

Thermal	Physical	Chemical
Pyrolysis	Absorption	Electrochemical treatment
Plasma treatment	Centrifugation	Wet oxidation
Vitrification	Filtration	Molten salt oxidation
Microwave treatment	Physical / mechanical decontamination	Direct chemical oxidation
	Drying and evaporation	Acid digestion
	Distillation	Advanced oxidation
	Direct immobilisation	Supercritical water oxidation
	Phase separation	Biological treatment
		Alkaline hydrolysis

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3.2 Criteria for assessment

A preliminary assessment of the 21 technologies was undertaken to determine which are likely to prove valuable in the management of non-incinerable oils. Two linked criteria were adopted for the assessment:

- **Technical effectiveness:** will the technique materially improve the manageability of the waste stream?
- **Technological readiness:** is the technique currently being used industrially to treat wastes or is it in the development stages? Near-market solutions are preferred to those requiring significant R&D.

Technical effectiveness gives an overall view of effectiveness based on waste stream characteristics and the nature of its radioactive content. Waste stream characteristics embrace the nature of the oil and any major non-radiological species that may limit the applicability of any given technology, for example, the water content and solid content. The nature of radioactive contamination describes both the physicochemical nature of the active material and the level of contamination that may limit the applicability of any given technology, for example, contamination associated with another liquid phase, contamination associated with a solid phase or contamination that is chemically bound to the oil.

Technological readiness covers whether or not the technology has been used to treat organic radioactive wastes previously, and if so, if it has specifically been applied in the treatment of contaminated oils. This is intended as a high-level assessment of technological readiness based on previous application of the technologies worldwide and the degree to which the technologies have been developed. Near-market technologies will, in general, be much easier to implement than technologies which require considerable research and development to determine their suitability.

Given the varying challenges posed by the differing groups of oil waste, each technique was assessed for each waste group separately.

3.3 Assessment of potential technologies

An outline of the key features of each technology, and an outline of the results of the assessment are given below. More detailed technology descriptions and a more extensive assessment of their suitability are given as Appendix 2, where key references are to be found. The overall results are summarised in Table 4 below.

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3.3.1 Thermal destruction

Pyrolysis

Pyrolysis is related to incineration, but is based on the thermal decomposition of organic material in an inert or oxygen-deficient atmosphere to destroy the waste and convert it into an inorganic powder. The operating temperature is lower than for incineration and this combined with the reduced oxygen level means that some of the volatile species are retained within the pyrolysis residue. Steam reforming is often applied after plasma treatment to remove the carbon fraction completely.

The assessment concluded that pyrolysis is likely to be effective in the treatment of tritiated oils, tritiated water in oil and oily water. It may be effective for oils with active solids, depending on the size of the solids. It is however, not effective for oil contaminated solids as the solids are unlikely to be sufficiently finely divided for the process to be sufficiently effective [2, 3].

Carried forward for detailed assessment

Plasma treatment

Plasma treatment uses an electric arc to generate temperatures in excess of 20,000 °C. This extreme temperature causes the molecular structure of the organic material to break down (vaporise) into its constituent atoms leaving a granular inorganic material or slag. Direct vitrification of the slag by addition of glass frit during plasma treatment can result in a more robust, monolithic wasteform.

Due to the extreme temperatures utilised during plasma treatment, it is likely to be effective in treating all five of the identified waste groups [2, 3].

Carried forward for detailed assessment

Vitrification

The vitrification process combines feedstock material with glass forming compounds at high temperature, to produce a solution of radionuclides in a molten glass matrix. This is then poured into a container and upon cooling forms a monolithic, glass block. The high temperature process destroys organic material; however, during this process volatile radionuclides are released to the off-gas system.

Vitrification has only previously been routinely applied to solid organic wastes and liquid inorganic wastes, but not liquid organic wastes such as oil. The oil would have to be mixed with some suitable substrate such as sand to allow vitrification. There would therefore be the need for significant research and development before the technique could be deployed, but without any certainty of a successful outcome [2-4].

Excluded from further consideration

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Microwave treatment

In this approach, microwave energy is used to heat the waste and hence destroy the organic components. The microwave energy causes molecular vibrations in polar molecules, which in turn heats the waste and breaks down organic chemical bonds. Very high temperatures can be achieved, with the process producing an inorganic fused solid mass which can present a challenge for disposal.

As oils are generally non-polar, it is likely that the waste would not be heated sufficiently to destroy the organic components within it. Microwave treatment has not previously been applied for the treatment of contaminated oils and would therefore require considerable research and development to determine its suitability [2, 5].

Excluded from further consideration

3.3.2 Physical separation / immobilisation

Absorption

Liquid waste is immobilised by absorption onto a substrate such as clay or some form of polymer. The liquid is simply brought into contact with the absorbent, resulting in a solid product that retains the liquid. Absorption may be followed by cementation if required for final disposal or incineration as a solid feedstock.

Absorption is likely to be effective in treating tritiated oils, tritiated water in oil, oily water and oils with active solids. It may not be effective in treating oil contaminated solids, depending on the solid form [2, 6-8].

Carried forward for detailed assessment

Centrifugation

Centrifugal separation is a widely used method for separating immiscible fluids with different densities or for separating solids from fluids. The centrifuge applies centrifugal force to a sample to separate heterogeneous mixtures. Oil can be heated prior to centrifugation to reduce its viscosity thus making separation more straightforward. Oils are often filtered before centrifugation to remove larger pieces of solid.

Centrifugation is likely to be effective in separating oils with active solids and oily water. It will not separate organically bound tritium from tritiated oils or the oil from oil contaminated solids. It may be possible to separate the tritiated water from tritiated water in oil [9-11].

Carried forward for detailed assessment

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Filtration

Filtration is widely used to separate insoluble solids from liquid, and has been applied to oils contaminated with solids. Examples of filtration processes include pressure filters and cartridge filters. Filter selection is important as fine particles may pass through some filters while viscous liquids may not pass through certain filters. Oil can be heated prior to filtration to reduce its viscosity thus making filtration more straightforward.

Filtration is only effective for treating oils with active solids, and potentially oil contaminated solids, depending on the form of the solid. It will not be effective in treating tritiated oils, tritiated water in oil or oily water [12-14].

Carried forward for detailed assessment

Physical / mechanical decontamination

Decontamination consists of a range of methods for removing radioactive contaminants from waste, for example, solvent washing, laundering and surface cleaning. Secondary wastes will be produced with any decontamination method and hence the treatment of these must also be considered. The main advantage of decontamination is that the radioactive content is removed leaving the non-radioactive material for reuse or conventional treatment such as incineration.

Decontamination is likely to be effective for treating tritiated water in oil, oily water, oils with active solids and oil contaminated solids. It is not effective for treating organically bound tritium in tritiated oils [2, 15].

Carried forward for detailed assessment

Drying and evaporation

Drying and evaporation are commonly used to remove free water from radioactive and other wastes. The technique may be used for solid wastes containing a significant amount of water (drying), or aqueous wastes, which will result in a concentrate containing most of the radioactivity (evaporation). In the case of evaporation, the waste is heated, a process that may also be applied as part of drying processes. To accelerate the process, the water vapour driven off by the evaporation process can be removed using ventilation.

The technology is only potentially applicable to the waste groups containing water, i.e. tritiated water in oil and oily water. It has only previously been applied to aqueous waste streams. The specific methods and equipment for drying/evaporating the water from contaminated oils are therefore unknown and the technology requires significant research and development [2].

Excluded from further consideration

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Distillation

Distillation consists of two distinct steps: evaporation followed by condensation. By applying heat, one component of a mixture is made volatile, and when it is cooled down this component is recovered as a clean liquid or distillate.

Distillation can be used to separate liquid phases with different boiling points such as solvents from aqueous liquid mixtures. In principle it could be used to separate radionuclide-bearing phases such as tritiated water from oil. However, there is no evidence that this approach has been applied on a significant scale and significant research and development would probably be required to demonstrate its effectiveness [2].

Excluded from further consideration

Direct immobilisation

With this approach, raw waste is directly mixed with a binding material, for example, cement, bitumen or resin. The original waste does not change, but is completely embedded and thus retained in a solid matrix. Direct immobilisation allows for the production of a wastefrom suitable for disposal in a single step. Immobilisation should convert a liquid organic waste into a solid wastefrom suitable for direct disposal.

It is unclear whether it will be possible to incorporate oil effectively into a cementitious grout or a resin with which it is likely to be immiscible. Similarly, it is unclear whether oil could be incorporated effectively into bitumen. Unincorporated oil would have the potential to form pockets of oil within the encapsulant, thus allowing its easier release from the matrix [2, 12, 13].

Excluded from further consideration

Phase separation

Phase separation is a form of physical separation. For unemulsified liquid wastes, it is when a heterogeneous (though not emulsified) mixture is separated into two or more distinct components or phases, e.g. free oil and free water with the denser liquid (water) having settled below the less dense liquid (oil). Separations of two liquids are not 100% efficient as it is very difficult to separate one liquid from the other completely.

Only water/oil mixtures could be treated by this route. The effectiveness of treatment would require that the water and oil formed two distinct phases without the presence of significant colloidal mixing and this is open to considerable doubt. This latter requirement could be of critical importance in detritiating mixtures of oil and tritiated water [2, 16].

Excluded from further consideration

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3.3.3 Chemical destruction

Electrochemical treatment

Electrochemical treatment is generally based on the creation of highly reactive ions and their subsequent use to oxidise and break down organic chemical bonds and hence destroy the organic material. This approach has been applied successfully to radioactive oil wastes in the UK through the Arvia process. Alternative approaches such as the Silver II process have been successfully applied to other organic liquids.

Electrochemical treatment will be effective for treating tritiated oils, tritiated water in oil and oily water. It may be effective for treating oils with active solids, if the solids are small enough, but it won't be effective for treating oil contaminated solids as the solids are unlikely to be sufficiently divided [2, 17].

Carried forward for detailed assessment

Wet oxidation

Wet oxidation processes use the soluble salts of redox sensitive elements with hydrogen peroxide or air/oxygen to bring about the chain reaction oxidation of organic material into carbon dioxide and water, leaving inorganic residues which retain most of the radioactivity. The process uses highly oxidising hydroxyl radicals to destroy the organic component of the waste in a reaction similar to incineration.

Wet oxidation will be potentially effective in the treatment of tritiated oils, tritiated water in oil and oily water. Due to the requirement of no solid content, oils with active solids and oil contaminated solids cannot be treated using wet oxidation [2, 15, 18].

Carried forward for detailed assessment

Molten salt oxidation

During molten salt oxidation, the combustible organic species are oxidised in a bath of alkaline molten salts at temperatures between 500 and 950 °C. These conditions have the effect of oxidising the organic constituents of the waste to produce carbon dioxide and water. The inorganic component residues formed are retained within the organic-free molten salt. Recycling of the salt removes the residues for immobilisation.

Molten salt oxidation has only previously been applied on a large scale to mixed wastes (combined radioactive and hazardous wastes). Operational experience to date has been limited and the process is largely in the development phase, with a bench scale facility being developed at Lawrence Livermore National Laboratory in the USA. Continued research and development would be required to determine whether it is feasible for oils [2, 3].

Excluded from further consideration

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Direct chemical oxidation

Direct chemical oxidation retains the benefits of an aqueous system (capturing dust while products remain within a liquid medium) but increases the efficiency of oxidation by specifically utilising sodium or ammonium peroxydisulphate. The peroxydisulphate ion is a strong oxidant and hence the oxidation reactions do not require catalysis. An inorganic residue is produced which can be encapsulated for disposal.

Direct chemical oxidation has been used to treat organic waste solvents. Generally, technologies suitable for treating waste solvents are not necessarily also suitable for treating lubricants or oils as although both are liquid organic wastes their compositions are substantially different (both physically and chemically). Considerable research and development would be required to determine its suitability for oils [2, 19].

Excluded from further consideration

Acid digestion

Acid digestion or wet combustion uses hot, strong mineral acids (sulphuric acid and nitric acid at around 250 °C) to oxidise the organic components of the waste, producing a range of gases and an inorganic sulphate residue. It is a thermal desorption process involving carbonisation of organic wastes in hot sulphuric acid and oxidation of the resultant carbon by nitric acid. The residue product is easily leachable and requires conditioning for disposal.

Acid digestion has only been applied previously to digest solid organic wastes and not liquid organic wastes, or specifically oils. This technology could be proven as technically feasible with it being most promising for the solid containing waste groups; however, considerable uncertainty would exist on the final disposition of the oils in the process. Considerable research and development would be required to determine whether acid digestion is suitable for digesting oils [2, 3].

Excluded from further consideration

Advanced oxidation

Advanced oxidation processes are a class of treatment methods that include the use of ultraviolet light and oxidants (hydrogen peroxide or ozone), sometimes combined with catalysts, to destroy organic material, with carbon dioxide and water being produced. These techniques are similar to wet oxidation and have been applied industrially to wastewaters containing small amounts of organic species.

Advanced oxidation processes are only applicable to trace organics in water-based waste streams and not for the treatment of raw oil waste. Significant research and development would be required to determine whether advanced oxidation could be suitable for oils, and the large difference in composition between aqueous waste streams and oils make it unlikely to be technically feasible [2, 20].

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Excluded from further consideration

Supercritical water oxidation

Supercritical water oxidation uses the properties of water at above its critical temperature and pressure (374 °C and 22 MPa), combined with air, to oxidise organic material to produce carbon dioxide, water and an insoluble inorganic residue. Under supercritical conditions, water acts like a non-polar fluid and all organic material becomes soluble. The inorganic product forms a concentrated sludge which would then need to be immobilised.

Supercritical water oxidation has only previously been applied to dilute aqueous waste streams. The oily water waste streams relevant to this study contain less than 50% water, so even that waste group is unlikely to be suitable for supercritical water oxidation. Significant research and development would be required to determine whether supercritical water oxidation could be applied to oils, although the large difference in composition between dilute aqueous waste streams and oils make it unlikely to ever be technically feasible. This technology is also highly energy intensive and hence would require a complex operational plant [2, 21].

Excluded from further consideration

Biological treatment

Biological treatment or biodegradation uses carefully-selected micro-organisms (bacteria or fungi) to metabolise and digest the organic components of the waste. Under aerobic conditions, the gaseous product is carbon dioxide while anaerobic conditions would produce a 50:50 mixture of carbon dioxide and methane. Inorganic material in the feedstock would remain associated with the biomass.

Biodegradation is generally used to treat water-based waste streams with low organic content. Biological treatment is therefore unlikely to be feasible for this application as the oil makes up the most part of each of the five waste groups. Bio-reactors are also highly sensitive to the specific composition of the waste (i.e. choice of bacteria) and would therefore require accurate waste characterisation and a complex operating plant. Considerable research and development would be required to determine its suitability for oils [2, 22].

Excluded from further consideration

Alkaline hydrolysis

Alkaline hydrolysis is a wet, chemical extraction process where a liquid organic waste is brought into contact with an aqueous alkaline solution. Hydrolysis reactions then alter the nature of the organic species, resulting in the transfer of radioactivity to the aqueous phase. Subsequent separation of the phases results in a clean organic liquid. The

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process has been applied to waste solvents and following treatment the solvent can be recycled.

Alkaline hydrolysis has previously been applied to treat reprocessing waste solvents such as TBP/OK (tri-butyl phosphate/odourless kerosene) containing actinides. Generally, technologies suitable for treating waste solvents are not necessarily suitable for treating lubricants or oils, as although both are liquid organic wastes, their compositions differ greatly both physically and chemically. Significant research and development would be required to determine its suitability for oils [2].

Excluded from further consideration

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Table 4: Summary table showing the feasibility of the 21 technologies against each waste group

	Technology	Tritiated oils (organically bound ³ H)	Tritiated water (³ HOH) in oil	Oils with active solids	Oily water (<50% H ₂ O)	Oil contaminated solids
Thermal	Pyrolysis	Yes	Yes	Possible	Yes	No
	Plasma treatment	Yes	Yes	Yes	Yes	Yes
	Microwave treatment	Possible	No	No	No	No
	Vitrification	No	No	No	No	No
Physical	Absorption	Yes	Yes	Yes	Yes	Possible
	Centrifugation	No	Possible	Yes	Yes	No
	Filtration	No	No	Yes	No	Possible
	Decontamination	No	Yes	Yes	Yes	Yes
	Drying and evaporation	No	Possible	No	Possible	No
	Distillation	No	Possible	No	Possible	No
	Direct immobilisation	No	Possible	No	Possible	No
	Phase separation	No	Possible	No	Possible	No
Chemical	Electrochemical treatment	Yes	Yes	Possible	Yes	No
	Wet oxidation	Possible	Possible	No	Possible	No
	Molten salt oxidation	No	No	No	No	No
	Direct chemical oxidation	No	No	No	No	No
	Acid digestion	No	No	No	No	No
	Advanced oxidation	No	No	No	No	No
	Supercritical water oxidation	No	No	No	No	No
	Biological treatment	No	No	No	No	No
	Alkaline hydrolysis	No	No	No	No	No

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4. Assessment of the credible technologies

4.1 Introduction

Section 3 identified eight credible technologies for the management of non-incinerable oils on the basis of their likely efficacy and technological readiness. This section moves on to a further assessment of these approaches. No attempt is made to rank the approaches in terms of their favourability – such an activity would require better characterisation data on the waste streams and possibly more data on practical application than are currently available for some techniques. Rather, the approach has been to evaluate the credible techniques against a number of criteria developed to highlight the potential advantages and limitation of each technique. These criteria are summarised below:

Impact of waste stream characteristics

The physicochemical nature of the oil – for example, the water and solvent content or the burden of solids - may limit the applicability of some techniques.

Nature and extent of radioactive contamination

The suitability of a potential treatment technique may depend upon the physical and chemical form of the radionuclides. For example are the radionuclides chemically bound to the oil or present as a discrete solid or liquid phase?

Technical effectiveness

How effective is the technique likely to be? What are the key uncertainties and assumptions underpinning this assessment?

Technological readiness

Where a suitable near-market solution exists is it likely to be preferred to solutions requiring significant R&D as it requires less investment of resource and represents a lower risk option.

Nature and disposability of products

This criterion considers the products of processing in terms of volume change from feedstock, and physicochemical nature. Processes which produce reductions in volumes of material for final disposal are likely to be preferred over those which result in an overall increase in the volume of these wastes and other products. Similarly there will be a preference for techniques that yield products which can be demonstrated to be disposable.

Nature and disposability of secondary wastes

This criterion considers the secondary wastes arising from processing in terms of their quantities and ease of management.

Discharges

This criterion assesses the nature and extent of discharges to atmosphere or to water.

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Economic issues

This study does not consider costs in any detail, but is intended to provide a high-level view on whether the technique is likely to be economically viable.

Safety issues

Any processing technique must be implemented safely. This attribute addresses how difficult a safety case might be to formulate.

The complete assessments are provided in Appendix 2. Overviews are provided below describing the key information (technical effectiveness, technological readiness, product disposability, economic issues) gathered for the eight credible technologies.

4.2 Further assessment of the technologies based on thermal destruction

4.2.1 Pyrolysis

Pyrolysis has been used worldwide for the treatment of LLW. As solids need to be in a granular or powder form, oil contaminated solids are not suitable and some oils containing active solids may also not be suitable, depending on the size of the solids. Pyrolysis is coupled with steam reforming to remove the carbon fraction completely from the carbon-rich char products, resulting in a greater volume reduction and an improved final wasteform (inorganic powder) for disposal [2, 3, 12].

- Produces a product – an inorganic powder – in greatly reduced volumes compared to that of the feedstock. Volume reduction and hence concentration of the radioactivity may lead to the waste being classified as ILW (Intermediate Level Waste) rather than LLW. The product will require further treatment – perhaps by encapsulation – before disposal.
- The process produces some off-gases which must be managed before discharge to atmosphere. There will therefore be some secondary wastes arising from the off gas treatment plant. In addition, the discharge authorisations for the plant may act as a restriction on the materials that can be accepted.
- A pyrolysis plant is not currently in operation in the UK, although facilities are operating in Europe (France, Germany, Belgium and Sweden), and also in Japan and the USA.
- Significant capital and lifecycle costs would be associated with any new static pyrolysis plant; however, costs would be reduced if the facility were also used for other types of waste (other LLW or potentially ILW).

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4.2.2 Plasma treatment

Plasma treatment has been used internationally to treat LLW, ILW and high activity wastes. Due to the extremely high temperature, plasma treatment is suitable for all of the identified waste groups. Plasma treatment can be combined with vitrification which yields an enhanced wasteform for disposal [2, 3, 16].

- The treatment produces a product – a granular inorganic material or slag – in greatly reduced volumes compared to that of the feedstock (volume reduction by a factor of one hundred or more is possible). Direct vitrification of the slag during plasma treatment yields an enhanced (monolithic) wasteform for disposal but this makes the system more expensive to construct and operate. Volume reduction and hence concentration of the radioactivity may lead to the waste being classified as ILW rather than LLW.
- The process produces some off-gases which must be managed before discharge to atmosphere. There will therefore be some secondary wastes arising from the off gas treatment plant. In addition, the discharge authorisations for the plant may act as a restriction on the materials that can be accepted.
- There is no plasma facility currently in operation in the UK, although there is the ZWILAG facility in Switzerland as well as plants in Japan and South Korea.
- Construction of a new static plant in the UK would involve high capital and lifecycle costs. However cost effectiveness would increase significantly if the facility was also used for other types of LLW, or HAW where its particular characteristics offered technical benefits over other options.

4.3 Further assessment of the technologies based on physical separation / immobilisation

4.3.1 Absorption

A wide variety of absorbent materials (e.g. vermiculite, bentonite and synthetic polymers) have been used for the management of contaminated oils. The assessment below focuses on the use of the synthetic 'Nochar' polymers which are commercially available and have been successfully trialled for the small to medium scale management of oils.

Nochar polymers are expected to be effective for the management of all the waste groups identified, with the exception of oil contaminated solids. Small particles of active solids may be absorbed into the pores of the polymer, although the removal of large particulate, perhaps by filtration, might be necessary before the treatment could be applied. Solidified Nochar products meet the criteria for long-term burial at WIPP, NTS

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and Envirocare in the USA where they have also been certified as incinerable, producing less than 0.02% ash [2, 6-8, 12].

- Nochar polymers are currently being used in the USA, Canada and Romania to solidify contaminated oils (e.g. turbine and pump oils) and are also being or have been trialled in a number of countries including the UK, France and Japan.
- The process produces a solidified polymer product potentially suitable for disposal or incineration. Although this would have to be confirmed in a UK context, experience overseas gives some confidence that disposal may be possible. Due to the addition of the substrate the final volume can be three to five times that of the feedstock. Some R&D would be required for individual waste streams to ensure the selection of the optimum polymer (or mixture of polymers) was selected, and that the ratio of oil to polymer was appropriate.
- The availability of hydrophobic and hydrophilic polymers offers the possibility for the treatment of oil/water mixtures.
- Low capital and lifecycle costs (including cost of polymer) compared to thermal processes for a static or mobile plant. There would be additional costs if the solidified product was found to require further conditioning for disposal.

4.3.2 Centrifugation

Centrifugation has been widely used outside the nuclear industry to recycle lubricating oils by removing solid wear products, and therefore has clear potential application to the removal of finely dispersed or granular active solids from an oil matrix. It has also been used in the nuclear industry for the treatment of contaminated oils as part of the NNL OWL process. In principle, centrifugation should also be able to separate the aqueous and oil phases for oil water mixtures. However, the efficiency of separation of finely dispersed solids from oil, or of oil/water emulsions would need to be established. Furthermore, larger solids would need to be removed from the oil by filtration before application of the technique. Centrifugation cannot be applied to oil contaminated solids or to tritiated oils. High viscosity liquids or sludges may not be suitable for centrifugation (even after heating to reduce the viscosity) [9-11].

- Centrifugation is a non-destructive process which produces separated phases for recycling, onward treatment or disposal, i.e. oil that can be incinerated, tritiated water for treatment by conventional aqueous routes, solids/sludges requiring conditioning for disposal. Separation of phases will not increase the overall volume, but any further treatment of the phases may do so. There is potential for volume concentration and hence production of some ILW.
- Generation of secondary wastes would be limited to those produced by routine maintenance of the equipment and filters (where filtration is required). These

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wastes are likely to be oil-contaminated. Discharges to the environment are expected to be minimal.

- Equipment for recycling lubricating oils is commercially available at modest cost. Although the costs associated with modifying it to manage radioactively contaminated oils have yet to be established, they seem unlikely to be substantial. Operating costs are expected to be low.

4.3.3 Filtration

Filtration is a non-destructive process which produces a separated oil phase for onward management, together with filters contaminated with oil and active particulate. It is therefore only applicable to waste streams containing relatively small quantities of insoluble solids within an oil matrix. High viscosity liquids or sludges may not be suitable for filtration (even with the application of heat to reduce the viscosity). The effectiveness of the technique may be limited if the solid phase is of colloidal dimensions. Correct selection of a filter medium will be critical to the success of the approach [12-14].

- Contaminated oil filtration is currently carried out in the UK, Canada and the USA. Filtration is often used prior to centrifugation to remove the larger solids.
- Generation of secondary wastes will be limited to the used filters and those produced by routine maintenance of the equipment. These wastes are likely to be oil-contaminated. Discharges to the environment are expected to be minimal.
- Low capital costs for equipment and low lifecycle costs. Most economical if large volumes of oil are to be filtered. There are additional costs for onward treatment of separated oils and solids.

4.3.4 Physical / chemical decontamination

Decontamination in the context of oils can be described largely as the use of chemical methods to remove the radioactive contaminants from the oil, as opposed to using chemical methods to destroy the organic content of the waste. It covers a range of methods including solvent washing (e.g. NNL's OWL or ARTEMIS processes), surface cleaning (e.g. using supercritical carbon dioxide) and laundering. In the latter, oil contaminated solids may be treated using conventional detergents or solvents. Decontamination cannot remove organically bound tritium from tritiated oils but is suitable for tritiated water in oil, oil with active solids and oily water [2, 13, 15, 23].

- The OWL process was developed by NNL in the UK. It is a solvent washing process which uses sulphuric acid and has successfully treated approximately 1000 drums of oil and tens of tonnes of tri-butyl phosphate (TBP) / odourless kerosene (OK). The OWL process is currently being used at NNL Springfields site by Trawsfynydd to treat problematic oil wastes with success.

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- The OWL process produces decontaminated oil suitable for recycling or incineration. Oil-free solids or residues are recovered for onward treatment – NNL's ARTEMIS process is a solvent washing process and has been developed specifically for oily residues.
- The OWL process is offered as an existing commercial service by NNL and hence costs are directly related to the volume and type of waste being treated. The process can be carried out at the bench-scale. There may be additional costs for any onward treatment of the products of the process.
- Secondary wastes from these processes include spent decontamination reagents and waste generated by equipment maintenance.

4.4 Further assessment of the technologies based on chemical destruction

4.4.1 Electrochemical treatment

Electrochemical processes generally require a liquid feed or a liquid with finely dispersed solids, and hence are not suitable for oil contaminated solids, and depending on solid size, oils with active solids. Examples of electrochemical processes for treating radioactive organic wastes are the silver II process and the Arvia process [2, 17, 24-26].

- The Arvia process was developed by Arvia Technology for the treatment of contaminated oils. The process uses Arvia's graphite adsorbent material, Nyex, to adsorb and hence separate the organics to the bottom of the vessel. The Organic Destruction Cells lie at the bottom of the vessel and when a current is passed through them and the conducting Nyex material, oxidation of the adsorbed organic species occurs which turns them into carbon dioxide and water. The Arvia process has been developed at the bench-scale and has been used up to large scale active trials at Trawsnyydd.
- The Arvia process produces an aqueous product containing the inorganic species that is suitable for treatment via conventional aqueous treatment routes. Due to the addition of water at the start of the Arvia process, the waste volume is increased before using a conventional treatment route. After conventional treatment, volume reductions are significant.
- The silver II process was used to destroy TBP at Dounreay, using highly reactive Ag^{2+} ions but has not been used to treat contaminated oils. Ag^{2+} ions, generated electrolytically, are used to oxidise organic species to carbon dioxide and water, leaving solid materials behind for onward treatment.

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- Both processes have the potential to release volatile radionuclides to the gas phase and therefore require a gas treatment plant which will produce secondary wastes. Spent Nyex will require disposal as graphite LLW.
- The Arvia process is available as a bench-scale or full-scale plant although there are significant costs associated with scaling-up the process for a static full-scale plant. Operating costs are reduced as the Nyex material is regenerated *in-situ* to a large extent. There would be additional costs for onward treatment of the products of the process.

4.4.2 Wet oxidation

Wet oxidation requires a liquid feed and is not suitable for treating solid waste phases such as those found in oil contaminated solids or oils with active solids. Examples of wet oxidation processes used to treat organic radioactive wastes include ModulOx and NNL's SWORD process. NNL's SWORD process was developed specifically to destroy tritiated oils [2, 15, 18].

- ModulOx was a mobile wet oxidation plant developed in the UK to treat ion exchange resins and aqueous organic effluents, with mixed results. NNL's SWORD process is currently being developed in the UK for the treatment of tritiated oils.
- The SWORD process produces carbon dioxide and water as well as inorganic residues. The resultant residues may be encapsulated in, for example, cement or other grout. There are significant volume reductions with complete oxidation of the organic constituents of the waste.
- Both processes have the potential to release volatile radionuclides to the gas phase and therefore require a gas treatment plant which will produce secondary wastes.
- Generation of secondary wastes will be limited to those produced by routine maintenance of the equipment.
- The SWORD process is likely to be offered as a commercial service by NNL (similarly to the OWL process) and hence costs would be directly related to the volume and type of waste being treated. The process can be carried out at the bench-scale if smaller volumes of oil are to be treated. Operating and maintenance costs can be high for wet oxidation as special alloys are needed which are capable of resisting high temperatures/pressures and corrosive attack. There may be additional costs for any onward treatment of some products.

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4.5 Summary

At least one credible option has been identified for each waste group. None of these techniques, however, is a solution in its own right. All produce products and/or secondary wastes which will require onward management. Those processes which concentrate the activity may produce small volumes of solid ILW for management rather than the rather larger volumes of liquid LLW oil which were the feedstock. For many of the techniques, efficacy depends upon the exact nature of the feedstock, and careful characterisation. Trialling would be required before committing to any approach.

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5. Conclusions

Evaluation of the available inventory data has shown that the quality of characterisation for non-incinerable oils is poor. It is possible that, when these materials are adequately characterised, a significant volume will be found to be suitable for incineration without further treatment.

Credible technologies fall into three broad groups: those that destroy the oil thermally; those that destroy the oil chemically, and those that decontaminate the oil through phase separation.

As shown in Table 5 below, there is at least one credible technology that could be applied for each waste group identified in the inventory. None of the technologies identified is likely to provide a complete solution, although thermal techniques and absorption could be used to manage most of the waste groups, and all will generate products or secondary wastes that will require conditioning before disposal.

Given the sensitivity of some approaches to the physicochemical nature of the feedstock, it will be necessary to trial potential approaches on samples of oil from individual waste streams to ensure optimisation of conditions.

6. Recommendations

To take the findings of this study forward and to facilitate the implementation of waste management solutions, the following recommendations are made:

- A programme of characterisation is required to improve the quality and completeness of the inventory information; enabling the identification and implementation of waste management solutions. The National LLW Programme should promote and support the delivery of such characterisation activities.
- This study has identified that thermal treatment is a technology that could be used for the management of the range of different oil waste groups. The output of this study should be made available to the ongoing Thermal Treatment Integrated Project Team (IPT), set up by NDA, so that this potential opportunity can be recognised.
- Thermal treatment is a technology that has tolerance for a diverse range of feedstock. To enable the opportunity for the use of thermal technology for problematic waste management to be recognised, the National LLW Programme should undertake an assessment of the suitability of thermal treatment for the management of other problematic wastes, and should make the output available to the NDA Thermal Technology IPT.

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- Waste producers who hold group 2, 3, 4 and 5 oil wastes should assess the suitability of the OWL process (or similar decontamination processes) for their wastes.
- The National LLW Programme should, in collaboration with Magnox Ltd, produce and disseminate a briefing note on the use and effectiveness of the OWL decontamination process to make learning from the ongoing Trawsfynydd oil treatment available to the wider LLW management community.
- The output of this study should be made available to RWM Ltd Upstream Optioneering team to facilitate the assessment of the HAW oil inventory and the identification of common opportunities to take forward.
- Develop and deliver – seeking NDA funding as appropriate – a programme of work to undertake disposability assessments for oil absorption technologies.

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Table 5: Credible treatment technologies and their feasibility by waste group

	Technology	Tritiated oils (organically bound ³ H)	Tritiated water (³ HOH) in oil	Oils with active solids	Oily water (<50% H ₂ O)	Oil contaminated solids
Th	Pyrolysis	Yes	Yes	Possible	Yes	No
	Plasma treatment	Yes	Yes	Yes	Yes	Yes
Ph	Absorption	Yes	Yes	Yes	Yes	Possible
	Centrifugation	No	Possible	Yes	Yes	No
	Filtration	No	No	Yes	No	Possible
Ch	Decontamination	No	Yes	Yes	Yes	Yes
	Electrochemical treatment	Yes	Yes	Possible	Yes	No
	Wet oxidation	Possible	Possible	No	Possible	No

Th = Thermal, Ph = Physical, Ch = Chemical

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Images reproduced from PPG26 Safe Storage Drums and Intermediate Bulked Containers (NIEA, SEPA, Environment Agency, May 2011).

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Appendix 1: Grouped inventory tables

Group 1: Oils with organically bound tritium

No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
1	5H307	Culham	100	Transformer oil	Transformer oil	Future

Group 2: Oils with tritiated water

No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
1	2D30	Sellafield	107	Waste oils	Oils and hydraulic fluids from machinery within controlled areas and active areas	Current
2	2A30	Sellafield	25	Waste oils	Reactor blower lubricating oil from within controlled areas and active areas	Current and future
3		Dungeness B	1.3	Highly tritiated oils	Waste oil contaminated with tritium	Current
4		Hartlepool	1.3	Highly tritiated oils	Waste oil contaminated with tritium	Current
5		Harwell LEPT	1	Highly tritiated oils	Extracted from machinery used on reactors at Harwell	Current
6	5C47	Harwell	2	Organic wastes	Miscellaneous glovebox & cell operations, scintillant counting and pump oils. (Oil (70.0%), scintillants (12.8%), genklene (15.9%), 30% TBP/OK (1.3%). Scintillants mainly comprise toluene and xylene.)	Current and future

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Group 3: Oils with activated solids

No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
1		Sellafield	22	Waste oils (Hydraulic)	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
2		Sellafield	0.2	Waste oils (Silicon)	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
3		Sellafield	0.2	Waste oils (Mixture)	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
4		Sellafield	0.01	Waste oils (Mineral)	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
5		Sellafield	3	Waste oils (Mineral)	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
6		Sellafield	0.33	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
7		Sellafield	0.33	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
8		Sellafield	0.33	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment.	Current

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No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
					Waste includes hydraulic oils and oily waste from maintenance operations.	
9		Sellafield	0.8	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
10		Sellafield	2	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
11		Sellafield	3.5	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current and future
12		Sellafield	8.5	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
13		Sellafield	0.003	Waste oils	Lab generates 1 litre/year. Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current and future
14		Sellafield	0.019	Waste oils	This record has been updated to consolidate the entry of the facility. Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current and future
15		Sellafield	0.04	Waste oils		Current
16		Sellafield	0.41	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment.	Current

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No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
					Waste includes hydraulic oils and oily waste from maintenance operations.	
17		Sellafield	2.25	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations. LLW (TBC).	Current and future
18		Sellafield	0.025	Waste oils		Current
19		Sellafield	6	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
20		Sellafield	1	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
21		Sellafield	1	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
22		Sellafield	0.2	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
23		Sellafield	0.18	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current and future
24		Sellafield	0.01	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current and future
25		Sellafield	1	Waste oils	Waste oils arise from various sources e.g.	Current

National Waste Programme

No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
					Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	
26		Sellafield	0.3	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
27		Sellafield	1	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
28		Sellafield	0.02	Paraffin (Sample ID: LSN 1065121)		Current
29		Sellafield	0.01	Paraffin	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current and future
30		Sellafield	0.05	Oil residues	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
31		Sellafield	1	Mineral oil from plant machinery	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current
32		Sellafield	0.2	Free oil	Anticipated that a number of small packages will be present. Also may exist in machinery in the cells i.e. Gear boxes, hydraulic rams	Future
33		LLWR Ltd	200	Waste oils	Waste oils arise from various sources e.g.	Current and future

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No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
					Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	
34		LLWR Ltd	1	Waste oils	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current and future
35	7A34	Aldermaston	22	LLW contaminated oil	Contaminated oils originate from three sources - cutting oil from machining operations, lubricating oils and spent oil from vacuum pumps. The former are most heavily contaminated via pieces of swarf, and the latter two types by fine particles.	Current and future

Group 4: Oily water

No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
1		Harwell	0.03	Oily water		Current
2		Heysham A		Oily water		
3		Trawsfynydd	2.8	Oil, absorbent and oily water	Drums of oil, absorbent, grease and oily water.	Current

Group 5: Oil contaminated solids

No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
1		Sizewell B	4.6	Oily rags	Highly active oily rags (Dose rate 5 - 100 μ Sv/h)	Current

National Waste Programme

No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
2		Sellafield	36	Oil soaked waste	Waste oils arise from various sources e.g. Vehicle gearboxes, plant and equipment. Waste includes hydraulic oils and oily waste from maintenance operations.	Current

Other oils

No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
1		Sellafield	100	Cumulated oils	Oil is currently stored in a range of tanks but a programme of work has been initiated to cumulate this oil within oil tanks	Current
2		Sellafield	1	Redundant uncharacterised oils - yellow storage cabinet		Current
3		Sellafield	1	Redundant uncharacterised oils - red storage cabinet	Redundant materials. Unknown Rad Cat.	Current
4		Sellafield	1	Redundant uncharacterised oils - blue storage cabinet	Unknown Rad Cat.	Current
5		Sellafield	0.025	Oil - yellow liquid with odd black spec (Sample ID: 1065131)		Current
6		Sellafield	0.025	Oil - yellow liquid with odd black spec (Sample ID: 1065130)		Current
7		Sellafield	0.025	Oil - yellow liquid with odd black spec (Sample ID: 1065129)		Current
8		Sellafield	0.025	Oil - yellow liquid with odd black spec (Sample ID: 1065128)		Current

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No.	Waste ID	Site	Volume (m ³)	Waste Type	Source/Description	Current/Future Arising
9		Sellafield	0.25	Oil - slightly viscous yellow liquid (Sample ID: 1065123)		Current
10		Sellafield	0.025	Oil - brown/green liquid (Sample ID: 1065138)		Current
11		Sellafield	0.025	Hydraulic oil - dark green/blue liquid (Sample ID: 1065133)	pH = 7, Fourier Transform Infra-Red - Organic Material, high correlation with Shell Tellus37 Oil when compared using "compare" software.	Current
12		Sellafield	0.025	Hydraulic oil - dark green / blue liquid (Sample ID: 1065135)		Current
13		Sellafield	0.005	Material ex-THORP laser - PCBs oil		Current
14		Sellafield	0.03	Material ex-THORP laser - oil		Current
15		Sellafield	0.125	Houghto-sate 620 oil	Used in machinery and vehicles	Current
16		Sellafield	0.4	Contaminated oil		Current
17		Dungeness B	0.25	TWST oil	TWST oil	
18		Hinkley Point B		TWST oil	TWST oil	
19		Oldbury	1.47	Oily sludge drums	Oil and sludge originating from effluent processing and cleaning of oil tanks	Current
20		Sizewell B	1.5	Highly active oil	Highly active oil	Current
21		Trawsfynydd	1.6	Free oil	Drums of free oil	Current

National Waste Programme

Appendix 2: Initial assessment of all technologies with further assessment of credible technologies

Pyrolysis

Description

Pyrolysis is related to incineration, but is based on the thermal decomposition of organic materials under an inert or oxygen deficient atmosphere to destroy the waste and convert it into an inorganic powder (containing metal oxides and salts). The pyrolysis gas generated is burned in a simple combustion chamber and then treated in a flue gas cleaning section. The operating temperature for pyrolysis at 500-550 °C is significantly lower than for incineration. At these temperatures the problem of corrosive species such as phosphoric oxides causing corrosion to the pyrolysis equipment is removed as the oxides readily form stable inorganic phosphates. Also, at the reduced temperatures and oxygen levels, the most volatile species such as caesium (Cs) and ruthenium (Ru) are largely retained within the pyrolysis residue and do not require treatment in the off-gas system. However, other volatile elements such as tritium (H-3), carbon-14 (C-14) and iodine-129 (I-129) are released to the off-gas system.

Technological Readiness

Pyrolysis is an established method for the treatment of contaminated oils and other radioactive wastes and a diverse range of pyrolytic systems (downdraft, updraft, bubbling fluidised bed or entrained flow) are used in facilities worldwide. Countries with pyrolytic systems include Belgium, France, Japan, Sweden and the USA. General wastes suitable for pyrolysis are oils, ion exchange resins, organic solvents, sludges, plastics, filters, cellulosic materials and soils. Fixed pyrolysis plants are also capable of processing highly radioactive wastes with high activities and dose rates. Pyrolysis is generally applied with steam reforming or incineration as a second stage process to remove the carbon content to improve volume reduction and the final waste form. A typical pyrolysis (fluidised bed)/steam reforming plant is the Studsvik Processing Facility in the USA. Sodium/potassium bearing wastes can cause operational problems for fluidised bed pyrolysers. Halogenated wastes may require off-gas treatment to address dioxin and dibenzofuran constituents [1, 2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Solid or liquid feed. Can be used for higher activity wastes.	Licensed for treatment of tri-butyl phosphate (TBP) waste solvent, kerosene and hydraulic oil at a Belgian facility since 1999.
2	Solid or liquid feed. Able to process waste with high water content. Can be used for higher activity wastes.	
3	Solid or liquid feed. However solid must be in granular/powder form. Can be used for higher activity wastes.	
4	Solid or liquid feed. Able to process waste with high water content.	
5	Solid or liquid feed but the solid must be in granular/powder form.	N/A

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Application of Thermal Technologies for Processing of Radioactive Waste, IAEA-TECDOC-1527, December 2006.
2. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, 2004.

National Waste Programme

Pyrolysis – Further Assessment

Attribute	Assessment
Impact of waste stream characteristics	Can treat a wide range of solid or liquid wastes, however, solids must be in granular or powder form (particle size <5 cm) which rules pyrolysis out for oil contaminated solids and potentially oils with active solids. Able to process wastes with high water and organic content.
Nature and extent of radioactive contamination	Can be used for the treatment of high activity wastes. Volatiles (H-3) are released to the off-gas system.
Technical effectiveness	Effective for the liquid waste groups but not oil contaminated solids and, depending on solid size, oils with active solids.
Technological readiness	Extensive commercial experience in the processing of wastes with high organic content. Licensed for the treatment of TBP waste solvent, kerosene and hydraulic oil at a Belgian facility since 1999. Pyrolysis plants also operate in Sweden, France, Germany, Japan and the USA.
Nature and disposability of products	Methane, ethane, benzene, toluene, inorganic powder (oxides and salts), tars and carbon-rich chars due to excess carbon. Substantial volume and mass reductions. Pyrolysis is often coupled with steam reforming to completely remove the carbon fraction, which results in a greater volume reduction and an improved final wasteform for disposal. Inorganic product can be directly disposed, vitrified or encapsulated.
Nature and disposability of secondary wastes	An off-gas system is required and hence produces secondary wastes such as HEPA filters, sludges and scrubber salts/solutions. Compared to incineration, gas flow rates are low which reduces demands on the off-gas system.
Discharges	Discharges to the atmosphere after off-gas treatment. Insignificant NO _x production as the process is reducing.
Economic issues	Significant capital costs and overall lifecycle costs. Cost is driven by the complexity and degree of regulation of the waste to be treated. Running costs are directly related to the waste volume. Costs can be reduced if the plant is also used for other types of LILW than oil. Additional costs if further conditioning of the inorganic product is required.
Safety issues	High temperature. May need to account for safe transport of the waste to an off-site facility.

References

1. IAEA, Application of Thermal Technologies for Processing of Radioactive Waste, IAEA-TECDOC-1527, December 2006.
2. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
3. IAEA, Innovative Waste Treatment and Conditioning Technologies at Nuclear Power Plants, IAEA-TECDOC-1504, May 2006.

National Waste Programme

Plasma Treatment

Description

Plasma treatment uses an electric arc to generate a temperature in excess of 20,000 °C. This temperature causes the molecular structure of materials to be broken into their constituent atoms in the form of a solid, glass-like material (slag). Direct vitrification of the slag by the addition of glass frit during plasma treatment may yield a wasteform with enhanced properties. The final wasteform is robust, free of organic material, and suitable for long-term storage and disposal. The electric arc can be generated by a conventional plasma torch 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.

Technological Readiness

Plasma technology has been used extensively for many years outside of the nuclear industry in the production of high purity metal alloys and for the plasma synthesis of acetylene. The first full scale plant for processing low level waste was the plasma arc centrifugal treatment plant (PACT) at the ZWILAG facility in Switzerland. The system is supplied with a drum feed with the final wasteform being a vitrified slag. There is a similar system in Japan. A graphite electrode plasma system is currently used at the KAERI waste treatment centre in the Republic of Korea. Liquid radioactive waste can be treated by injection into the stream of plasma gas or simultaneously with solid waste in the primary reaction chamber. Due to the higher temperature range of the plasma treatment process compared to that of conventional methods such as incineration, the range of applicable waste types is much greater and can include solid and liquid organic wastes as well as inorganic and mixed materials that require higher temperatures to break down [1, 2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Due to high temperature, a large range of applicable waste types including solid and liquid organic wastes.	Not yet proven for the routine treatment of oils. Plasma facilities for LLW operating in Switzerland, Japan and South Korea.
2		
3		
4		
5		

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Application of Thermal Technologies for Processing of Radioactive Waste, IAEA-TECDOC-1527, December 2006.
2. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, 2004.

National Waste Programme

Plasma Treatment – Further Assessment

Attribute	Assessment
Impact of waste stream characteristics	There are a large range of applicable waste types including solid and liquid organic wastes due to the extremely high temperature used (~20,000°C).
Nature and extent of radioactive contamination	Can be used for the treatment of very high activity wastes. Volatiles (e.g. H-3) are released to the off-gas system.
Technical effectiveness	Effective for the five waste groups.
Technological readiness	Not yet fully proven for the routine treatment of contaminated oils. There is limited full-scale plant experience; however, plasma facilities for LLW are currently operating in Switzerland, Japan and South Korea.
Nature and disposability of products	Granular inorganic material or slag. Direct vitrification of the slag during plasma treatment yields an enhanced wasteform for disposal but this makes the system more expensive to construct and operate. Volume reduction factors can exceed 100:1 (for organic waste).
Nature and disposability of secondary wastes	An extensive off-gas system is required and hence produces secondary wastes such as HEPA filters, sludges and scrubber salts/solutions. Compared to incineration, the off-gases contain increased concentrations of radioactive particles and nitrogen oxides as well as tens of grams of combustible components per kilogram of off-gas. This puts greater demands on the off-gas system and hence increases cost.
Discharges	Discharges to the atmosphere after off-gas treatment.
Economic issues	High capital costs and overall lifecycle costs. Need to operate with sufficient input waste stream to justify large investment – treating HAW alongside LLW may be an opportunity to improve cost effectiveness. Running costs are directly related to the volume of waste. Reduced costs for combined plasma/vitrification compared to separate facilities for treating and then conditioning the waste.
Safety issues	Extremely high temperature. High voltage. May need to account for safe transport of the waste to an off-site facility.

References

1. IAEA, Application of Thermal Technologies for Processing of Radioactive Waste, IAEA-TECDOC-1527, December 2006.
2. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
3. IAEA, Management of Low and Intermediate Level Radioactive Wastes with Regard to their Chemical Toxicity, IAEA-TECDOC-1325, December 2002.

National Waste Programme

Absorption

Description

Oil is immobilised by absorption onto a substrate such as a clay or polymer. The liquid is simply brought into contact with the absorbent, resulting in a solid product. Immobilisation by absorption may be followed by encapsulation in cement for final disposal or an alternative onward treatment method such as incineration. In the latter case liquids retained in absorbents can be fed into incinerator systems which are not equipped with liquid feeding systems. The radionuclides can either be retained with the oil in the absorbent matrix (e.g. organically bound H-3) or separated from the oil in the case of unabsorbed active solids or tritiated water (HTO). Hydrophilic polymers can also be utilised to absorb any water from the oil without absorbing any oil, i.e. to remove HTO.

Technological Readiness

This technique is proven for the absorption of oil but has not been widely adopted for treatments of large volumes of oil. It is an established method for immobilising turbine and pump oils. A number of absorbents are available, from clays to specific polymers, with the resultant material varying from dry particles to jelly-like solids, or to hard and dry solid mass. Development work in the 1980s reported the use of special cements for the solidification of organic liquid waste such as lubricating oils and scintillation fluids. More recently in the USA and the UK, an absorbent polymer has been used for the solidification of tritiated oils [1]. This 'Nochar' polymer was developed based on experience gained from major oil spill operations. The method of deployment is straightforward as waste oil is mixed with the absorbent by pumping the oil into a drum containing the polymer. The oil is then absorbed without mechanical mixing which facilitates a reduction of operator dose as well as the possibility of remote handling to minimise potential H-3 exposure [2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Nochar polymer will solidify the oil containing the H-3.	Nochar is currently used for oils containing H-3 at a NPP in Romania and sites in the USA. It has also been tested at Sellafield.
2	A different mixture of Nochar polymers can be used depending on the water content.	Nochar is currently used to remove tritiated water from oil at a NPP in Romania and sites in the USA. It has also been tested at Sellafield.
3	Any solid contaminants too large to be absorbed into the pores of the polymer are left untreated.	Nochar is currently used to separate solids from oil at a NPP in Romania and sites in the USA. It has also been tested at Sellafield.
4	A mixture of Nochar polymers can be used depending on the water/oil content or one polymer can be used that will react with the oil only and in doing so separate it from the water.	Nochar is currently used for oils mixed with water at a NPP in Romania and sites in the USA. It has also been tested at Sellafield. Used 'N910 Petro Bond' for the oil and 'N960 Acid Bond' for the water.
5	The polymer will separate the oil from the solids, but will not fully extract the oil from any absorbents.	Nochar is currently used to separate solids from oil at a NPP in Romania and sites in the USA. It has also been tested at Sellafield.

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. H. Cassidy and D. Kelley, Oil Immobilisation Program at Sellafield: An Innovative Approach, WM'07 Conference Proceedings, 2007.
2. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
3. G. Teodorov, L. Toro, A. Sandru, D. Kelley and D. Dumitrescu, Pre-treatment of organic liquid waste stream at Cernavoda NPP, Presentation at ICEM 2011, 2011.
4. U.S. Department of Energy, Nochar Petrobond® Absorbent Polymer Tritiated Oil Solidification, Innovative Technology Summary Report DOE/EM-0598, 2001.

National Waste Programme

Absorption – Further Assessment

Attribute	Assessment
Impact of waste stream characteristics	In wastes containing both oil and water, it is possible to use both the Nochar 'Petro Bond' polymer to absorb the oil and the Nochar 'Acid Bond' polymer to absorb the water. Alternatively, absorption using one of the polymers leaves the other component in liquid form for onward treatment. Only solids with sufficiently small particle sizes can be absorbed into the pores of the polymer.
Nature and extent of radioactive contamination	Nochar polymers which are capable of treating tritiated oils and tritiated water have been developed. Active solids may be retained within the polymer but only if the particles are small enough.
Technical effectiveness	Effective for the identified waste groups except oil contaminated solids.
Technological readiness	Feasibility established for contaminated oils but not widely demonstrated for large volumes of oil. Nochar has been used to treat contaminated turbine and pump oils. Nochar polymers are currently being used in the USA, Canada and Romania and have also been trialled in the UK, Japan, France and elsewhere. R&D (and costs) would be required to determine disposability of the solidified polymer product for different waste streams.
Nature and disposability of products	A solidified polymer product containing the absorbed oil and/or water for final disposal. Further conditioning of the solidified polymer product may be required for disposal, e.g. immobilisation in grout. Significant increase in volume due to added substrate (overall volume is approximately tripled). Solid product is certified incinerable as a solid feed for incinerators incapable of processing liquids (<0.02% ash).
Nature and disposability of secondary wastes	Some solids may not be absorbed into the polymer – these may require conditioning for disposal.
Discharges	Some non-radioactive liquid discharges from cleaning of the equipment, but small in quantity.
Economic issues	Requires specific equipment with lower capital costs than for thermal processes. Static or mobile plant. Low operating costs include the cost of the polymer (assumed to be similar to the costs of encapsulation per unit waste). Additional costs for any further conditioning if required. Costs to determine disposability of the solidified polymer product for different waste streams.
Safety issues	Low chemical hazard to operators but this can be easily managed.

References

- IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
 - H. Cassidy and D. Kelley, Oil Immobilisation Program at Sellafield: An Innovative Approach, WM'07 Conference Proceedings, 2007.
 - G. Teodorov, L. Toro, A. Sandru, D. Kelley and D. Dumitrescu, Pre-treatment of organic liquid waste stream at Cernavoda NPP, Presentation at ICEM 2011, 2011.
 - U.S. Department of Energy, Nochar Petrobond® Absorbent Polymer Tritiated Oil Solidification, Innovative Technology Summary Report DOE/EM-0598, 2001.
- IAEA, Innovative Waste Treatment and Conditioning Technologies at Nuclear Power Plants, IAEA-TECDOC-1504, May 2006.

National Waste Programme

Centrifugation

Description

Centrifugal separation is a widely used method for separating immiscible fluids with different densities or for separating solids from fluids. A centrifuge applies centrifugal force to a sample by revolving it at high revolutions per minute (rpm) to separate heterogeneous mixtures. In principle, centrifugation should allow for the separation of the organic, aqueous and solid phases and these waste streams can then be further treated accordingly, e.g. the organic component (i.e. oil) can be incinerated. Each of the three secondary waste streams is in principle straightforwardly manageable; however, this may depend on how well separation is achieved. In particular, the amount of residual oil in the solid and the water may affect their suitability for future treatment. The efficiency of separation can be increased by reducing oil viscosity and this can be achieved by heating the oil before treatment. It is not clear to what extent any H-3 will be removed within the aqueous phase, as this depends on the extent of isotopic exchange (i.e. organically bound H-3 will be retained in the oil phase).

Technological Readiness

Centrifugation is used in industry and in laboratory settings. The technique is well-established for the recovery of oils for re-use or recycling and should be able to separate the organic, aqueous and solid phases in the waste stream allowing the removal of insoluble activated solids. Centrifugal oil cleaners are used industrially to remove particulates and impurities from oil allowing for it to be re-used [1]. Centrifugal oil-water separators are also used for waste water processing and in the cleanup of oil spills [2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Cannot remove H-3 from oil if organically bound.	N/A
2	It can separate the tritiated water from the oil. The effectiveness will depend on the degree of isotopic exchange of H-3.	It is currently used industrially for oils (separation of water from industrial oil). Needs to be tested for contaminated oils. Efficiency of separation not established for oil containing finely dispersed solids or colloidal/dissolved water.
3	It can potentially separate the active solids (particles that are >1 µm), leaving incinerable oil, water and solids/sludge.	It is currently used industrially for oils (separation of water from industrial oil). Needs to be tested for contaminated oils. Waste oil, water and solids can be separated in a high performance 3-phase decanter centrifuge.
4	It can separate the water from the oil, leaving incinerable oil and water.	It is currently used industrially for oils (separation of water from industrial oil). The ability to remove the final traces of water from the oil phase needs to be established.
5	Technique works on liquids, not solids.	N/A

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. William Harris, How Portable Centrifugal Oil Cleaning Systems Work, July 2009, accessed 16/12/14 [<http://science.howstuffworks.com/environmental/green-tech/sustainable/centrifugal-oil-cleaning.htm>].
2. MANN+HUMMEL, Centrifugal Oil Cleaners: High Performance Bypass Oil Filtration catalogue, accessed 16/12/14 [https://www.mann-hummel.com/fileadmin/user_upload/service/catalogues/pdf/MH_Centrifuges_en.pdf].
3. Waste oil, water, and solids separation in one high performance 3-phase decanter centrifuge: [<http://hiller-us.com/waste-oils.php>] accessed 09/01/15.

National Waste Programme

Centrifugation – Further Assessment

Attribute	Assessment
Impact of waste stream characteristics	In principle, it should be practicable to separate the organic, aqueous and solid phases within the waste. Efficiency of separation is not established for oil containing finely dispersed solids or colloidal/dissolved water.
Nature and extent of radioactive contamination	Should allow for the removal of insoluble active solids depending on size/density (generally particles that are >1 µm). For tritiated water in oil, it is not clear to what extent the H-3 will be separated, as the extent of isotopic exchange and efficacy of oil-water separation is uncertain.
Technical effectiveness	Effective for oil with active solids and oily water. Not a viable solution for oil-contaminated solids or oils with organically-bound H-3. Effectiveness needs to be properly established for tritiated water in oil.
Technological readiness	The technique is well-established for the recovery of industrial oils for re-use or recycling (separation of water from industrial oil). Equipment is widely available and not unduly expensive. Nuclear experience is mainly with separation of solids from aqueous phases. It is used as part of NNL's OWL process for oils. Need to test its suitability for contaminated oils.
Nature and disposability of products	Oil that can be incinerated. Tritiated water and solids/sludges both requiring further treatment/conditioning. Separation of phases will not increase volume, but further treatment of the separated phases may increase the overall volume.
Nature and disposability of secondary wastes	Tritiated water requiring further treatment possibly by conventional water treatment routes. Solids requiring conditioning for disposal.
Discharges	Some non-radioactive liquid discharges from cleaning of the equipment, but small in quantity.
Economic issues	Low capital costs for equipment (static or mobile). Low operating costs. Some financial risk associated with the need to demonstrate that phases are adequately separated and suitable for onward treatment (i.e. the cost of R&D and trialling). Additional costs for any further treatment or conditioning.
Safety issues	No significant safety issues arising from processing.

References

1. Waste oil, water, and solids separation in one high performance 3-phase decanter centrifuge, [<http://hiller-us.com/waste-oils.php>] accessed 09/01/15.
2. William Harris, How Portable Centrifugal Oil Cleaning Systems Work, July 2009, [<http://science.howstuffworks.com/environmental/green-tech/sustainable/centrifugal-oil-cleaning.htm>] accessed 16/12/14.
3. MANN+HUMMEL, Centrifugal Oil Cleaners: High Performance Bypass Oil Filtration catalogue, [https://www.mann-hummel.com/fileadmin/user_upload/service/catalogues/pdf/MH_Centrifuges_en.pdf] accessed 16/12/14.

National Waste Programme

Filtration

Description

Filtration systems are used to remove insoluble impurities to produce a liquid for discharge or further treatment. Particle-bound radioactive species can be effectively removed from contaminated oils using different filtration processes, e.g. pressure filters or cartridge filters. Filter selection is important as fine particles may pass through some filters while viscous liquids may not pass through some filters. Filtration systems are often coupled with supplemental treatment technologies, such as chemical pre-treatment, evaporation, crystallisation, ion exchange or membrane technologies, to further improve the effluent quality.

Technological Readiness

Oil filtration is currently used to treat contaminated oils in Canada, the UK and the USA. Filtration is also used to treat aqueous waste streams containing insoluble impurities and also to remove any sizeable solids prior to oil centrifugation. Oil may be heated prior to filtration to reduce its viscosity and hence accelerate the filtration process. After filtration, oils and lubricants may be suitable for reuse or recycling. Filtration should only increase waste volume in the form of spent filters, however further treatment of the separated components from filtration may increase the overall volume significantly.

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Cannot separate organically bound H-3 from tritiated oils.	N/A
2	Cannot separate liquids from other liquids or H-3 from HTO.	N/A
3	Will separate the active solids from the oil, depending on particle size and filter 'pore' size.	Used to filter active solid contaminated oils in Canada, the UK and the USA. Used prior to oil centrifugation. Oil can be heated to reduce viscosity which eases filtration.
4	Cannot separate liquids from other liquids.	N/A
5	May separate oil from some solids, but not absorbents.	Used to filter active solid contaminated oils in Canada, the UK and the USA. Used prior to oil centrifugation. Oil can be heated to reduce viscosity which eases filtration.

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Innovative Waste Treatment and Conditioning Technologies at Nuclear Power Plants, IAEA-TECDOC-1504, May 2006.
2. IAEA, Mobile Processing Systems for Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-T-1.8, May 2014.
3. Oil Filtration Systems, [<http://www.oilfiltrationsystems.com/>] accessed 02/02/15.

National Waste Programme

Filtration – Further Assessment

Attribute	Assessment
Impact of waste stream characteristics	Separates the liquid and solid phases. Fine particles may pass through some filters so an appropriate filter must be selected. High viscosity liquids or sludges are difficult to filter and hence may not be suitable.
Nature and extent of radioactive contamination	Only particle-bound radioactivity may be removed effectively. Unlikely to be effective in treating oil contaminated solids if oil is soaked into a substrate, e.g. oily rags.
Technical effectiveness	Effective in the treatment of oils with active solids. Not an effective solution for oils with organically-bound H-3, oils with tritiated water, or oily water. Unlikely to be effective in treating oil contaminated solids.
Technological readiness	Used for contaminated oils in Canada, the UK and the USA. Oil may be heated prior to filtration to reduce viscosity and ease filtration. Equipment is widely available. Filtration is generally used before centrifugation to remove solids too large for centrifugation easily.
Nature and disposability of products	Oil that can be incinerated. Solids requiring treatment or conditioning. Filtration will not increase volume, but further treatment of the separated components may increase overall volume.
Nature and disposability of secondary wastes	Spent filters requiring treatment or conditioning.
Discharges	Liquid discharges from cleaning of the equipment or filter, but small in quantity.
Economic issues	Likely to be economical in the case of large volume of oils to be filtered. Low capital costs for equipment. Low operating costs. Additional costs for any further treatment or conditioning.
Safety issues	No significant safety issues arising from processing.

References

1. IAEA, Innovative Waste Treatment and Conditioning Technologies at Nuclear Power Plants, IAEA-TECDOC-1504, May 2006.
2. IAEA, Mobile Processing Systems for Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-T-1.8, May 2014.
3. Oil Filtration Systems, [<http://www.oilfiltrationsystems.com/>] accessed 02/02/15.

National Waste Programme

Physical / Chemical Decontamination

Description

Decontamination would be used to remove radioactive contaminants from the waste. Secondary waste will be produced with every decontamination method therefore the consequences of treating the resulting product must be evaluated before applying a method. These methods include solvent cleaning, liquid-liquid extraction and surface cleaning with supercritical CO₂. Advantages of decontamination include the reuse of material or the possibility of disposal as non-radioactive waste. Decontamination separates the radionuclides from the waste stream into, for example, active solids and decontaminated oil or tritiated water and decontaminated oil.

Technological Readiness

Contaminated oils have previously been decontaminated by liquid-liquid extraction. This method is used at a Czech nuclear power plant where a mixture of oil and water is pumped into a closed tank with a capacity of 1 m³. The mixture consists of 500 litres of oil and 100-200 litres of demineralised water. Circulation can take 1-3 hours, and when the phase equilibrium has been established water is discharged from the lower section of the tank. The water contains the radioactive contaminants and is treated in a water purification system. The cleaned oil can be disposed of as inactive waste. During oil collection it is necessary to segregate non-chlorinated oils from chlorinated substances as the latter are either unacceptable for incineration or their incineration would be very expensive due to corrosion by chloride. Supercritical CO₂ has been used in Germany to separate oil from swarf and sludges as in the supercritical state (32 °C and 300 bar), CO₂ has unique solvent properties. At a pressure of 400 bar, 1 kg of supercritical CO₂ was able to dissolve 100 g of oil [1]. In the UK, the NNL has the OWL (Oil Waste Leaching) process for the decontamination of oils [2]. OWL has been mostly used for water miscible cutting oils but also for hydraulic and lubricating oils. If necessary, centrifugation is used prior to washing of the oil using 4 M H₂SO₄ at 60 °C with the addition of mild oxidants. If required, further treatment with NaOH or KOH solution has proven successful. Emulsion breaking additives can also be used to enhance phase separation.

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	A more aggressive approach is required.	N/A
2	The OWL process has successfully treated a range of oils.	In the UK the NNL has the OWL (Oil Waste Leaching) process for treating hydraulic, lubricating and water miscible cutting oils.
3	The OWL process has treated 200 tonnes of uranium-contaminated oil. Varying amounts of solids are tolerated.	
4	The OWL process has successfully treated a range of oils.	
5	Oil can be decontaminated from some solids using supercritical CO ₂ . Material/PPE can use detergents/solvent.	Supercritical CO ₂ has been used in Germany to separate oil from chips and sludges in cutting oils.

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

- IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
- D. Coppersthaite, Processing Liquid Organic Wastes at the NNL Preston Laboratory, ICM2013, [<http://www.asmeconferences.org/ICM2013/pdfs/96071.pdf>] accessed 16/12/14.

National Waste Programme

Physical / Chemical Decontamination – Further Assessment

Attribute	Assessment
Impact of waste stream characteristics	In the case of NNL's OWL (Oil Waste Leaching) process, i.e. solvent washing, there is limited tolerance to solid content. Decontamination of oil from contaminated solids may be achieved using supercritical CO ₂ .
Nature and extent of radioactive contamination	Tritiated oils require a more aggressive approach than decontamination; hence the NNL has developed the SWORD process (see Wet Oxidation) specifically to destroy tritiated oils.
Technical effectiveness	Effective for the identified waste groups except tritiated oils and oil contaminated solids. Oil contaminated solids may be decontaminated using supercritical CO ₂ , depending on the solid form i.e. non-absorbent.
Technological readiness	In the UK, NNL has developed the fully industrialised OWL process/service for treating water miscible cutting oils, hydraulic oils and lubricating oils. Following processing any uranium present would be recovered for recycling to fuel or conditioning and wastes rendered suitable for disposal. Approximately 1000 drums of oil and tens of tonnes of TBP/OK have been processed using OWL. The OWL process is currently being used by Magnox at Trawsfynydd to treat problematic oil waste streams successfully. Decontamination of oil from oil contaminated solids may be achieved using supercritical CO ₂ (as in Germany for swarf/sludges in cutting oil), depending on the solid form. Conventional detergents/solvents may be used for absorbents/PPE.
Nature and disposability of products	Solid- and solvent-free oil is recovered – the OWL service ensures that the oil meets 'out of scope' activity levels hence treated oil can be converted into fuel oil or incinerated. Oil-free solids or residues can be recovered for further treatment or conditioning.
Nature and disposability of secondary wastes	Decontamination produces secondary wastes, e.g. aqueous waste solvent waste from the OWL process (solvent washing). Oil-free solids or residues can also be recovered for onward treatment by, for example, NNL's ARTEMIS process (solvent based washing process developed for oily residues).
Discharges	Discharge of liquid within acceptable limits after effluent treatment.
Economic issues	Typically low costs depending on decontamination method, i.e. using supercritical CO ₂ is more expensive than solvent washing. Costs are directly related to the waste volume when using a commercial service. Additional costs for further treatment or conditioning.
Safety issues	Low chemical hazard to operators but this can be easily managed.

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. D. Coppersthaite, Processing Liquid Organic Wastes at the NNL Preston Laboratory, Presentation at ICEM 2013, 2013, [<http://www.asmeconferences.org/ICEM2013/pdfs/96071.pdf>] accessed 16/12/14.
3. NNL website, Commercial Services - Waste and Residue Processing – Organic Wastes and Residues [<http://www.nnl.co.uk/commercial-services/waste-and-residue-processing/organic-wastes-and-residues/>] accessed 20/01/15.
4. IAEA, Mobile Processing Systems for Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-T-1.8, May 2014.

National Waste Programme

Electrochemical Treatment

Description

Electrochemical methods are based on the creation of highly reactive ions and their subsequent use to break organic bonds and hence destroy the organic material. The most common method, known as the silver II process, utilises a highly reactive form of silver (Ag^{2+} ions) in a standard electrochemical cell. The feedstock is fed into the reaction vessel containing a HNO_3 and silver nitrate solution in an anolyte circuit. The anolyte solution is circulated through the electrochemical cell where the natural Ag^+ ions are transformed into highly reactive Ag^{2+} ions which attack the organic feed. The organic matter is broken down into insoluble inorganic salts, CO_2 and H_2O , which migrate across a membrane, preventing bulk mixing of the anolyte and catholyte. The reaction turns the Ag^{2+} ions back into Ag^+ ions which are recycled to continuously generate the active Ag^{2+} species. The insoluble inorganic precipitates are extracted from the anolyte circuit using a hydrocyclone. The cathodic reaction involves reduction of HNO_3 and protons to HNO_2 , NO_x and H_2O . The HNO_2 and NO_x are oxidised to HNO_3 through reaction with O_2 and H_2O . There is no volatilisation of low molecular weight species which are formed as intermediates during the destruction process, and the process can be readily started and stopped by switching the current on or off. Active solids are retained within the insoluble inorganic salt, however, off-gas equipment is required for volatile species (H-3 and C-14) [1].

Technological Readiness

Whilst the technique is in principle feasible for use on oils, it has not been widely used for their destruction on a routine basis. It is suitable for the treatment of a wide range of liquid organic wastes but not solids unless they are very finely dispersed in a liquid. The technology has been developed to 4 kW pilot plant scale and operated on a semi-continuous basis at Dounreay to destroy radioactive wastes such as TBP [2]. The technology has been deployed in the USA for the treatment of military waste. The silver II process has also been investigated in Belgium.

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Can treat a wide range of liquid organic wastes even with 100% organic content.	Pilot plant operational at Dounreay to destroy TBP. Technology deployed in the USA for treatment of military waste.
2	Can treat a wide range of liquid organic wastes even with 100% organic content.	Pilot plant operational at Dounreay to destroy TBP. Technology deployed in the USA for treatment of military waste.
3	Not suitable for solid waste unless finely dispersed in a liquid. Active solids may be finely dispersed.	N/A
4	Can treat a wide range of liquid organic wastes even with 100% organic content.	Pilot plant operational at Dounreay to destroy TBP. Technology deployed in the USA for treatment of military waste.
5	Liquid feed required. Not suitable for solid waste unless finely dispersed in a liquid.	N/A

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. D. F. Steele, A Method for the Treatment of Waste Matter, European Patent EPO 297 738 B1, filed 1989; US Patent 4 874 485, filed 1989; Japanese Patent 64030689, filed 1988; UKAEA London.

National Waste Programme

Electrochemical Treatment – Further Assessment

Attribute	Assessment
Impact of waste stream characteristics	A liquid feed is required as the technique is not suitable for solid waste unless finely dispersed in a liquid.
Nature and extent of radioactive contamination	Able to treat tritiated oils and oils with finely divided active solids. A basic off-gas system is required (due to low H-3 activity in the vented gases).
Technical effectiveness	Effective for the liquid waste groups but not oil contaminated solids and, depending on solid size, oils with active solids.
Technological readiness	A pilot Ag(II) plant was operational at Dounreay to destroy TBP. The Arvia Process uses an ODC (Organic Destruction Cell) with an adsorbent graphite material, Nyex, to destroy radioactive organics including hydraulic and turbine oils. Arvia Technology and Magnox Ltd undertook full-scale active trials (of the 'Arvia Titan') at Trawsfynydd with the R&D stage being completed in 2013. Arvia is also working with the Department of Energy in the USA and Areva in France to identify opportunities to use the Arvia process.
Nature and disposability of products	CO ₂ , H ₂ O, insoluble inorganic residue. The product aqueous system containing the inorganic residue can be treated as aqueous waste (e.g. in an active effluent treatment plant as at Trawsfynydd).
Nature and disposability of secondary wastes	Spent electrodes and spent adsorbent material (graphite LLW from the Arvia process) which can be sentenced to the LLWR.
Discharges	Discharges to the atmosphere after off-gas treatment. Laboratory scale tests showed low fractions of the overall H-3 activity in the off-gas which implies that the off-gases from a full-scale plant could potentially be managed by direct discharge (following HEPA filtration).
Economic issues	Option of reduced capital costs for a bench-scale plant compared to a full-scale plant (i.e. expense of scaling up). Low operational costs in part due to the <i>in-situ</i> regeneration of the Nyex (minimising secondary waste production). Additional costs to treat the aqueous phase.
Safety issues	No significant safety issues arising from processing.

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. D. F. Steele, A Method for the Treatment of Waste Matter, European Patent EPO 297 738 B1, filed 1989; US Patent 4 874 485, filed 1989; Japanese Patent 64030689, filed 1988, UKAEA London.
3. Arvia Technology Limited, Arvia Process, [<http://www.arviatechnology.com/index.php/technology/nyex>] accessed 26/01/15.
4. D. Wickenden and M. Lodge, The Arvia Process for Oil Waste Destruction, Presented at CIRIA, London, UK, June 2012 [http://www.safegrounds.com/pdfs/Events_2012/Benefitsresearch_june2012_presentation6.pdf] accessed 26/01/15.
5. N. W. Brown, D. A. Wickenden and E. P. L. Roberts, On-site destruction of Radioactive Oily Wastes Using Absorption Coupled with Electrochemical Regeneration, Presented at WM2012, Phoenix, USA, March 2012.

National Waste Programme

Wet Oxidation

Description

The wet oxidation technique uses soluble salts of redox sensitive elements with H₂O₂ or air/O₂ to bring about the chain reaction oxidation of organic materials, producing CO₂, H₂O and inorganic salts retaining the radionuclides. The process uses highly oxidising hydroxyl radicals to abstract hydrogen atoms or to add across unsaturated bonds to form organic radicals. Reduction or oxidation by the transition metal ion can stabilise the organic radical, allowing further attack by hydroxyl radicals. Eventually the organic carbon structure is completely converted in a reaction analogous to incineration. Wet oxidation can be applied at low temperatures and pressures, generally using hydrogen peroxide, sometimes with a catalyst, or at high temperatures and pressures using oxygen or compressed air as the oxidant. Once initiated, the oxidation reaction is generally exothermic [1].

Technological Readiness

Wet oxidation is not an established method for the treatment of oils. The technique is suitable for low concentration water miscible organic feeds. Application of this chemical method has proven successful for the treatment of ion exchange resins with either an iron or copper catalyst. Promising results with a 99% organic carbon reduction and 78% volume reduction led to the development of a mobile treatment plant in the UK by AEA Technology, Magnox Electric, GNS mbH and NV Belgoprocess. It was designed to treat up to 100 litres of organic exchange resin per day and was contained within a single ISO transport container. The resultant slurry residues were encapsulated in cement [2]. Constraints of the technique include a reliance on soluble heavy metal catalysts and that it can result in incomplete oxidation. Where a high temperature is required, the systems require special alloys to sustain high pressure and to resist corrosive attack. The SWORD wet oxidation process developed by the NNL in the UK retains about 98.4% of the H-3 content within the H₂SO₄ or condensate although further laboratory development and testing is required [3].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	The technique is suitable for liquid organic feeds and not solids. The SWORD process was developed by the NNL to destroy tritiated oils.	The SWORD (Springfields Waste Organic Residue Digester) process is effective in the destruction of oil but requires further laboratory development and testing. H-3 recovery expected to improve with efficient off-gas treatment.
2	The technique is suitable for liquid organic feeds and not solids.	Mobile treatment plant (ModulOx) in the UK. NNL's SWORD process in the UK for oil but requires further development & testing.
3	The technique is suitable for liquid organic feeds and not solids.	N/A
4	The technique is suitable for liquid organic feeds and not solids.	Mobile treatment plant (ModulOx) in the UK. NNL's SWORD process in the UK for oil but requires further development & testing.
5	The technique is suitable for liquid organic feeds and not solids.	N/A

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. R. G. Charman and M. A. Twissell, Wet oxidation mobile pilot plant demonstration on organic radioactive wastes, European Commission, EUR 19064 EN, Final report, 1999.
3. D. Coppersthaite, Processing Liquid Organic Wastes at the NNL Preston Laboratory, ICEM2013, [<http://www.asmeconferences.org/ICEM2013/pdfs/96071.pdf>] accessed 16/12/14.

National Waste Programme

Wet Oxidation – Further Assessment

Attribute	Assessment
Impact of waste stream characteristics	The technique is suitable for liquid organic feeds but not solids. Wet oxidation may produce undesirable effects for some solid phases.
Nature and extent of radioactive contamination	NNL developed the SWORD (Springfields Waste Organic Residue Digester) process specifically to destroy tritiated oils which could not be treated using the OWL process (see Decontamination).
Technical effectiveness	The technique is not suitable for solids which rules it out for oil contaminated solids and oils with active solids. Effectiveness for the liquid waste streams requires further development and testing.
Technological readiness	A mobile treatment plant (ModulOx) was used in the UK to treat organic ion exchange resins and aqueous organic effluents. NNL have developed the SWORD process for treating tritiated oils, however, the process requires further development and testing.
Nature and disposability of products	CO ₂ , H ₂ O and inorganic residues. Significant volume reductions. Resultant slurry residues can be encapsulated in cement or other grout.
Nature and disposability of secondary wastes	An off-gas system is required which will produce secondary wastes. Secondary wastes comprise the distillate from the reaction vessel as well as spent scrubber liquor. These can be treated using conventional aqueous waste treatment routes.
Discharges	Discharges to the atmosphere following off-gas treatment. About 98.4% of the H-3 content is retained within the aqueous phase – H-3 recovery is expected to improve with efficient off-gas treatment.
Economic issues	There are R&D costs associated with developing the SWORD process to a sufficient extent for use. High lifecycle costs due to the high levels of maintenance required - where a high temperature is required, systems require special alloys to sustain high pressure and resist corrosive attack. Additional costs for conditioning the inorganic residue for disposal. The SWORD process could potentially become available as a commercial service.
Safety issues	Low chemical hazard to operators but this can be easily managed.

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. R. G. Charman and M. A. Twissell, Wet oxidation mobile pilot plant demonstration on organic radioactive wastes, European Commission, EUR 19064 EN, Final report, 1999.
3. D. Coppersthaite, Processing Liquid Organic Wastes at the NNL Preston Laboratory, Presentation at ICM 2013, 2013, [<http://www.asmeconferences.org/ICEM2013/pdfs/96071.pdf>] accessed 16/12/14.

National Waste Programme

Vitrification

Description

The vitrification process combines (pre-calcined) feedstock materials with glass forming compounds at high temperature, usually to produce a solution of radionuclides in a glass matrix which is then poured into a container and allowed to cool to form a monolithic block. The high temperature destroys any organic species in the waste which would otherwise result in the release of volatile and gaseous species requiring scrubbing in an off-gas system prior to discharge. Active solids are retained in the glass matrix while volatile radionuclides go into the off-gas system.

Technological Readiness

Vitrification is not an established technique for the treatment of oils. The technique has been researched extensively and applied to the treatment of high level waste for more than 40 years in France, Germany, Belgium, Russia, Japan, the UK and the USA. There has been considerable interest, particularly in France, in the application of vitrification technology to other wastes than high level waste, for example sludge waste containing organic species that act as radionuclide complexants. Vitrification is currently used to immobilise some intermediate and low level wastes in countries such as Russia, Slovakia and the USA. The LILW that has been vitrified includes shredded combustible solid waste, spent ion exchange resins and concentrated borated liquid waste. The technique has generally been applied to liquid inorganic or solid organic wastes but not oils (organic liquids). Geomelt demonstration trials are currently taking place at Sellafield before progressing to active wastes in collaboration between NNL and Kurion [1-3].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Vitrification is applied to liquid inorganic or solid organic wastes but not organic liquids.	Typically used for HLW as at Sellafield. Has been used for some LILW in Russia, the USA and Slovakia.
2	Vitrification is applied to liquid inorganic or solid organic wastes but not organic liquids.	
3	Vitrification is applied to liquid inorganic or solid organic wastes but not organic liquids. Solids must be granular/powder.	
4	Vitrification is applied to liquid inorganic or solid organic wastes but not organic liquids.	
5	Vitrification is applied to liquid inorganic or solid organic wastes. Solids must be granular/powder.	

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. IAEA, Application of Thermal Technologies for Processing of Radioactive Waste, IAEA-TECDOC-1527, December 2006.
3. C. Scales, Thermal Treatment of Wastes, Presentation at NNL Technical Conference 2014, May 2014 [<http://www.nnl.co.uk/media/1587/nnl-tech-conference-presentation-charlie-scales-thermal-may-14.pdf>] accessed 09/01/15.

National Waste Programme

Microwave Treatment

Description

This method uses microwave energy to heat the waste and destroy organic components. The microwave energy is supplied to the waste, which can be in either batch form (i.e. in a container) or on a continuous transport system (i.e. on a conveyor belt). The energy causes molecular vibration in dipolar molecules, which in turn heats the waste and breaks down organic chemical bonds. Steam or other moisture can be added to dry waste to increase the efficiency of the microwave heating. Very high temperatures can be achieved, and the process produces an inorganic fused solid mass. This fused solid product may itself present a challenge to subsequent conditioning for disposal.

Technological Readiness

This is not an established method for the treatment of oils. The method has been demonstrated on a number of solid organic wastes, but not liquid organic wastes such as oil. Microwave treatment has been applied for the drying of wet waste (such as ion-exchange resins and sludges), to melt waste (such as plastics), to induce chemical reactions to destroy organic components of waste, or to sterilise radioactive medical waste. High power microwave systems can also be used to melt inorganic residues such as salts in scrubber concentrates or sludges, or as a source of heat for vitrification systems. The off-gas produced during waste processing may require further treatment prior to discharge [1]. A bench scale microwave-enhanced, Raney nickel catalysed process has been used for the detritiation of commercial oil [2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Issues associated with the lack of polarity of oil.	A bench scale microwave-enhanced, Raney nickel catalysed process has been used for the detritiation of commercial oil [2]. Used to dry wet waste (ion-exchange resins & sludges), melt plastic waste, to induce reactions to destroy organics or to sterilise radioactive medical waste.
2	Issues associated with the reduced polarity of oil compared to water.	
3	Issues associated with the lack of polarity of oil.	
4	Issues associated with the reduced polarity of oil compared to water.	
5	Issues associated with the lack of polarity of oil.	

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. J. R. Jones, P. B. Langham and Shui-Yu Lu, Microwave-enhanced tritium-hydrogen exchange: application to radioactive waste reduction, Green Chemistry, 4, 464-466, 2002.

National Waste Programme

Drying and Evaporation

Description

Drying and evaporation are used as techniques to remove free water. It may be used for solid waste that contains a significant amount of water (drying) or for aqueous waste streams resulting in a solid or sludge-like concentrate that contains the major part of radioactivity (evaporation). In the case of evaporation, the waste is heated; however, heat may also be applied to the drying process. To accelerate the process, the water vapour driven off by the evaporation process can be removed by ventilation. Drying/evaporation can be carried out using readily available equipment scaled to the needs of the particular waste generation/treatment facility. Radionuclides may not be entirely removed from the oil during drying/evaporation in the case of tritiated water or especially organically bound H-3. Active solids would also not be separated from the oil using this technique.

Technological Readiness

This technique is not currently established for the treatment of oils. Further testing of the technique for the treatment of oils is required to determine suitability. For some organic radioactive wastes, drying and evaporation may be suitable prior to subsequent treatment such as immobilisation, e.g. ion exchange resins may be dried prior to encapsulation. For disposal purposes, the waste acceptance criteria of no (or negligible) free liquid being present is commonly applied. Materials with free liquids must therefore be dried for disposal. Oil is itself a free liquid thus drying/evaporation alone is not suited for the treatment oils. Evaporation is widely employed in chemical processing where the technique has proven useful in significantly reducing the volume of aqueous waste streams. The use of thermal evaporators may result in secondary waste (e.g. air filters) which will also require treatment and disposal [1].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Organically bound H-3 would not be removed from the oil.	Employed in the chemical processing industry to reduce aqueous waste streams also containing organic materials.
2	May be able to evaporate some of the tritiated water from the oil.	
3	Active solids would remain in the oil.	
4	Used for solids containing significant amounts of water or aqueous waste streams. May evaporate off some water.	
5	Used for solids containing significant amounts of water or aqueous waste streams. No water present to remove.	

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

- IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.

National Waste Programme

Distillation

Description

The distillation technique has two steps, evaporation and then condensation. By applying heat, one component from a mixture is made volatile, and when it is cooled down this component is recovered as a clean liquid (or 'distillate'). A particular disadvantage of distillation is that volatile radionuclides such as H-3 are not removed from the distillate. Non-volatile radionuclides would also remain in the original waste, which would therefore require further treatment.

Technological Readiness

Distillation is not an established technique for the treatment of oils. It has been investigated as a method for decontaminating spent reprocessing solvents such as TBP for potential re-use. The technique is most useful if the distillate can be used again (hence its application to specific liquids such as TBP), or if it makes the liquid suitable for free release or treatment in commercial facilities. The technique has been used at reprocessing facilities in France and the UK. It is worth nothing however, that advanced equipment is required for the large scale distillation of organic liquids [1].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Organically-bound H-3 would not be removed.	Investigated for spent reprocessing solvents such as TBP for possible reuse.
2	Volatile radionuclides such as H-3 would not be removed from the distillate but the distillate may be easier to treat.	
3	Active solids would remain within the oil.	
4	May separate water from the oil.	
5	Distillation is carried out on liquids.	N/A

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.

National Waste Programme

Direct Immobilisation

Description

Raw waste is directly mixed with a binding material, for example, cement, bitumen or resin. The original waste material is largely unaffected, but is completely embedded and thus isolated from the environment. Direct immobilisation of organic waste allows for the production of a wasteform suitable for disposal in a single step. Pre-treatment of the waste may be needed prior to immobilisation and complex mechanical equipment may be required for waste products with relatively high level of activity, such as ion exchange resins. The immobilisation method benefits by the conversion of liquid into solid material, which will provide increased safety during storage or for direct disposal.

Technological Readiness

This is not an established method for the treatment of oils. The method has however been demonstrated on a number of solid and liquid organic wastes. In the UK, organic ion exchange resins have been directly encapsulated in epoxy resin at the Trawsfynydd power plant. The technique for immobilising spent resin in polymers (polyester styrene monolithic blocks) is used commercially in France and India. In Germany, the Netherlands, Sweden, the USA and elsewhere, ion exchangers and sludges are directly immobilised in cement (with mobile equipment available for this). Bituminisation is used for dry ion exchange resins in Belgium, France, Romania and Sweden.

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Insufficient aqueous content for cementation.	N/A
2	Cementation is possible if the aqueous content is sufficiently high. Emulsifiers would initially be used to create a suspension of oil in water.	Cementation is currently used for LILW in the UK, France, Germany, Slovakia and the USA.
3	Insufficient aqueous content for cementation.	N/A
4	Cementation is possible if the aqueous content is sufficiently high. Emulsifiers would initially be used to create a suspension of oil in water.	Cementation is currently used for LILW in the UK, France, Germany, Slovakia and the USA.
5	Insufficient aqueous content for cementation.	N/A

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. IAEA, Innovative Waste Treatment and Conditioning Technologies at Nuclear Power Plants, IAEA-TECDOC-1504, May 2006.
3. IAEA, Mobile Processing Systems for Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-T-1.8, May 2014.

National Waste Programme

Phase Separation

Description

Phase separation is a type of physical separation and can be used as a treatment method for wastes that are essentially a mixture of two or more distinct components (or phases). In the present context this approach can be used to separate the two distinct phases of oil and water, though to work effectively these must not exist in the form an emulsion.

Technological Readiness

This is not an established method for the treatment of oils. Phase separation has been used in the past to treat reprocessing liquids; however, none of these installations are currently in operation. Clearly distinct liquids can be separated by siphoning off the more dense liquid from the less dense liquid. Liquid separations are generally not 100% efficient and some contaminant will often remain in non-product waste stream. Phase separation of liquids is not a technique that has wide applicability due to the limited degree of separation that can be achieved in general. The degree of separation can also vary greatly by waste stream.

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Organically bound H-3 cannot be separated from the oil using phase separation.	N/A
2	Possible only if the oil and tritiated water phases are clearly separate and not emulsified.	Phase separation has been used in the past to treat reprocessing liquids; however, none of these installations are currently in operation.
3	Doesn't separate solids from liquids.	N/A
4	Possible only if the oil and water phases are clearly separate and not emulsified.	Phase separation has been used in the past to treat reprocessing liquids; however, none of these installations are currently in operation.
5	Doesn't separate solids from liquids.	N/A

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. IAEA, Management of Low and Intermediate Level Radioactive Wastes with Regard to their Chemical Toxicity, IAEA-TECDOC-1325, December 2002.

National Waste Programme

Molten Salt Oxidation

Description

Molten salt oxidation has been developed as an alternative to the traditional incineration of organic waste. The combustible organic species are oxidised in a bath of alkaline molten salts at temperatures between 500 and 950 °C which has the effect of oxidising the organic constituents of the waste. The organic constituents react with oxygen to produce CO₂, N₂ and H₂O, with the inorganic component residues formed being contained within the organic-free molten salt. Any acid gases produced in the oxidation, such as hydrochloric acid, are scrubbed by the formation of the stable alkaline salts. Recycling of the salt removes the residues from the bath for immobilisation. The spent salt produced in the process can be converted into a ceramic as part of the process. Low levels of gaseous emissions are produced (negligible dioxin and furan production) although extensive off-gas equipment is generally employed, producing additional quantities of scrubber liquors and/or salts. Radioactive species are captured in the salt bath although some volatiles may be released to the off-gas (H-3, C-14, I-129).

Technological Readiness

This is not an established method for the treatment of oils. Operational experience to date has been limited. There are examples of its application for radioactive waste although the process is still largely in the development phase. The technique is generally used for mixed waste and not specifically liquid organic wastes. Molten salt extraction was used at the Rocky Flats facility in the USA to remove Am from Pu metal by oxidising and extracting the Am ion into the molten salt matrix. A bench scale facility was developed in 1997 at the Lawrence Livermore National Laboratory, USA [1, 2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Generally used for mixed waste (both radioactive and hazardous). Not previously used for oils.	In the development phase. Bench scale facility developed at LLNL, USA. Used at Rocky Flats, USA to remove Am from Pu.
2		
3		
4		
5		

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

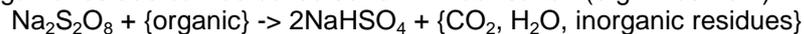
- IAEA, Application of Thermal Technologies for Processing of Radioactive Waste, IAEA-TECDOC-1527, December 2006.
- IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.

National Waste Programme

Direct Chemical Oxidation

Description

This method was designed to retain the benefits of an aqueous system (capturing dust while products remain within a liquid medium) but increase the efficiency of oxidation in an aqueous process by specifically utilising sodium or ammonium peroxydisulphate. The peroxydisulphate ion is a strong oxidant and the oxidation reactions require no catalysis. The organic material is converted to CO₂ and H₂O and the inorganic residue can be collected for immobilisation (e.g. in cement):



The operating temperature is 80-95 °C and the final bisulphate ion is recycled to produce new oxidant by conventional electrolysis. Radionuclides are retained within the inorganic residue [1].

Technological Readiness

This technique is not established for the treatment of oils. It is only suitable for the treatment of liquid organic waste. The method was developed at Lawrence Livermore National Laboratories in the USA and although it has been tested on organic liquids such as TBP and other solvents, the technique has not been routinely used for the treatment of oils and is in the development stage. Direct use of other oxidising chemicals has not been reported in this context. Acid digestion is the most closely related technique [2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Only used previously on organic waste solvents. Not oils.	Technique is in the development stage. Tested on organic liquids such as TBP and other solvents.
2		
3	Only suitable for liquid organic wastes. Not solids or oils.	
4	Only used previously on organic waste solvents. Not oils.	
5	Only suitable for liquid organic wastes. Not solids or oils.	

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. S. B. Eskander and H. M. Saleh, Wet oxidative degradation of cellulosic wastes. 3: Decomposition of tissue paper, ICEM'99 (Proc. 7th Int. Conf. on Radioactive Waste Management and Environmental Remediation, Nagoya, 1999), American Society of Mechanical Engineers, New York, 1999.

National Waste Programme

Acid Digestion

Description

The acid digestion technique uses hot, strong mineral acids (H_2SO_4 and HNO_3 at about 250 °C) to oxidise the organic components of the waste, producing a range of gases and an aqueous sludge consisting of inorganic oxides. It is a thermal desorption process involving carbonisation of organic wastes in hot commercial H_2SO_4 and oxidation of the resultant carbon by commercial HNO_3 . The end product is an easily leachable inorganic sulphate residue requiring subsequent treatment/conditioning prior to disposal (for example, encapsulation in a cement/glass/Synroc matrix).

Technological Readiness

This is not an established technique for the treatment of oils and is usually applied to solid wastes. It has been most commonly used for the recovery of plutonium from organic solid wastes and is also used for treating alpha-bearing solid wastes. The technique was pioneered in Belgium in the 1970s and was studied in a number of countries in the 1980s. Experience with a large scale plant was obtained in Germany and the USA. The process has proven successful for TBP, but organic liquids like trichloroethane and toluene are not easily digested. The process is not currently used on an industrial scale but is being re-examined in the USA for the processing of mixed chemically hazardous and radioactive waste [1, 2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Used to recover Pu from solid waste or to treat alpha-bearing solid waste. Not liquids.	Used in the USA for defence wastes (organic solids) plus in Germany, Japan and Belgium to recover Pu from solid waste.
2		
3		
4		
5		

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Application of Thermal Technologies for Processing of Radioactive Waste, IAEA-TECDOC-1527, December 2006.
2. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.

National Waste Programme

Advanced Oxidation

Description

The advanced oxidation process is a class of waste treatment methods that include the use of ultraviolet light and oxidants (H₂O₂ or ozone), sometimes combined with catalysts, to destroy organic materials, producing CO₂ and H₂O (with inorganic salts if catalysts are used). These techniques are similar to wet oxidation and are applied industrially to wastewaters containing small amounts of organic species.

Technological Readiness

This technique is not established for the treatment of oils or other organic waste streams but rather wastewaters containing small amounts of organic species. Experience of its application to radioactive waste is very limited. Advanced oxidation has been applied to industrial and 'Superfund' sites in the USA to successfully destroy halogenated solvents [1]. It has been demonstrated in a laboratory environment for oxidation of oxalic acid and TBP in HNO₃. The technique can be used in a mobile treatment plant with simple equipment at low temperature and pressure, however, successful application requires dilute aqueous systems (and therefore not oils) [2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Only applied to wastewaters containing small amounts of organic material.	Applied to industrial and 'Superfund' sites in the USA to successfully destroy halogenated solvents.
2	Only applied to wastewaters containing small amounts of organic material.	
3	Only applicable to dilute aqueous systems.	
4	Organic content is likely to be too high and hence unlike wastewaters.	
5	Only applicable to dilute aqueous systems.	

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. J. D. Zeff and J. T. Barich, UV/oxidation of organic contaminants in ground, waste and leachate waters, Water Pollution Research Journal of Canada, 27, 1, 1992.
2. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.

National Waste Programme

Supercritical Water Oxidation

Description

This technique uses the properties of water at above its critical temperature and pressure (374 °C and 22 MPa), combined with air, to oxidise organic material to produce CO₂ and H₂O with inorganic components, resulting in insoluble precipitates. It can be considered an advanced form of wet oxidation. Under supercritical conditions, water acts like a non-polar fluid and all organic material becomes soluble. This supercritical water can be mixed with oxygen in any proportion, and by increasing the temperature and pressure to 400 °C and 25 MPa all organic matter becomes unstable. In general, metals are converted to their oxides and precipitate from the fluid. The inorganic product forms a concentrated sludge which will need to be effectively immobilised [1].

Technological Readiness

This technique is not established for the treatment of oils. It is an efficient method for separating dissolved heavy metals and fission products from dilute aqueous waste streams. A system for alpha-contaminated waste including solvents, filters and ion-exchange resins is operated at Los Alamos National Laboratory in the USA [2]. The technique is also widely used for the destruction of chemical waste, military toxic waste and explosives in France, Germany, Sweden, Switzerland and the USA. It has been applied to municipal sewage in several countries. Supercritical conditions require a substantial plant operating at high temperatures and pressures.

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Separates dissolved heavy metals and fission products from dilute aqueous wastes.	Used for alpha-contaminated waste (solvents, filters and ion-exchange resins) at LANL, USA. Also used to destroy chemical waste, explosives and military waste.
2		
3		
4		
5		

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. C. K. Rofer, Supercritical water oxidation for treatment of mixed wastes, WM Symposia Proceedings, WM1991, 931-934, 1991 [<http://www.wmsym.org/archives/1991/V1/149.pdf>] accessed 05/01/15.

National Waste Programme

Biological Treatment

Description

Biological treatment or biodegradation involves the metabolisation of organic components of waste by appropriately-selected bacteria. These bacteria metabolise and digest the organic components of the waste. Under aerobic conditions, the gaseous product is CO₂ but anaerobic conditions will produce a 50:50 mixture of CO₂ and CH₄. Inorganic material remains associated with the biomass. If the waste contains C-14 or H-3, the gaseous products will be active, and will therefore require additional management.

Technological Readiness

This method has been demonstrated for some organic materials but not for oils, although it is theoretically feasible. However, it is only suitable for low volume, low concentration waste streams which makes it unlikely to be suitable for oils. Industrial experience of using bacteria for the biological treatment of waste shows that biological agents are often most effective when used for a specific substrate and for aqueous waste streams with a low concentration of organics. This technology is not widely utilised at present for the treatment of radioactive waste, although a pilot facility has recently been constructed for EDF. A pilot plant for the biological treatment of ion exchange resins was constructed in Finland [1, 2].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	For aqueous waste streams with a low concentration of organics.	Not currently employed industrially for radioactive waste. Pilot plant to treat ion-exchange resins in Finland.
2		
3	For aqueous waste streams with a low concentration of organics. Not recommended for solid organic waste.	
4	For aqueous waste streams with a low concentration of organics. Oil (organic) content too high.	
5	For aqueous waste streams with a low concentration of organics. Not recommended for solid organic waste.	

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.
2. Environmental Agencies Requirements Working Group (EARWG), Waste Minimisation Database [<http://www.rwbestpractice.co.uk/Main.aspx>] accessed 14/01/15.

National Waste Programme

Alkaline Hydrolysis

Description

Alkaline hydrolysis is a wet, chemical extraction process in which a liquid organic waste is put into contact with an aqueous alkaline solution. Hydrolysis reactions (nucleophilic substitution in which the attacking nucleophile is a hydroxide ion) alter the nature of the organic species and result in a transfer of the radioactivity to the aqueous phase. Subsequent separation of the phases results in a clean organic liquid. The process is applied to waste solvents containing actinides such as uranium and following treatment the solvent can be recycled.

Technological Readiness

This technique is not established for the treatment of oils. It has very limited application for radioactive organic waste and often produces complex waste products that require further treatment to make them suitable for disposal. It has previously been used for the treatment of waste solvents from spent fuel reprocessing, e.g. TBP (tri-butyl phosphate)/OK (odourless kerosene), allowing the dilutant to be recycled. It is the main chemical treatment method employed at the Solvent Treatment Plant (STP) at Sellafield. The plant was commissioned in 2001 with a 30 year prospective lifetime to treat 750 m³ of TBP/OK from THORP and Magnox reprocessing operations [1].

Initial Assessment

Group	Technical Effectiveness	Technological Readiness
1	Used to treat organic waste solvents containing actinides such as uranium. Not lubricants.	Employed at STP (Solvent Treatment Plant) at Sellafield to treat TBP/OK (tri-butyl phosphate/odourless kerosene) from reprocessing.
2		
3	Used to treat organic waste solvents containing actinides such as uranium. Not lubricants or solids.	
4	Used to treat organic waste solvents containing actinides such as uranium. Not lubricants.	
5	Used to treat organic waste solvents containing actinides such as uranium. Not lubricants or solids.	

1 = Tritiated oil, 2 = Tritiated water in oil, 3 = Oil with active solids, 4 = Oily water, 5 = Oil contaminated solids

References

1. IAEA, Predisposal Management of Organic Radioactive Waste, Technical Report Series No. 427, July 2004.