Technical Summary Report **Project UKRSR07**

Identification and assessment of alternative disposal options for radioactive oilfield wastes

January 2005

DISSEMINATION STATUS
Unrestricted

RESEARCH CONTRACTOR
This document was produced by Genesis Oil & Gas Consultants Ltd

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1 EXECUTIVE SUMMARY

This report is the third deliverable for the SNIFFER UKRSR 07 project. It contains a digest of the findings of the first two reports for this study.

The Phase 1 report (SNIFFER 2004a) investigated the origins and occurrence of naturally occurring radioactive material (NORM).

NORM origins and quantification

Amounts of NORM waste produced on the United Kingdom Continental Shelf (UKCS) were quantified and predictions made of potential arisings from future production and during decommissioning. Data obtained from operators, decontamination contractors, literature review, disposal outlets and the regulators has been included in the estimates.

NORM contaminated deposits in oil and gas production occur in two main forms:

- As mineral scales, and sludges of particulate scale, containing radium and its decay products;
- As thin coatings and "black sludges" in gas and condensate processing equipment, mainly containing decay products from Radon-222, predominantly Lead-210 and Polonium-210.

The estimates of the current arisings have been prepared and are summarised in section 4.4.6 of this report. The main findings are summarised in the points below:

- The total activity discharged in produced water is relatively high due to the volumes produced.

- The largest arising of solid NORM occurs through offshore decontamination, either through routine cleanout and descaling operations or from decommissioning. Terminal vessel sludges and pigging waxes account for the bulk of NORM solids dealt with onshore.

- Onshore equipment decontamination accounts for a small fraction of the total activity and volume of solids discharged to sea.

- The masses of solids from decommissioning are small in comparison to offshore decontamination. In all of the cases reviewed the actual amount of NORM solids disposed of from decommissioning has been significantly lower than original predictions.

- The general trend in solid NORM is a slight increase in operational arisings in the next 2-3 years, as new facilities outpace decommissioning, followed by a steady decline as decommissioning increases in pace. Total arisings peak in about 2007 and are sustained by decommissioning arisings until around 2012, after which there is a sharp decline. By 2040, mass and activity via all disposals is estimated to be between 5-10% of its current value.

- The total activity in produced water is also predicted to peaks in 2007 but falls steadily thereafter. By 2040, mass and activity via all disposals is estimated to be between 5-10% of its current value. Produced water discharged to sea is predicted to have already peaked and is in decline.

The Phase II Report (SNIFFER 2004b) investigated NORM waste minimisation and disposal options for the NORM from the UKCS and produced a ranking of potential disposal options.

NORM prevention, removal methods and waste reduction
A review of methods is presented. Of the NORM prevention methods, the only method widely used on the UKCS is chemical scale inhibition and to a lesser extent sulphate removal from injection water. NORM removal onshore and offshore is predominantly by mechanical means, mainly water jetting (with and without abrasives).

Waste reduction of solid NORM arisings is not routinely carried out on the UKCS as most NORM is discharged to sea. There is currently no reliable method for reducing the overall amount of radioactivity transferred from the subsurface in oil and gas production.

There are some chemical waste reduction methods at different stages on development but none are currently in use on UKCS. There needs to be financial backing and regulatory impetus for their development for use on the UKCS. There are some novel methods at the pilot stage particularly waste reduction by chemical concentration.

NORM disposal options
There is a wide variety of disposal options that are available in principle and feasible options are discussed. Different options are suited to different types of NORM waste and a mixture of options may be the best solution.

From discussions with waste contractors it emerges that some degree of financial security or guaranteed customer base is required for development of new onshore disposal facilities along with an indication of regulatory support. Even with such assurances, the relatively small predicted amounts of NORM arisings for onshore disposal under the current regulatory regime, even at the peak of decommissioning, suggest that a multi-industry LLW disposal facility would be the viable option.

None of the disposal routes appears to present a significant occupational or public radiation exposure risk apart from landspreading. Consequently, factors other than dose may be equally important in determining acceptability.

A generic risk ranking of disposal alternatives for the UKCS has been carried out.

Capacity
Although the current disposal routes present no immediate capacity problems, there is the potential for future pressure on existing oilfield NORM disposal routes, for example OSPAR and EU targets to reduce discharges of naturally occurring radionuclides to sea to background levels by 2020. If this were to mean that offshore discharge was discontinued and solid NORM waste had to be brought onshore for disposal there would be insufficient capacity (currently none in Scotland for some of the wastes).

If the UK continues to rely on a single site (Drigg) as the main onshore disposal route for non-exempt NORM waste, some assurance will need be sought by the regulators that oil and gas NORM waste will continue to be accepted.

If nothing is done to provide alternative onshore disposal routes there is the potential for stockpiling and consequent problems with public relations, licensing and ultimate disposal. The UK oil and gas industry is reliant on a single nearshore discharge to dispose of almost all NORM from onshore decontamination and on a single disposal facility for non-exempt wastes. Currently, the total amounts are low and appear to be within existing capacities, but this assumes that the capacity is available if required and this cannot be guaranteed at present. It also assumes that there will not be regulatory changes which discontinue the current practice of offshore disposal of most of the NORM waste.

2 GLOSSARY AND ABBREVIATIONS

ALARA	As Low as Reasonably Achievable
Alpha radiation Alpha particle	Radioactive decay by ejection of a high energy charged particle consisting of 2 protons and 2 neutrons (equivalent to a Helium nucleus). Alpha particles lose their energy over a very short range in air and have little penetrating power but are relatively harmful if inhaled/ingested.
Barite	Barium sulphate (common mineral scale)
BAT	Best available technology
bequerel Bq, kBq, MBq, GBq, TBq	SI unit of activity equivalent to 1 nuclear transformation per second. kBq kilobecquerel; one thousand Bq MBq Megabecquerel 10^6 Bq GBq Gigabecquerel, 10^9 Bq TBq Terabecquerel, 10^{12} Bq
Beta radiation Beta particle	Radioactive decay by ejection of a high energy negatively charged particle (an electron) from the nucleus of an unstable atom. Smaller and more penetrating than alpha particles but less penetrating than gamma radiation
BGS	British Geological Survey
BNFL	British Nuclear Fuels Limited
BPEO	Best Practicable Environmental Option
BPM	Best practicable means; within a particular waste management option, the level of management and engineering control that minimises, as far as practicable, the release of radioactivity to the environment whilst taking account of a wide range of factors, including cost effectiveness, technological status, operational safety, and social and environmental factors
CFA	Conditions For Acceptance (of radioactive waste), specifically for the Drigg disposal facility. There are restrictions on the nature and quantity of wastes accepted and use of alternative sites
Cm 2919	A statement of Government policy for the management of radioactive wastes, published in 1995
CNS	Central North Sea
Controlled burial	Defined in Cm 2919 in terms of the authorised disposal of some LLW at suitable landfill sites that possess good containment characteristics
CoRWM	Committee for Radioactive Waste Management
COVRA	Centrale Organisatie Voor Radioacteif Avfal : Radioactive waste repository in the Netherlands
Decay series	A succession of radionuclides each of which is transformed by radioactive decay into the next member until a stable nuclide is reached. The first member of the series is the parent, the succeeding nuclides are the progeny or daughters.
DEFRA	Department for Environment, Food and Rural Affairs, the Government department responsible for environmental protection policy in England
DOWS	Downhole oil water separation
Dose Limit	Maximum dose from ionising radiation to the general public from sources ref. to Euratom Basic Safety Standards (excluding medical procedures) current limit in UK is 1mSv/yr
Drigg	The facility for the near-surface disposal of most of the UK's solid LLW operated by BNFL, near Sellafield, in Cumbria

DTI	Department of Trade and Industry, the environmental regulator responsible for the offshore oil and gas industry with the exception of radiological issues
EA	Environment Agency, the onshore environmental regulator for England and Wales and responsible for authorising radioactive waste disposals onshore and offshore. EA's jurisdiction offshore includes the predominantly gas-bearing fields of the Southern North Sea and fields in the English sector of the Irish Sea.
EEMS	Environmental Emissions Monitoring System, a non-statutory reporting system for reporting emissions from the UKCS oil and gas industry via UKOOA.
EHS	Environment and Heritage Service of Northern Ireland (the radiological regulator in Northern Ireland)
EPA90	The Environmental Protection Act 1990; legislation that, among other things, made changes to the management and regulation of waste management
EU	European Union
EO	Exemption Orders are regulations made under RSA93 which remove the need for individual regulatory approval of some activities and some classes of materials/wastes where it is considered that the radiological impact will be minimal and the provisions included in the orders themselves are sufficient to assure protection of the public.
FPSO	Floating Production, Storage and Offloading - a vessel converted to produce hydrocarbons offshore that is permanently moored on location for the field life
Gamma radiation	High energy electromagnetic gamma photons emitted from an unstable nucleus. Very penetrating.
G o M	Gulf of Mexico
Half life	The time required for half of the activity of the radioactive material to decay
IAEA	International Atomic Energy Agency
ICRP	International Committee on Radiological Protection
IRR 99	Ionising Radiations Regulations
keV	Kilo electron volts (1 keV= $1.6X10^{-19}$ Joules)
Landfill Directive	European Council Directive 1999/31; the Directive aims to prevent, or reduce as far as possible, the negative effect of use of landfill on the environment and on human health. A key provision is the separation of landfill sites into three classes, dealing with hazardous, non-hazardous and inert wastes
Low activity wastes	A non-legislative term used in the nuclear industry describing various solid radioactive wastes including most LLW, and all VLLW and other wastes subject to EOs
LLW	Low level radioactive waste; defined in Cm 2919 as ''waste containing radioactive materials other than those acceptable for disposal with ordinary refuse, but not exceeding 4 gigabecquerels per tonne (GBq/te) of alpha or 12 GBq/te of beta/gamma activity (e.g., wastes which, under existing authorisations, can be accepted by BNFL's disposal facility at Drigg in Cumbria)''
LPG	Liquified Petroleum Gas
LSA	Low specific activity, a term mainly used to describe scale occurring in the oil and gas industry containing daughters of uranium (^{238}U) and thorium (^{232}Th)

MOD	Ministry of Defence
MOL	Main Oil Line
NEA	Nuclear Energy Act (Netherlands)
NGL	Natural Gas Liquids
NGO	Non Governmental Organisation
NNS	Northern North Sea, commonly used term referring to the area of the North Sea east of Shetland containing predominantly oil fields
NORM	Naturally Occurring Radioactive Material.
OECD	Organisation for Economic Co-operation and Development
OLF	Olje Industriens Landsforening. (Norwegian UKOOA equivalent)
OSPAR	Oslo and Paris Commission for the protection of the marine environment of the North East Atlantic
PFA	(Power station) Pulverised fuel ash or fly ash
PPE	Personal protective equipment
Produced Water	Water that is extracted (produced) from a reservoir along with hydrocarbons
PSEO	The Radioactive Substances (Phosphatic Substances, Rare Earths etc.) Exemption Order 1962
PWRI	Produced water re-injection, which is undertaken either to assist in the recovery of hydrocarbons (e.g. by maintaining pressure in the reservoir), or as a means of minimising discharges to sea
RAM	Risk assessment matrix
RCL	Radioactively Contaminated Land
RSA 93	Radioactive Substances Act 1993 (as amended). Legislation which provides for the regulation of the disposal of radioactive wastes (including discharges to the environment) and provides for regulation of the accumulation and storage of radioactive wastes on non-nuclear sites. The provisions of the Act also specify which materials and wastes are regarded as being radioactive for the purpose of regulation
RWMAC	Radioactive Waste Management Advisory Committee, currently in abeyance, responsible for developing radioactive waste policy in the UK. Replaced in some respects by CoRWM
SE	The Scottish Executive; the Cabinet of the Scottish Parliament, which, in turn, is the body responsible for most aspects of environmental protection policy in Scotland under devolution arrangements
SEPA	Scottish Environment Protection Agency, Scotland's onshore environmental regulator and responsible for authorising radioactive waste disposals onshore and offshore. SEPA's jurisidiction covers the central and northern North Sea and areas west of Shetland (the Atlantic Margin).
SI	Scale Inhibitor
sievert (Sv) millisievert (mSv) microsievert (µSv)	Unit of Equivalent Dose. Equal to adsorbed dose (Grays, Gy, in joules /kg) multiplied by a Radiation Weighting Factor to account for different effects from different types of radiation. Sv units are also joules/kg. Typical annual background dose for UK residents is 2.6 mSv (0.0026 Sv) per year
Small Users	Organisations that use radioactive materials and create radioactive wastes that are not part of the nuclear sector, including hospitals, universities, and industrial undertakings
SNS	Southern North Sea, commonly used term referring to the area of the North Sea south of the Dogger Bank-Flamborough Head

SoLA	Substances of Low Activity Exemption Order; among other things, SoLA removes the need for individual authorisation of disposal of some solid radioactive wastes the activity of which is less than 0.4 becquerels per gram (Schedule 1 activity limits are disregarded for the purposes of SoLA)
SPB	Special precautions burial; sometimes called *controlled burial*
Total Activity	In this report, it is the regulator approved calculation of Total Activity for disposals under RSA 93, effectively $6x^{226}Ra + 8x\ ^{228}Ra + 3x^{210}Pb$ Bq/g. In practice there is often no analysis available for ^{210}Pb, it is not present or it is recorded as below limit of detection and only the Ra terms are used. ^{228}Ac is used as a proxy for ^{228}Ra as it is easier to detect.
Tubular	Length of high grade steel pipe (usually 26m) used to carry reservoir fluids up to a platform
UKAEA	United Kingdom Atomic Energy Authority
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association, an organisation representing almost all oil and gas operators in the UKCS
VLLW	Very low level radioactive waste; defined in Cm 2919 as ''waste which can be safely disposed of with ordinary refuse (''dustbin disposal''), each $0.1m^3$ of material containing less than 400 kilobecquerels (kBq) of beta/gamma activity or single items containing less than 40 kBq of beta/gamma activity''. VLLW normally excludes alpha-bearing waste and sets specific limits for tritium and carbon-14

3 INTRODUCTION

Naturally occurring radioactive material (NORM) occurs in small quantities in the oil and gas industry wastes on and offshore. Its occurrence has been known since the early 1900s and particularly since the 70s on the UKCS. For a variety of reasons, there has been a consensus that a review of the quantification of current and future NORM arisings from the UKCS is now necessary together with an examination of minimisation and disposal options.

Significant developments have recently occurred in waste disposal on land such as the Landfill Directive, which have indirect impacts on radioactive waste. Issues such as decommissioning wastes from nuclear power stations have brought the question of radioactive waste to the fore for all disposers, including small users such as the oil and gas industry. In the marine environment, there is an increasing focus on reducing of radioactive discharges to sea, while increasing numbers of platforms are being put forward for decommissioning with the potential for increased radioactive waste disposal. While the amount of solids for disposal is relatively small and presents no immediate problem, it is an important issue that could cause problems for the UK oil and gas industry were the few current disposal routes to become unavailable.

Regulators and industry have combined under the umbrella of SNIFFER to deal with this issue and identify appropriate and sustainable NORM handling, treatment and disposal techniques for current and future arisings. This project considers both tested and novel solutions and considers techniques used in other areas of the world.

This study has been carried out in two parts and two technical reports have been produced (both available from SNIFFER). This report is a summary of the findings of the first two reports:

- **Phase 1: NORM origins and quantification**
- **Phase 2: Waste minimisation and disposal options**

The Phase 1 report deals primarily with origins and the quantification of radioactive oilfield wastes onshore and offshore. Likely NORM arisings from different types of production and processing facilities are discussed. Data obtained from operators and the regulators has been included in the estimates. The study includes offshore production facilities, onshore terminals, major pipelines and onshore production facilities and covers the issues of current arisings, future lifetime of facility arisings and potential arisings on decommissioning.

The origins of NORM are discussed and occurrence of NORM in oil and gas production facilities and waste streams are investigated. The practical experience of operators on the UKCS and abroad in monitoring, removing and characterising NORM wastes is discussed using published information, the results of consultations with operators based on interviews and discussions and the results of an operator questionnaire.

The Phase 2 report discusses methods of NORM and NORM scale prevention, waste minimisation and disposal options. The current legislative framework for radioactive waste handling and disposal, as it pertains to NORM (LLW) disposal is summarised. The existing disposal capacity is reviewed.

This report is a summary; where further detail on any topic is required the reader is referred to the main technical reports (SNIFFER 2004a and b).

4 PHASE 1 SUMMARY: NORM ORIGINS, NORM WASTE QUANTIFICATION

4.1 NORM origins

Naturally occurring radionuclides are ubiquitous in the earths crust. The main contributors to oilfield NORM are the decay products from two of the primordial nuclides: uranium-238 (^{238}U) and thorium-232 (^{232}Th) which, with their very long half-lives, date from the formation of the earth. These nuclides are present both in the source rocks from which the hydrocarbons are extracted and in the reservoir rocks from which they are produced. The main nuclide contribution to oilfield NORM waste is from the reservoir rocks (Hartog. *et al* 2002), rather than the hydrocarbon source rocks.

The original depositional environment and geological setting of the parent rock will influence the amount ^{238}U and ^{232}Th present. ^{238}U and ^{232}Th both decay to produce a series of daughter products of which the most relevant to this report are ^{226}Ra, ^{228}Ra, ^{222}Rn, ^{210}Pb and ^{210}Po. **Figure 4.1** illustrates the ^{238}U and ^{232}Th decay series.

In nature radium occurs as the decay product of ^{238}U[1] (*i.e.* ^{226}Ra which has a half life of 1620 years) and ^{232}Th (*i.e.* ^{224}Ra which has a half life of 3.7 days and ^{228}Ra which has a half life of 5.6 years). ^{226}Ra is present at about 10^{-12} g/g crust rock corresponding to approximately 0.004Bq/g (Gessell and Eisenbud 1997).

Selective leaching of radium occurs in the subsurface. Mobilisation of radium is governed by a number of factors including: subsurface temperatures and pressure; which radium containing minerals are present and the chemical composition of the formation water.

The relative contribution of radioactivity from the hydrocarbon source rock versus the reservoir rock is subject to discussion but the consensus is that the reservoir makes the major contribution. Some ^{226}Ra and ^{228}Ra will be derived from both but most is likely to be from the reservoir rocks. ^{222}Rn will be transported from the source rock with the hydrocarbons and gas however it has short half life and will decay en route to the reservoir depending on migration distance. Diffusion time through the reservoir will depend on pressure, porosity and temperature. The equilibrium between NORM nuclides in the reservoir is likely to be disturbed by removal of gaseous ^{222}Rn along with hydrocarbons and gas. A summary of the origins and transport of NORM nuclides from the reservoir is shown in **Figure 4-2**.

[1] with very minor amounts of ^{223}Ra from ^{235}U not normally considered in discussion of oilfield NORM

Figure 4-1. ^{238}Uranium and ^{232}Thorium decay series

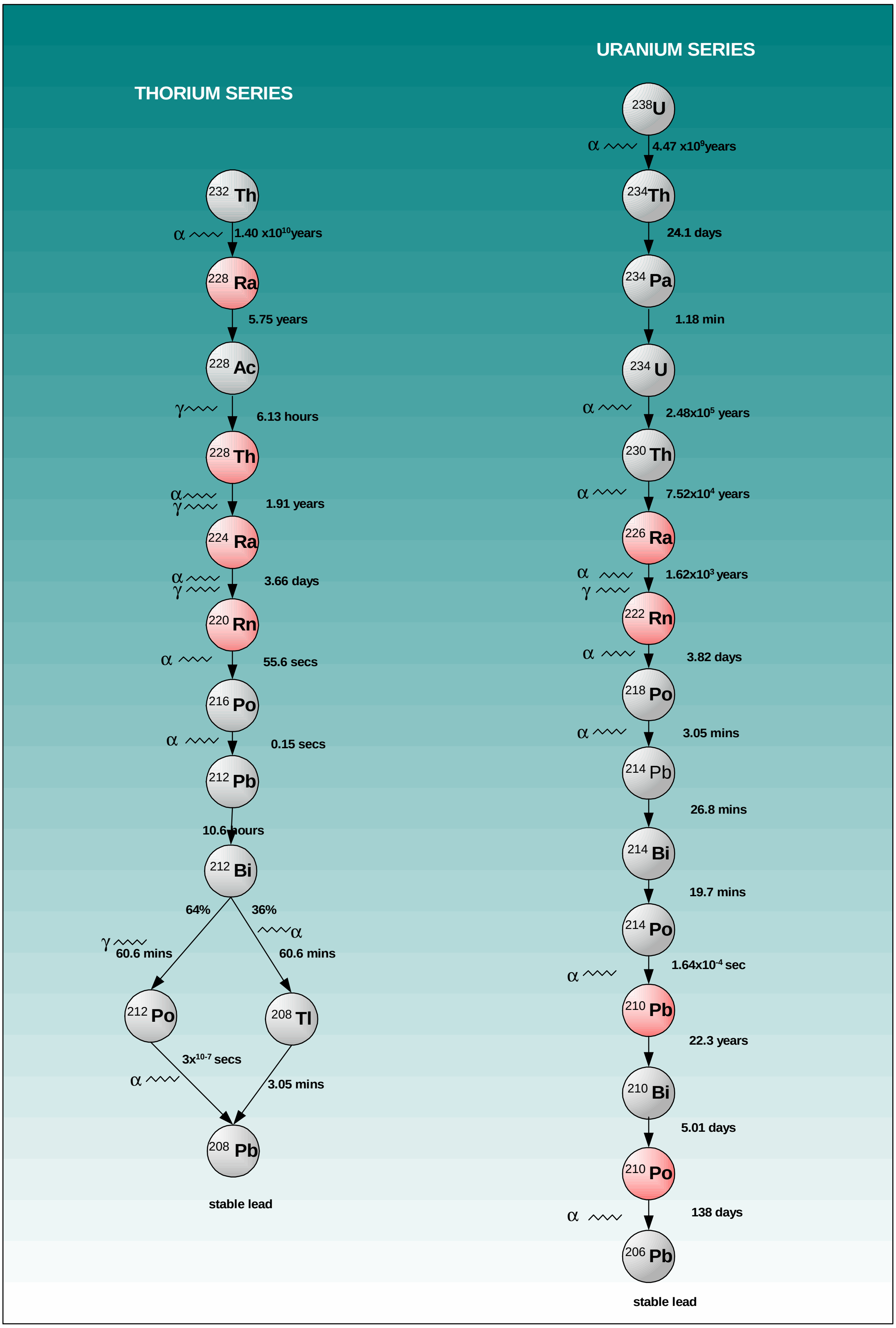
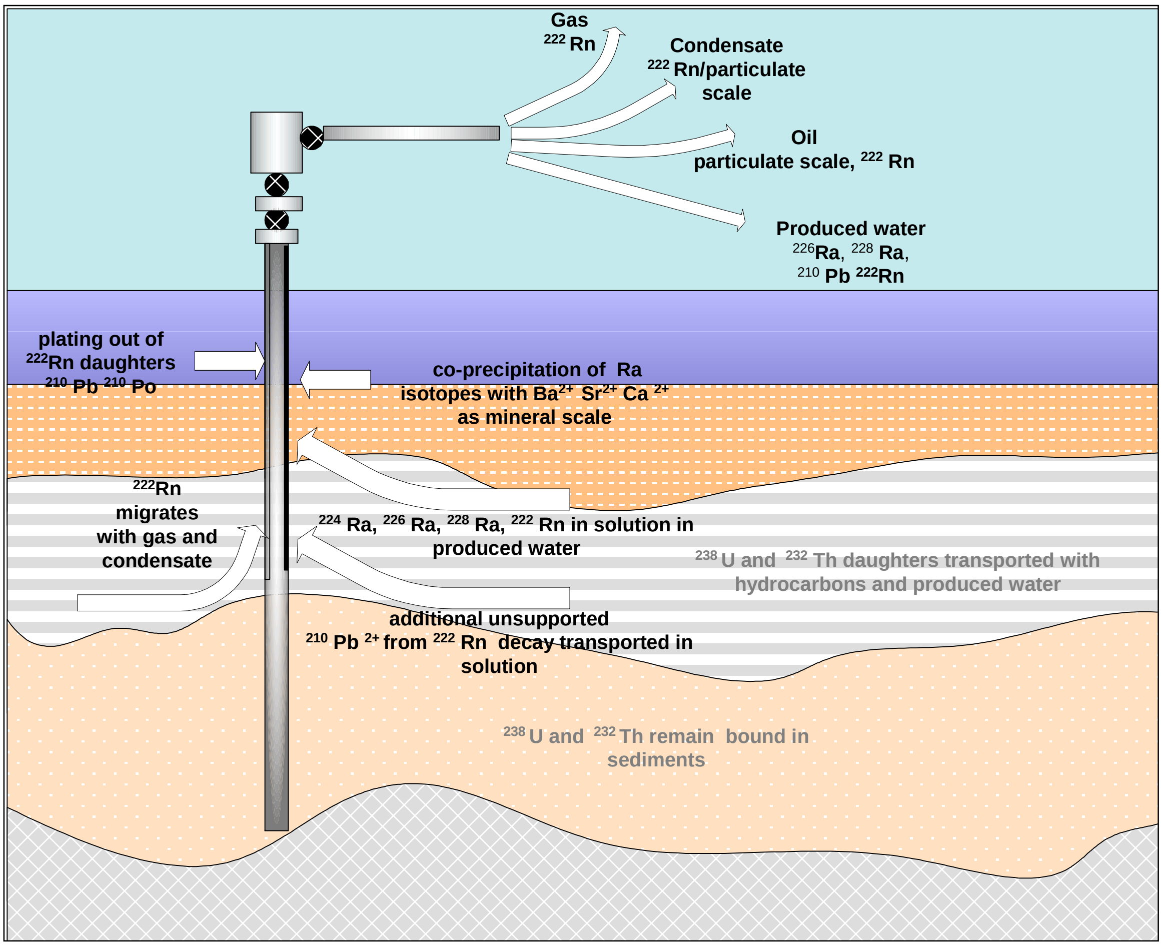


Figure 4-2. NORM origins and transport



4.2 NORM deposition

NORM nuclides are unavoidably produced from the subsurface with produced water and hydrocarbons. They may pass through a production facility in the water phase and be discharged in the produced water, and this is promoted by the use of scale inhibitors. Problems arise, however, when NORM forms deposits in pipework and equipment as this can interfere with production and present a radiation health and safety hazard during maintenance, dismantling and decommissioning.

NORM deposits fall into two broad groups, mineral scales and metallic films.

4.2.1 Mineral scales

Mineral scales consist of minerals precipitated from reservoir fluids.

- The commonest scales are sulphates ($BaSO_4$, $SrSO_4$) and carbonates (predominantly $CaCO_3$). Naturally occurring isotopes of radium (^{226}Ra and ^{228}Ra) have similar chemical properties to Ca, Mg, Sr, Ba (Group IIa metals) and become incorporated by substitution into the scale minerals. The proportion in which Ra co-precipitates with Sr and Ba is very small (10ppb) but the distribution of Ra is irregular and “hotspots” can occur. $RaSO_4$ is less soluble in water than $BaSO_4$ by an order of magnitude.

- Not all scales contain NORM nuclides but where the produced water contains measurable NORM it is likely that scale deposited will be radioactive. The commonest radioactive scales on the UKCS are sulphate scales although carbonate scales may also contain small amounts of NORM (usually below regulatory limits).
- Scale exists either as solid coatings on equipment or as mineral scale particulates and fragments in sludges and sands.
- Mineral scale is normally associated with oil and water processing equipment.
- The highest activities from NORM nuclides are usually found in downhole equipment: pumps, valves and tubulars.

Scale formation

All natural waters contain dissolved ions derived from contact with mineral phases in the sediments. Water from carbonate and calcite cemented sandstone reservoirs is rich in Ca^{2+} and Mg^{2+} whereas non-carbonate cemented sandstone formation water is usually rich in Ba^{2+} and Sr^{2+}. In reservoir fluids total dissolved solids can reach levels of 400,000mg/l in hypersaline brines (Crabtree *et al* 1999). In the North Sea the most common mineral scales are Gp II metal sulphates (mainly Ba and Sr) which usually contain some substituted Ra^{2+}.

In oil and gas facilities, the following conditions may lead to scale formation:

- Mixing of chemically incompatible waters
- Pressure changes
- Temperature changes
- Impurities
- Additives
- Variation of flow rates
- Changes in water acidity
- Fluid expansion
- Gas evaporation

The most important of these are mixing of incompatible waters and temperature changes. Temperature affects the solubility of the mineral phases. Under reservoir conditions Ba, Sr, Ca and Ra are leached from the formation and are present in soluble form in the produced water. When scaling occurs this Ra co-precipitates with Group II metals Ba or Sr.

For scale to develop the following are needed:

- Brine to be supersaturated with respect to the scaling minerals
- Adequate nucleation sites to be available for crystal growth
- Sufficient contact time to allow growth of a consolidated deposit

4.2.2 Metallic deposits

Metallic deposits are found on inner surfaces of gas/condensate transport lines and vessels and on gas production and processing equipment.

- This type of NORM has different nuclides associated with it to those usually present in mineral scales namely ^{222}Rn daughters (**Figure 4-1**). ^{222}Rn has a relatively short half life of 3.82 days but decays to form some longer lived nuclides. The daughters of most concern are ^{210}Pb (half life 22.3 years) and ^{210}Po (half life 138 days).
- Metallic NORM is particularly associated with LPG and NGL processing.
- These deposits are often present as thin, almost invisible, metallic films and coatings on the internal surfaces of gas and NGL processing equipment. These usually occur

with stable Pb and Fe oxides, carbonates, sulphides as thin coatings or sometimes nodules.

- NORM nuclide activity is often reported as activity per unit area rather than per gram as this type of deposit cannot be readily removed, although the accuracy of measurements done on a unit area basis is questionable.
- The levels of activity in this type of NORM vary from just over background to high 0.5-7,200 Bq/cm^2 for ^{210}Pb and ^{210}Po (Hartog *et al*, 1996, EPA, 1997) and can reach several thousand Bq/cm^2 on downhole equipment.

4.3 NORM occurrence

The vast majority of NORM occurs in oil production infrastructure (as opposed to gas/condensate production) and is associated with produced water. The main areas where NORM accumulation is encountered are locations where there is oil and water and where physical conditions change, *e.g.* in the well itself, in pipes, separators, degassers, heat exchangers and in water or hydrocarbon storage vessels.

Quantities and activities of NORM vary widely from facility to facility and from year to year. The following broad ranking of activities can be made, but there are exceptions:

Higher activity	Downhole scale
	Topsides scale
	Separator sludges
	Storage vessel sludges
	Produced sand
Lower activity	Pigging wax

Most occurrence of solids offshore is in the form of mineral scale. Most occurrence onshore is in the form of vessel sludges at terminals.

A summary of oilfield NORM sources and characteristics is given in **Table 4-1** and illustrated in **Figure 4-3**.

Chemical scale inhibitors are widely used offshore both in downhole treatments (scale squeezes) and in topsides processing. Treatments are designed to minimise scale accumulation in order to maximise production. These function either by chelating the scaling ions and keeping them in the produced water or by inhibiting nucleation and growth of scale mineral crystals. This does not reduce the amount of NORM nuclides produced overall but reduces deposition of NORM contaminated scale.

NORM arisings in terminals depend greatly on the nature of the fluids received. The use of scale inhibition at terminals is not widespread. Due to the size of many onshore process and storage vessels, accumulations can occur over some time resulting in infrequent but relatively large disposals. Mixing the produced water stream with any other water can result in rapid precipitation of NORM solids.

Table 4-1. Occurrence of NORM oil and gas industry equipment

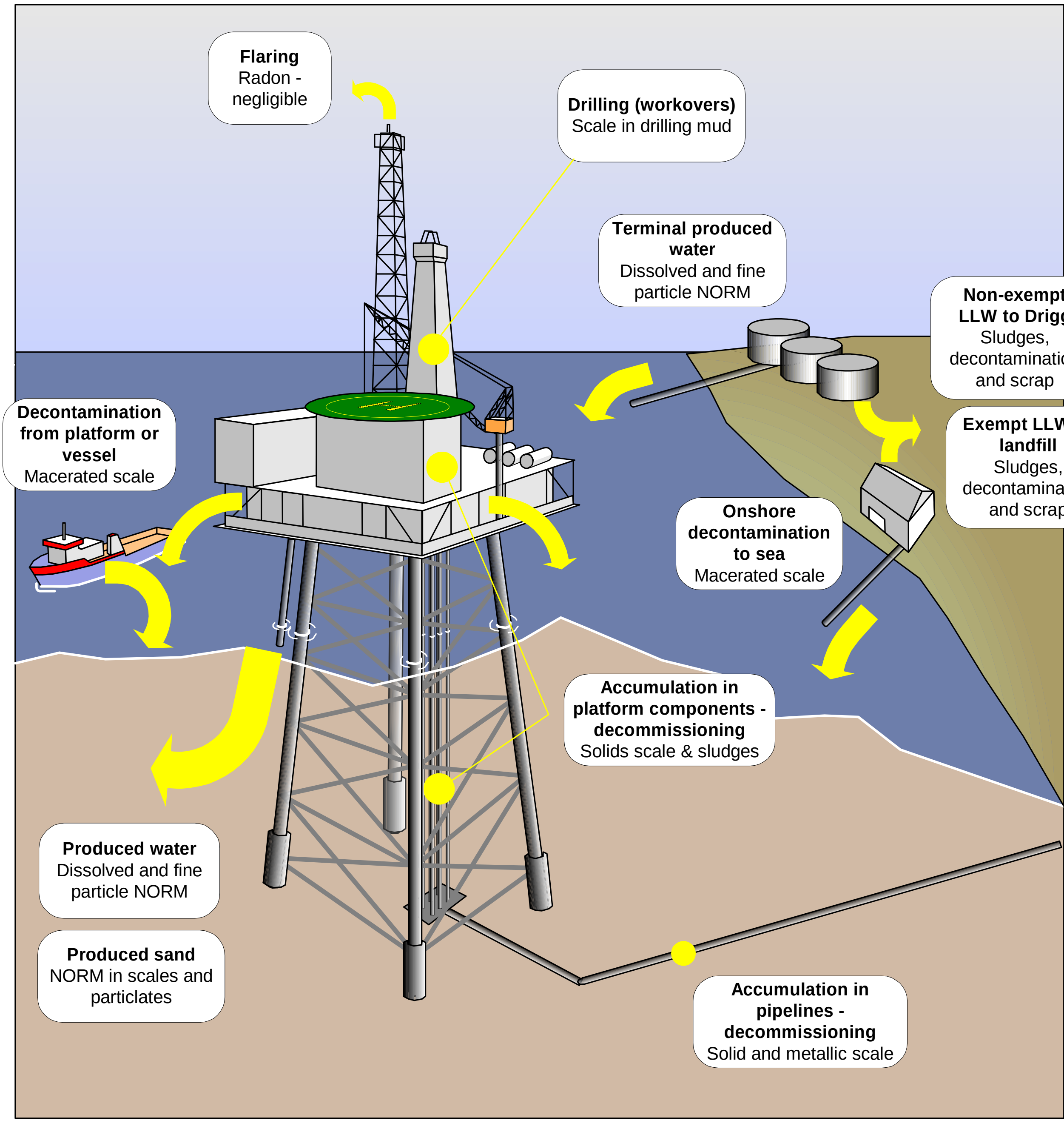
Type	Nuclides	Characteristics	Occurrence
LSA scales	^{226}Ra, ^{228}Ra and decay products	Hard deposits of barium, strontium sulphates plus much lower activity carbonates	Wet parts of oil production installations; well completions, water treatment plant
LSA sludge/sand	^{226}Ra, ^{228}Ra and decay products	Sand, clay, paraffin, heavy metals, waxes, sludges	Separators, skimmer tanks Water treatment equipment and water/product storage vessels
LSA films	^{226}Ra, ^{228}Ra ^{210}Pb and decay products	Thin films, thin scale deposits	Wet parts of gas production and processing installations; well completions
Gas deposits	^{210}Pb and decay products	Very thin films	Gas treatment and processing, condensate/LNG plant and transport
		Black sludges containing ^{222}Rn daughters (^{210}Pb and ^{210}Po)	Storage vessels, filters, sediment traps
Natural gas	^{222}Rn	Noble gas	Throughout production and distribution network
Produced water (in solution and as fine particulates)	^{226}Ra, ^{228}Ra and /or ^{210}Pb	Differing degree of salinity, large volumes in oil production, less in gas production	Ubiquitous Production facilities. Often low activity but very large volumes

Source: adapted from IAEA (1999)

Deposition of thin metallic ^{210}Pb and ^{210}Po NORM occurs routinely in gas equipment, and oil equipment in one onshore oil field. This is of very low mass in comparison with mineral scales but can be of locally high activity. There is very little volumetric data for these deposits. They do not usually interfere with production but may present an exposure risk on dismantling and decommissioning.

Seawater injection can dramatically alter the ionic concentrations in produced water and can lead to scaling on a dramatic scale, *e.g.* a well in one North Sea field sea fell from 30,000 barrels per day to nil within 24 hours of seawater breakthrough. In this instance the formation water was very rich in barium which precipitated out as $BaSO_4$ very rapidly on contact with the sulphate rich seawater. Seawater injection and subsequent breakthrough is renowned for causing scaling problems and has to be very carefully managed by injection of scale inhibitor or sulphate removal treatment for the seawater.

Figure 4-3. Main NORM waste streams from oil and gas activities



4.4 Quantification of NORM arisings on UKCS

Quantification of NORM arisings was carried out using data from the following sources:

- A review of literature, both UK and worldwide
- Reporting of radioactive wastes to SEPA/EA and DTI
- UKOOA produced water analyses
- Operator questionnaires
- Follow-up enquiries with operators having particular experience in NORM
- Enquiries with waste contractors and local regulators

A summary of the current estimated annual arisings of NORM is given in Section 4.4.6.

4.4.1 Literature review

An extensive literature search was carried out. There is an abundance of general information on NORM but relatively little published data on amounts or activity of operational NORM arisings for the UKCS oil and gas industry. These are included in the bibliography in this report.

The literature review yielded the most data on decommissioning wastes, although most data was in the form of pre-decommissioning estimates that have been shown to be far larger than actual arisings.

4.4.2 NORM reporting to regulators

Oilfield NORM wastes are classed as exempt or non-exempt from the Radioactive Substances Act (RSA) depending on the calculated activity for radium and polonium. If this is below 14.8 Bq/g the material is 'exempt' from RSA under the PSEO (Phosphatic Substances, Rare Earths etc. exemption order) although it is still 'radioactive waste' depending on the specific activity of the radioactive elements present.

Statutory reporting of all non-exempt NORM disposals, regulated by SEPA/EA under RSA, is submitted annually, although the EA has only recently instigated a formal reporting procedure and no data were available. In practice, only a small proportion of total NORM arisings is believed to occur in the EA region (the Southern North Sea). Non-statutory reporting of NORM solid disposals to DTI/UKOOA is undertaken via the Environmental Emissions Monitoring System (EEMS).

For this study, records of NORM disposals reported to SEPA and to the EEMS were obtained for 2002 and, where available, for 2003. Reported data from Scotoil were also obtained for 2002 and 2003. The data is summarised in **Table 4-2**.

RSA Reporting (SEPA/EA)

Under their RSA 93 discharge authorisations operators must report non-exempt offshore and onshore disposals. However, some operators have also reported exempt offshore disposals and this complicates interpretation of the overall totals.

Table 4-2. Summary of reported solid NORM arisings 2002/2003

<table>
<tr><th rowspan="2">Source</th><th colspan="2">Offshore
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activity GBq</th><th colspan="4">Onshore*
mass t
activity GBq</th></tr>
<tr><th>Exempt</th><th>Non-exempt</th><th>Exempt</th><th>Non-exempt</th><th>Total</th><th>Reported by Scotoil</th></tr>
<tr><td>SEPA 2002</td><td>n/a</td><td>390
25.8</td><td>n/a</td><td>30.4
15.7</td><td></td><td rowspan="2">44
13.1</td></tr>
<tr><td>EEMS 2002</td><td colspan="2">316.7
16.9</td><td>15.8
0.61</td><td>20.5
4.69</td><td>36.3
5.30</td></tr>
<tr><td>EEMS 2003</td><td colspan="2">598.9
29.2</td><td>4.76
0.19</td><td>22.1
14.1</td><td>26.9
14.3</td><td>36
28.6</td></tr>
</table>

Notes:
*means brought onshore; most is subsequently discharged to the marine environment.
The number of significant figures reflects the numbers reported, not necessarily their accuracy.
These totals are for settled solids and do not include activity discharged in produced water.

SEPA's 2002 offshore returns totalled 390 tonnes with an activity of 25.8 GBq, from 72 facilities (including nil returns).

- This is more than the EEMS offshore disposals for the same period, when it would be expected to be less, as it should only include non-exempt disposals. This casts doubt on the reliability of the EEMS data.
- No 2003 disposal data was available from SEPA, and although 33 questionnaire replies included the 2003 SEPA returns the completeness of this dataset could not be verified and it has not been included here.

SEPA's 2002 'onshore' returns, covering 25 facilities, showed 30.4 tonnes with an activity of 15.7 GBq.

- This would be expected to be less than the Scotoil returns as it should not include exempt material.
- The mass of material reported by Scotoil is indeed higher (44 tonnes) but Scotoil's reported activity is lower (13.1 GBq). This discrepancy in activities may partly be due to differences in sampling and estimation, but differences in mass may reflect omissions.

EEMS Reporting (UKOOA/DTI)
EEMS is a voluntary reporting system for upstream oil industry environmental emissions that includes onshore disposals of radioactive waste, divided into exempt and non-exempt categories, and offshore disposals.

The EEMS offshore total for 2002 was 316.7 t with an activity of 16.9 GBq

- Less than the SEPA total for 2002, when they might be expected to be higher, as they include exempt waste.

The EEMS onshore total for disposals is 36.3 t with an activity of 5.6 GBq

- The onshore non-exempt totals are also less than the SEPA totals, indicating some omissions.
- In both cases the EEMS onshore total is lower than that for Scotoil, when it should be the same or higher (as EEMS might include onshore disposal to a waste contractor or to Drigg). Again, this discrepancy in activities may partly be due to differences in sampling and estimation, but differences in mass may reflect omissions.

The number of facilities with returns reported to the EEMS database in 2003 was 55, but as nil returns are not recorded, it cannot be determined whether there are omissions. The current number of RSA authorisations for NORM disposal is 93, which suggests omissions in EEMS. In light of the above discrepancies, it would appear that some overhaul or validation procedure is necessary for the EEMS reporting of radioactivity to be meaningful in the future.

4.4.3 UKOOA Produced Water Data

At the end of 2002 to early 2003 UKOOA reported a study on the potential dose risks from NORM nuclides in produced water (Smith and Watson, 2003). Samples were obtained from 82 offshore facilities. Although not all of the facilities with RSA authorisations and registered NORM disposals were covered by the UKOOA study, the facilities where an analysis was undertaken represented 96% of all produced water discharged.

4.4.4 Operator Questionnaire

Questionnaires were prepared and sent out to all operators. These were in electronic format in Microsoft Excel for ease of completion and circulation within recipient organisations.
The questionnaire was divided into sections covering the following issues:

- NORM occurrence
- Scale prevention methods in place
- Provision of NORM data
- Produced water
- NORM decontamination
- NORM monitoring
- NORM in process equipment
- Disposal of NORM solids
- Questions for Terminal operators

The results were discussed in detail in the Phase 2 report and contributed to the estimates and conclusions throughout the study.

4.4.5 Discussion

The comparison of reported data suggests that neither the EEMS nor the SEPA returns data set is complete. Checks were carried on complete data sets supplied for a few individual facilities and for these the EEMS and SEPA records were correct. There was insufficient data available from most operators to attempt this exercise.

In theory, with a full set of SEPA/EA and EEMS returns, a reliable annual quantification could be made. To date, however, the data reported under EEMS and RSA are incomplete. The two reporting schemes are not comparable and do not necessarily provide a meaningful comparison between facilities, or between years.

From the more detailed returns and some of the questionnaires there is a considerable variation in the amount of exempt NORM discharge - between 0 and 99%. For installations where data for more than one year was available this was seen to vary from year to year depending on what vessel cleanouts, equipment change out and maintenance has been carried out in that return year. Often a significant proportion of the activity discharged to sea comes from the large volume but low activity sludges from vessel cleanouts. Higher activity material tends to be produced from scale removal.

For a large oil platform in a shut down and cleanout year there might be typically 10-15 tonnes of NORM-contaminated material disposed of to the offshore environment but for the same facility in a non-cleanout year less than one tonne of material may be produced. This makes prediction of a generic amount per facility almost impossible other than at the broadest level. To predict NORM for an individual facility, the historic record could be used to set the maximum and minimum likely discharges. Even this will only be a general indication and any changes in conditions which could lead to more scaling (new wells onstream, water injection, seawater breakthrough etc.) need to be taken into account.

There is a considerable variation in operator maintenance and shut down programmes ranging from annual to over 10 years plus for vessel entries and cleanout.

Complete data sets have been obtained for a number of facilities covering several years and these have been used as the main source of predictions, guided by all the other available data.

4.4.6 Summary of quantification

A summary of estimated current arisings is given in **Table 4-3**. The following observations can be made:

- The largest arising of solid NORM occurs through offshore decontamination.
- Terminal vessel sludges and pigging waxes account for the bulk of NORM solids dealt with onshore.
- The masses of solid NORM arisings from decontamination and decommissioning onshore are small in comparison to those offshore.
- The activity discharged in produced water is estimated to be around 200 times the activity occurring in NORM solids.
- While offshore and onshore decontamination operations appear to be relatively steady in quantity over time, decommissioning arisings and terminal arisings may vary widely from year to year.

4.5 Forecasting NORM generation

Forecasts of NORM generation have been made up to 2040 based on reasonable assumptions detailed in the Phase 2 report. There are a large number of unknowns, and unknowables e.g. the oil price and new discoveries, and while the forecasts represent a possible scenario based on best information, they should be treated with caution.

Figure 4-4 and **Figure 4-5** profile mass and activity of NORM solid arisings respectively, and **Figure 4-6** profiles activity in produced water discharged to sea.

Table 4-3. Estimated current annual arisings of NORM from the UK oil and gas industry

Description of NORM	Total Activity GBq	Amount of material	Relative confidence in source data
Produced water to sea	9840	282 Mm^3	Medium
Reinjection	278	7.5 Mm^3	Medium
Offshore decontamination	23	1,300 t	Medium
Workovers	4	35 t	Low
Platform decommissioning (offshore)	1.5	15 t	Low
Platform decommissioning (to onshore)	0.2	1.8 t	Low
Pipeline decommissioning (to onshore)	<14.8 Bq/g Ra >14.8 Bq/g Ra	0.2 t 3.8 t	Low
Onshore decontamination	9.5	36 t (in suspension)	High
In water to terminals	12	220,000 m^3	Medium
Terminal decontamination	6	500 t	Low
Produced water discharged at terminal (by deduction)	6	220,000 m^3	Low
In product	No data for UK		

Figure 4-4. Forecast of mass of NORM solid arisings

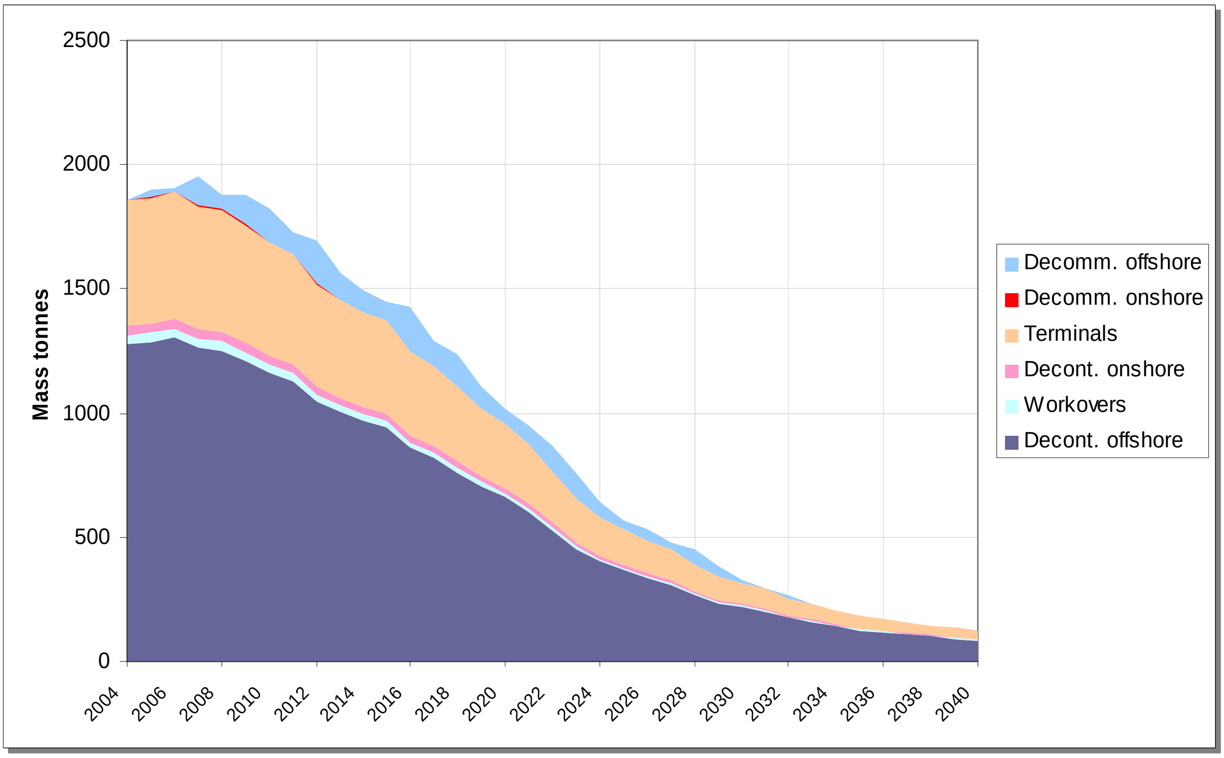


Figure 4-5. Forecast of activity in NORM solid arisings

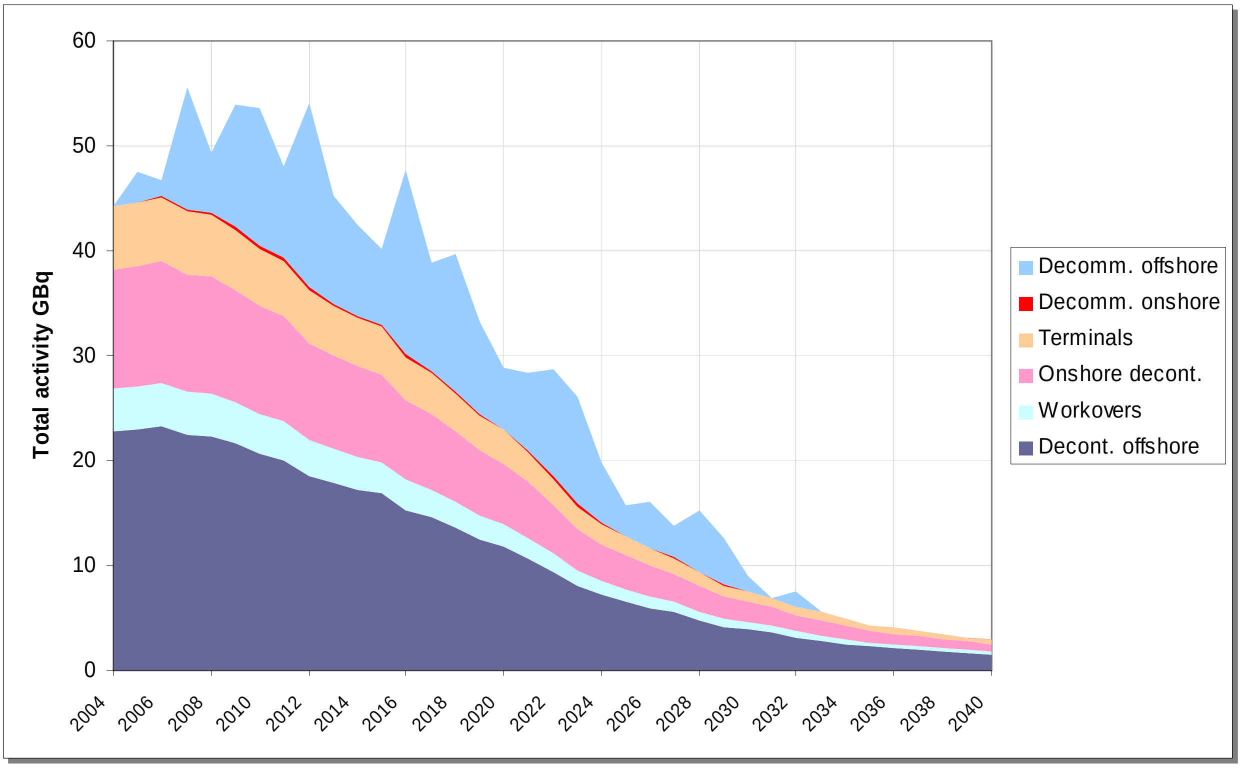
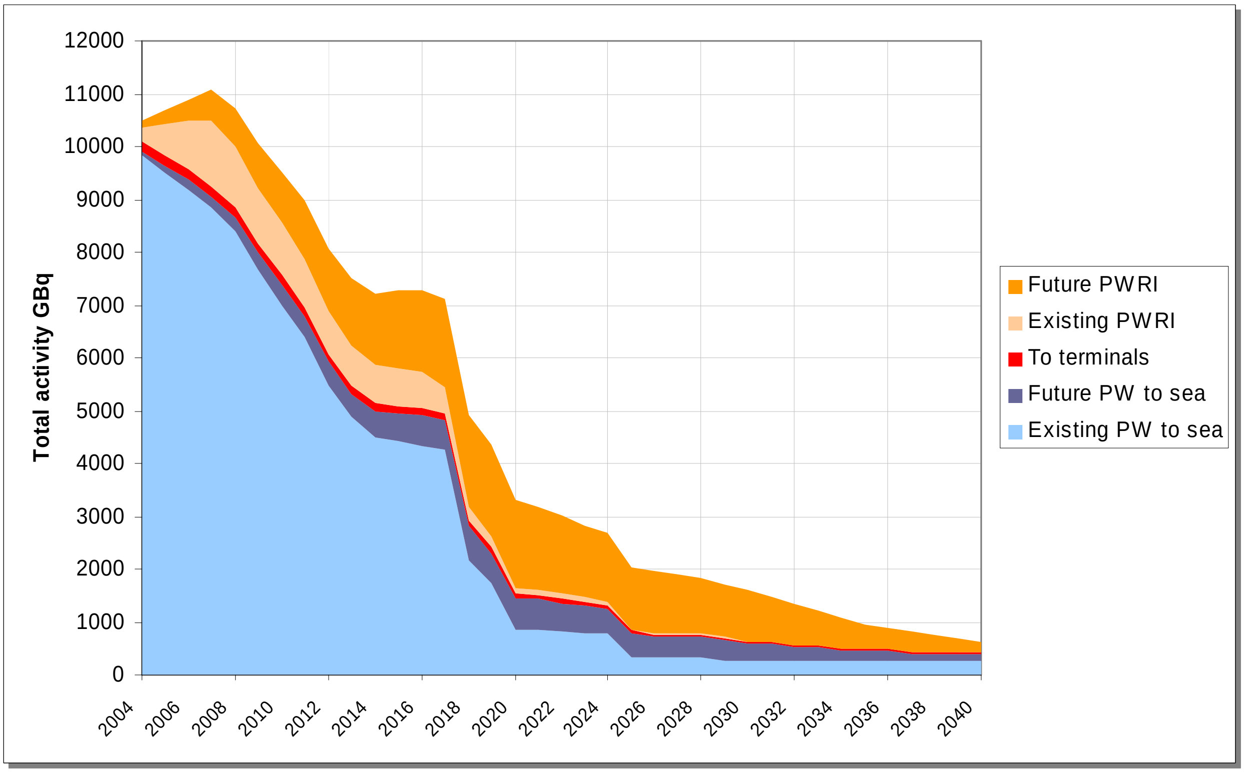


Figure 4-6. Forecast of activity in produced water



5 PHASE 2 SUMMARY: PREVENTION, MINIMISATION, TREATMENT AND DISPOSAL

5.1 NORM prevention, removal and waste reduction methods

The Phase 2 report discusses NORM waste prevention, waste reduction methods, removal methods and disposal methods in detail. A summary of the findings is included here.

5.1.1 Waste reduction

NORM waste reduction may involve one or both of the following:

- Volume reduction of amount of waste at source.
- Volume reduction by treatment after production.

The first is the ideal situation but often not practicable in oil and gas installations for the reasons discussed under prevention. Although these methods reduce the volume of LLW, they still require an authorised disposal route.

Basic waste reduction processes such as physical segregation of NORM wastes can achieve high volume reductions in primary (solid NORM) and secondary NORM wastes (contaminated equipment, PPE, containers) produced offshore and are normally incorporated in operator waste management plans.

In the UK supercompaction is used to reduce volumes of waste to be disposed of e.g. at Drigg. This is essentially the compaction of wastes within sealed steel drums using a large hydraulic vice. This is a very effective method for items such as PPE, contaminated packaging etc. but is not suited to scrap steel or wastes that consist predominantly of minerals or that are oily. Wastes must be dry and oil-free before supercompaction.

Waste reduction techniques from other NORM industries may also be of use for oilfield NORM wastes. Most are neither expensive nor complex, and are tried and tested technologies. They result in a small volume of LLW still requiring disposal with the bulk of the waste no longer radioactive as defined by RSA and therefore suitable for conventional disposal routes.

5.1.2 Prevention, minimisation and treatment options

Prevention and minimisation are the first steps in the waste hierarchy. In its strictest sense, NORM prevention and minimisation refers to limiting as far as possible the migration of radionuclides out of the reservoir. As was discussed in the Phase 1 report, however, there is no reliable, reported means of achieving this and the NORM that is present in the reservoir will be produced along with the fluids in which it is present. Techniques have been identified below that could prevent NORM exiting the reservoir although no practical details of trials or applications of these have been identified.

Based on data from operators, waste contractors, and vendors and published data, the following options were identified and evaluated (further details are in the Phase II report).

Table 5-1. Summary of NORM prevention, minimisation, removal and waste reduction options

	Status of techniques	Effectiveness
Prevention		
Downhole removal of NORM nuclides in the reservoir	Development	Not proven
Downhole oil water separation (DOWS)	Commercial	Not proven as NORM prevention method
Preventing and minimising NORM solids		
Scale inhibitors	Commercial	Good
Sulphate removal	Commercial	Good
Electrochemical	Development - Commercial	Selectively good
Engineering solutions	Commercial	Good/Fair
Removing NORM from produced water	Commercial	Not proven
Magnetic prevention	Trialled/commercial	Not proven
Removing NORM deposits		
In situ chemical dissolution	Commercial	Limited
In situ mechanical removal of scale	Commercial	Good
Offshore NORM removal from opened/dismantled equipment	Commercial	Good
Chemical decontamination	Commercial	Selectively good
Acoustic removal	Laboratory	Not proven
Microbial scale removal	Laboratory	Not proven
Liquid nitrogen	Laboratory	Not proven
Percussive removal	Trialled	Good
NORM waste reduction		
Chemical segregation/dissolution and separation	Development	Selectively good
Selective nuclide removal - ion exchange media	Development	Selectively good
Waste segregation/dewatering	Commercial	Good

5.2 NORM disposal options.

There is a wide variety of disposal options available in principle, and feasible options are discussed. Different options are suited to different types of NORM waste and a combination of options may be the best solution in a particular case.

The options are described below in an abridged form; further details can be found in the Phase 2 report. **Table 5-2** summarises the options, which are then discussed in the following sections. **Figure 5-1** illustrates these options.

Each disposal method is described in a table with the following subheadings:

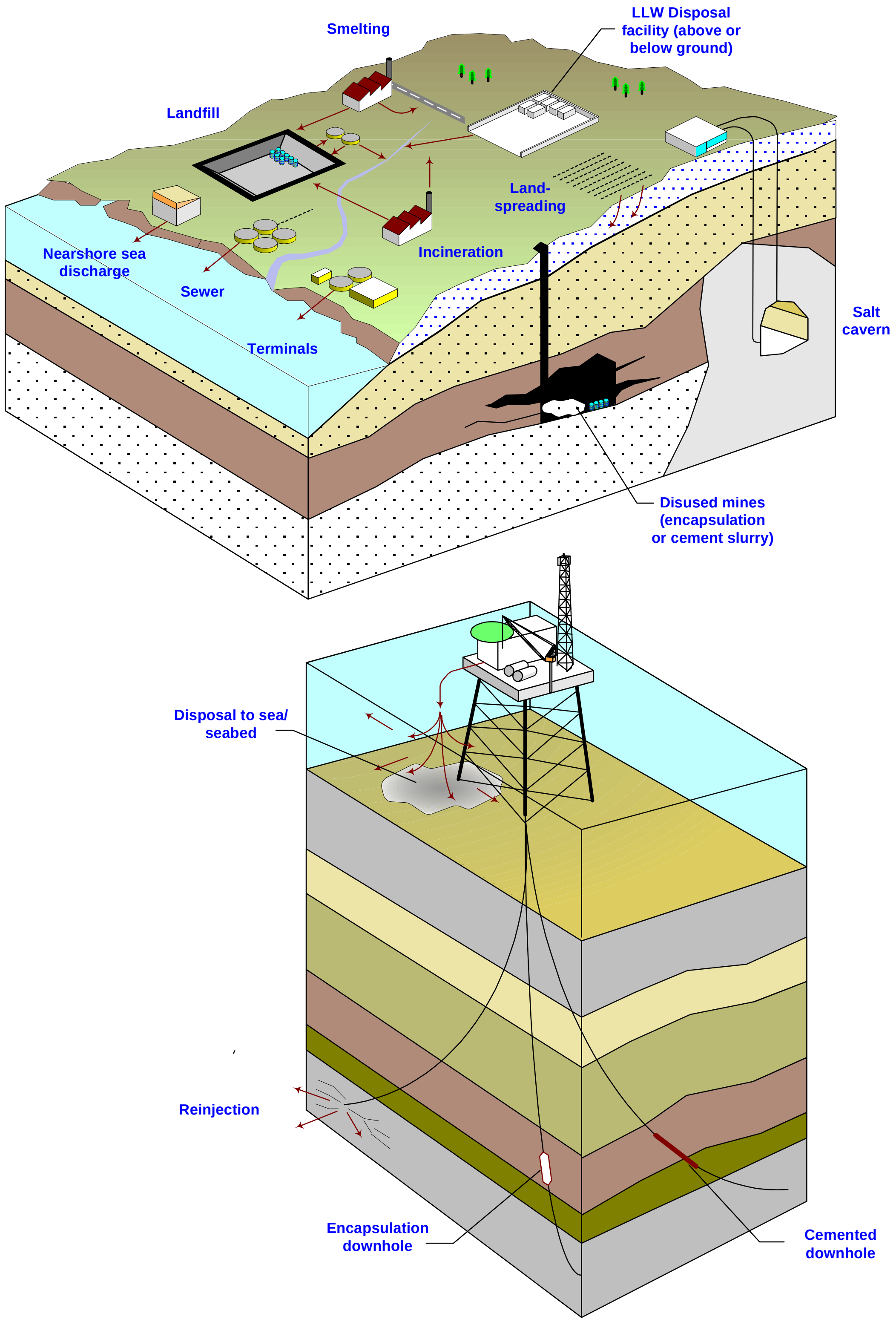
- Description
- Pros
- Cons
- Applicability to UKCS NORM disposal

Table 5-2. Summary of NORM disposal options considered

Offshore	Sea disposal offshore discharge
	Sea disposal nearshore discharge
	Re-injection of dissolved NORM (e.g. produced water)*
	Re-injection of solid NORM slurry*
	In situ downhole abandonment
	Encapsulation and downhole disposal
Onshore	Onshore built disposal facility
	Onshore landfill
	Landspreading
	Smelting
	Incineration
	Disused mineworkings
	Disposal in salt caverns
	Sewer
Export	Export to any of the options above in a foreign country

* Reinjection may also occur onshore but this is of minor application in the UKCS to date

Figure 5-1. Illustration of NORM disposal options



5.2.1 Sea disposal from offshore installations

Description

Most produced water is currently discharged offshore with a small percentage being reinjected or being passed to terminals. Produced water, and the NORM it contains, disperses rapidly in the sea after discharge.

Solid NORM arisings from offshore equipment descaling or from process and storage vessel cleanouts (sands, sludges) are macerated to 1mm and discharged to sea. Depending on the particular current regime, the NORM will be more or less rapidly dispersed.

Offshore facilities may have fixed de-oiling and maceration equipment or this may be brought onboard by cleaning contractors. Wastes that cannot be de-oiled cannot be discharged to sea. Discharge of workover NORM wastes from drilling vessels is not yet authorised in the UK but authorisations are under consideration by SEPA.

Pros

- Minimal handling and transport required reducing occupational exposure risk
- Low risk of public exposure as far offshore
- Limited dose risk to critical groups: offshore workers, fishermen
- Low tech approach which can be used on any facility
- Is currently in use

Cons

- Inconsistent with OSPAR aspirations to reduce radioactive discharges to sea
- Environmental impacts on the marine environment are not well documented and not usually monitored. The small particles resulting from maceration are more likely to be bioavailable than large pieces of scale and more likely to yield metal ions due to the higher surface area.
- Reputational issues as sea discharge (including produced water) from the oil and gas industry accounts for a significant proportion of alpha activity discharge into the OSPAR area (although the dose is trivial)

Applicability to UKCS NORM disposal

Offshore sea disposal is very widely used on the UKCS and accounts for the vast majority of solid NORM disposal. Current onshore disposal routes could only accommodate a small fraction of all the solid NORM waste disposed of offshore.

Denholm Industrial Services has investigated the possibility of operating a ‘NORM ship’. This could travel to offshore facilities and clean NORM-contaminated equipment adjacent to the facility and discharge the NORM waste either under the facility’ authorisation or under its own RSA authorisation. This has a significant capital cost, however, and would require industry buy-in. It also raised reputational concerns for the ship owner and was not pursued further for that reason.

Suitability: produced water and de-oiled solid NORM

5.2.2 Sea discharge to nearshore via outfall

Description

NORM can be discharged to the nearshore marine environment via a pipeline where a suitable RSA authorisation exists or can be obtained. This is currently the main disposal route for the UK for NORM from onshore decontamination. Scale that has been removed by high pressure water/abrasive jetting and reaming is ground and discharged (after oil removal) via a sea outfall. The discharge is dispersed to sea by water movement.

This outlet is mainly provided by one contractor (Scotoil) although some UK oil and gas terminals also have an authorised NORM sea discharge and RWE Nukem has a small facility in Dorset. One terminal has a larger authorisation than Scotoil but this is only for local NORM arisings and not likely to be available as a general disposal route. New authorisations may be granted and one has recently been applied for in the North of Scotland.

NORM is also discharged from terminals in produced water to nearshore.

Pros

- Simple and efficient process.
- Current outlets are close to where NORM is landed or produced, removing the requirement for transporting NORM waste (with attendant exposure risks).

Cons

- Any discharge in proximity to people could raise concerns
- Inconsistent with OSPAR aspirations of reducing radioactive discharges to sea
- Monitoring costs requirement due to proximity to public areas.
- Possible impacts on Habitats Directive site
- As currently practiced, reliant on one facility for onshore decontamination.

Applicability for the UKCS

It is currently the main disposal route for NORM from onshore decontamination of equipment from the UKCS.

Most is carried out by Scotoil services in Aberdeen. This facility utilises a discharge line that was originally used by a phosphate fertiliser plant that had a discharge consent for NORM. The discharge has been in use for oil field NORM since the mid 1980s. Its presence is not well known outside the industry and although dose risk assessments and monitoring have never demonstrated any risk to the public, it and the customers it serves are potentially vulnerable to malicious attention.

There is also a NORM decontamination facility at Winfrith in Dorset (operated by RWE NUKEM), which can utilise the UKAEA sea outfall until 2006 when this route will be discontinued.

Nearshore discharges continue to be authorised for existing sites and new discharges may still be authorised in the UK.

Based on the Phase 1 report estimates, the disposal capacity of the existing facilities should be sufficient to cope with future decommissioning demand from the UKCS. It would not be nearly large enough, however, to accommodate a significant proportion of all current solid arisings offshore, should these ever be returned to shore.

Suitability: produced water and de-oiled NORM solids

5.2.3 Reinjection

***Description*:**

Produced water is already reinjected at many UKCS fields, much of this water would be 'radioactive' under RSA. Produced water reinjection is expected to increase to meet OSPAR targets for reducing oil in produced water discharges. There is a presumption that new facilities will reinject produced water unless there is a strong argument not to.

Solid NORM can be finely ground into a water-based slurry that can be re-injected into a suitable subsurface formation by hydraulic fracturing. Cuttings re-injection equipment may be used where present. NORM reinjection is dependent on the availability of a suitable formation i.e. thick, high permeability and preferably sealed by impermeable horizons above and below.

NORM wastes are routinely reinjected in the Norwegian sector. It was decided in 1998 that offshore re-injection was the best disposal method for oil and gas field NORM wastes (SFT, OLF pers. comm.). Norway permits reinjection at the facility at which it was generated as for other operational wastes. Transport of NORM for re-injection to other facilities in the same field (intra-field) is also permitted but inter-field transport (to a different field) is not undertaken. Several platforms, with cuttings re- injection facilities already installed, are currently re-injecting NORM or applying to do so (Statoil pers comm. and BP Norge pers. comm.). Where there is no capacity for re-injection NORM waste is shipped to shore.

Produced water has to be disposed of using BAT in Norway, which excludes the generation of secondary hazardous wastes e.g. removal of NORM nuclides into ion exchange resins or onto filters which creates a more concentrated radioactive waste. Produced water is re-injected where feasible but otherwise discharged to sea.

Reinjection is used more widely offshore and onshore in the US (Smith et al 1996, Reed et al. 2001).

Pros:

- NORM is returned whence it came and is permanently removed from the surface environment.
- No transport of NORM arisings is required minimising exposure risks to personnel.
- For facilities that already have suitable disposal cuttings re-injection equipment installed, there would be little extra cost or emissions.
- It utilises tried and tested technology.

Cons:

- Where cuttings re-injection equipment is not installed the high capital cost for disposal of a relatively small volume would not be justifiable where discharge to sea was already permitted.
- The power consumption of slurry pumps is high with consequent atmospheric pollution.
- There has to be a suitable disposal well in the field, or intra- or inter-field transport for disposal would have to be investigated (such as is permitted for drill cuttings disposal).
- Onshore, it must be demonstrated that there is no potential for aquifer contamination

Applicability for UKCS NORM

This disposal method has obvious potential as one of the solutions for UKCS NORM disposal. Reinjection of radioactive produced water already takes place. Many installations are considering produced water re-injection as a way of meeting their oil in water OSPAR targets, which will reduce NORM discharged in produced water but this will not help with solid NORM waste re- injection as more powerful pumps are required for slurry injection.

NORM reinjection has been successfully used onshore in the UK where cuttings injection equipment is already installed. At facilities where slurry re-injection equipment is not already installed the capital cost, general feasibility and cost of extra emissions weigh against its use.

It is anticipated that reinjection of NORM presents no legal obstacles; the UK has signalled its intention to OSPAR to permit this and Norwegian operators already undertake this. Inter-field reinjection may require further investigation although inter-field cuttings reinjection is permitted with conditions. No operators in the UKCS have yet notified the regulators of an intention to carry out NORM solids re-injection but it is being actively considered.

Containment of the radioactivity should not be difficult to prove, as the nature of the subsurface in offshore fields very well known, and the sites are deep and far removed from aquifer contamination. Reinjection at onshore sites would be more difficult to justify given the proximity of receptors although dissolved NORM from decontamination has been reinjected onshore in the past.

Suitability: produced water, operational discharges and decommissioning wastes, providing site-specific conditions and equipment permit.

5.2.4 Downhole abandonment in situ

Description:

This involves NORM-contaminated tubulars being left in place downhole when a well is decommissioned, as opposed to withdrawing the tubulars and removing and disposing of any NORM. Although pumps and other valuable equipment can also be left, they are normally recovered for re-use. As part of the normal well abandonment process, producing zones are sealed to avoid the risk of future hydrocarbon contamination, e.g. by cementing inside the annulus and inside the production tubing. This has been carried out in the US in the Gulf of Mexico (Young *et al.* 1994). Near the surface, some production tubing must be removed to place a cement plug. No transport of waste is entailed and the cost of a workover rig/vessel can be avoided.

Pros

- Minimises cost
- Avoids NORM decontamination and disposal onshore or nearshore
- NORM on tubulars is permanently isolated from the environment
- Avoids having to remove, transport, and decontaminate tubulars with associated exposure risks
- Is compatible with current well abandonment guidance (UKOOA, 2001)

Cons

- Suitable only for NORM on well tubulars
- Not all wells will be suitable (case by case basis).

Applicability to UKCS NORM

The NORM in producing zones of wells is usually the most radioactive in a facility. There is therefore a distinct advantage in leaving it in situ. In the UK, if the tubulars were pulled to be cleaned then the NORM would either be discharged to sea offshore or sent for onshore decontamination and subsequent disposal to nearshore. According to the UKOOA Guidelines for the Suspension and Abandonment of wells, downhole tubulars and equipment may be left in situ on abandonment. This approach would have to be agreed with the DTI on a case by case basis. For facilities with large numbers of wells to be abandoned, this could be a useful NORM disposal method.

Suitability: contaminated equipment at decommissioning

5.2.5 Encapsulation and downhole disposal

Description

This involves the sealing of NORM wastes in containers followed by permanent disposal to the subsurface in disused wells.

NORM waste is placed into sections of tubular (or some other container), sealed in and deposited in the well. This is then cemented in place with a coloured marker in the sealing cement to warn against well re-entry.

This disposal method is widely used in the US but has not been undertaken in the UK. Scaife et al (1994) give some examples of this in practice from the US. One disposal (non encapsulated) was carried out offshore (Gulf of Mexico) where NORM contaminated sludge was poured into the casing of a well to be abandoned and sealed in with a cement plug. In another, 31 drums of NORM were sealed into sections of casing onshore then transported offshore for disposal in a disused well. It does not state whether any conditioning of the waste was carried out prior to disposal. There are also instances of slurrified NORM waste being pumped down disused wells, uncontainerised, and secured with a final cement cap.

Pros

- Simple and effective
- When containerised prior to disposal this provides permanent isolation from the environment

Cons

- Licensing/permit implications (if applicable) in UK would need to be clarified, especially if the radioactive waste is brought from onshore or another site and because additional material (the containers) is deposited
- Capacity is limited by the well geometry

Applicability for UKCS NORM disposal

This method might be of particular use during decommissioning where relatively small volumes of NORM are present and could be disposed of prior to well abandonment and capping.

For the UKCS the transport of NORM waste back offshore for disposal is likely to raise licensing difficulties. It is commonly held that while OSPAR does not prohibit ‘operational discharges’ from oil and gas platforms, once material has been landed onshore, any transport back offshore is seen to be ‘waste disposal’ which is prohibited.

Suitability: solid NORM waste disposal at decommissioning

5.2.6 Onshore built disposal facility/repositories

Description

NORM waste is conditioned in situ by cementing into drums. These are then placed into a suitable disposal facility. In this context, 'disposal facility' means a site that is the final place of disposal, versus a repository where there is the implication that waste can be inspected or recovered later.

In the UK, the only non-exempt LLW disposal facility is Drigg, where drums are grouted into ISO containers before being placed onto a concrete base in an open 'vault'. When the vault is full the space between waste containers is backfilled with granular packing material and the whole vault is covered with a permeable cap of mixed soil and porous media.

Other facilities exist in other countries e.g. most EU countries, including covered surface containment and geological repositories.

Pros

- Established disposal route
- Simple technology
- Currently in use
- Confidence about fate of waste

Cons

- High cost of existing facility; potentially over engineered for such a low activity waste
- Capacity problems
- Long term monitoring costs
- Requires land transport of NORM wastes
- Associated with more hazardous wastes
- Unlikely to be economic for oilfield waste only

Applicability for UKCS NORM

This is a current onshore NORM disposal route for non-exempt NORM waste to a single facility, Drigg. There are, however, capacity issues both for radium activity and for volume: Drigg has a radium limit which is not likely to be increased and, until expansion plans are approved, there will be volume constraints. Although oilfield NORM would only amount to a fraction of the limits, it is expected that pressure from other waste streams would make the capacity available to oilfield NORM very small and uncertain.

A new facility could overcome many of the 'cons' noted above, especially if it was purely for NORM or purely for LLW. It is very unlikely that a facility for oilfield waste on its own would be economic given the small volumes and variable nature of the arisings

Suitability: solid NORM wastes, contaminated equipment from operational and decommissioning phases.

5.2.7 Landfill

Description

NORM waste and contaminated equipment is transported by road to a landfill site. Non-exempt radioactive waste double-wrapped in paper bags is deposited loose into a hole dug in previously deposited non-radioactive waste in a lined, excavated cell and covered immediately. This is termed special precautions burial in the policy document Cm2919 and must be done under RSA authorisation. Cm2919 also states that radiological monitoring of the leachate should be undertaken. After each day, and when full, waste is covered with topsoil or granular material and ultimately the whole site is capped.

Exempt waste may be deposited in the same manner as non-radioactive waste. Radioactive waste that is hazardous due to its non-radioactive properties, e.g. oily wastes, have to be treated as coming under the Hazardous Waste Directive, requiring for example pre-treatment and disposal only in a hazardous waste landfill.

Note that a 'landfill' that took only radioactive waste would fall under RSA and be termed a disposal facility; disposal facilities are described in the previous section.

Pros

- Simple, established method
- Takes advantage of existing technology/waste management infrastructure
- Current method for exempt wastes

Cons

- Dearth of, and lack of capacity in, current landfills that take LLW
- Lack of interest from most private landfills due to controversial nature of waste and small volume
- Additional leachate monitoring requirements for non-exempt wastes
- Long lead time to consent and open new facilities
- Lack of financial incentive to open new facilities
- Potential public opposition

Applicability to UKCS NORM

Landfill is currently in use for disposal of exempt NORM wastes. Sufficient landfill operators will accept exempt waste for there to be no capacity issue. This can be as a non-hazardous material (including attached to scrap) or as a hazardous oily waste that otherwise could not be discharged to sea. Currently it is rarely used for solid mineral scale as this is normally disposed of to the marine environment, although it may be used for this.

There are currently no sites for non-exempt LLW in Scotland and very few in England and Wales. A list of sites and further details are given in the Phase 2 report.

Authorisations can be made to permit landfill disposal of non-exempt NORM wastes (LLW), relieving pressure on disposal facilities such as Drigg, although additional leachate monitoring is required and some companies are reluctant to take such waste. Given the current volumes requiring disposal, the financial incentives for new facilities are small compared with the (potential) reputational issues of radioactive waste.

Suitability: solid NORM wastes and contaminated equipment

5.2.8 Landspreading

Description

This has been carried out in the US to a limited extent (Veil *et al* 1998). It is a 'dilute and disperse' method where NORM wastes are mixed with clean soil until they are below regulatory limits and land spread (Smith *et al* 1996). This has been used to treat historic NORM accumulations from onshore produced water ponds and waste pits in the US. The EPA reports that present use of this method of disposal is limited. It was the practice to use the same tract of land for repeated landspreading episodes but this has been abandoned and new US regulatory developments will effectively prohibit landspreading of NORM wastes.

Landspreading has been permitted for oilfield NORM disposal on the assumption that the barium sulphate scale disposed of is insoluble under surface and near surface conditions and the radium it contains is therefore not biologically available. However, in a recent study in Mississippi (Swann et al 2004) barite scale was mixed with soils and incubated. All samples showed a greater extraction of soluble radioactivity than found with standard experiments using sterile NORM and groundwater. They concluded that radium is released from the barite lattice by action of soil micro-organisms and can pass into the food chain. Dose estimates for landspreading were well above trivial levels.

Pros

- Cheap
- Low technology

Cons

- Dilution to avoid regulation is not permitted by SEPA/EA
- Potential public/NGO opposition (reputation)
- Risk of groundwater contamination
- Lack of control over exposure to public from windblown NORM
- Requires transport of NORM from site of generation.
- Non-trivial exposure risks to public - ingestion and inhalation (windborne)

Applicability to UKCS NORM disposal

This is very unlikely to be considered suitable for disposal of UKCS NORM. It is now largely discontinued in US due to potential for public radiation exposure and to contaminated land issues and need for remediation.

There may be complications in authorising such a disposal route, i.e. in demonstrating that this is the Best Practicable Means to minimise public exposure, or if the waste is exempt, obtaining consent under as 'landfill' under the PPC authorisation under the Landfill Regulations.

Most oilfield NORM is produced offshore and this disposal route would entail transporting it to land with attendant exposure risks.

Suitability: not suitable for use in the UK

5.2.9 Smelting

Description

Equipment can be smelted without decontamination followed by recycling of the metal and disposal of the slag (Sappok *et al* 1999). This has been carried out for Conoco (now ConocoPhillips) as part of the decommissioning process for their Kotter and Logger platforms in the Dutch sector of the North sea. The contaminated steel was exported for smelting in Germany by Siempelkamp, a company used to handling contaminated scrap from the nuclear industry.

40 tonnes of scrap was smelted in 8 tonne batches. The resultant steel was free of NORM radionuclides and ready to be recycled for any use. The activity from the NORM was concentrated in the slag (98%) the remaining 2% was in the filter dust (mainly ^{210}Po and ^{210}Pb). The average activity of the slag was below 65 Bq/g (from ^{226}Ra), which in Germany was low enough to allow its use as road metal. This would not be the case in the UK. The secondary waste generated was 13% of the original volume. This consists of 95% slag and 5% coarse dust collected from the filters.

Whether there are suitable smelting facilities in the UK is not certain. The possibility was successfully trialled in the past in the UK by a major operator but is not currently carried out. There might be more interest from UK steel producers now that the price of steel has risen as this would provide high quality steel from a known source There should be no particular impediment to shipping contaminated equipment to Germany for smelting.

Pros

- High quality tubular steel is recycled
- Reputationally positive
- Process reliable and tolerant of variable NORM characteristics
- There is a considerable reduction in tonnage of contaminated waste (87%).

Cons

- Availability of suitable smelters uncertain
- Requirement for RSA authorisation if smelting non-exempt NORM contaminated steel (and other legislative issues)
- Creation of radioactive secondary wastes slag and dust filters.
- Disposal of contaminated slag. If non-exempt and in the UK, the slag would have to be disposed of as LLW

Applicability for UKCS NORM

This method has been successfully trialled in the UK but is not an ongoing practice.

Smelting was discussed with British Steel by an operator in the mid 1980s (pers. comm.) and an experimental plant was authorised by the regulator for smelting of NORM-contaminated tubulars. This work established that the steel produced was NORM-free. Further, by controlling the activity of the material charged to the furnace an exempt slag can be produced. Smelting was revisited by the same operator in the early 90's when a firm in Scotland was identified. In order to control the activity of the slag smelting needs to be carried out in discrete batches in an electric arc furnace. The activity of each charge can be calculated so as not to create a non-exempt LLW slag. The original trial was cut short when non-exempt NORM was detected and by the time the company had received their RSA authorisation to receive non-exempt scrap, they had gone into receivership. In 1994, another plant in England showed interest in this source of high quality scrap but this was not pursued.

Altra consultants (1993 patent Appendix 2) patented smelting to remove radioactive contamination by mixing with non-contaminated metal to reduce the overall level of radiation in the smelter (dilution).

This option might be worth reconsidering especially as part of decommissioning, as it may be combined with recycling of decommissioned components. The rate at which NORM is added must be controlled to avoid producing a LLW slag, e.g. by controlling the mixture of feed scrap.

This option has recently become more attractive following rises in the world steel price and it is likely that smelters would be interested in high quality steel from a trustworthy source.

Suitability: Solid or metallic NORM on tubulars and other steelwork

5.2.10 Incineration

Description

This is used for small volumes of contaminated PPE, packaging and exempt radioactive oily wastes (Shanks pers. comm.).

Incineration is suited to combustible materials, although non-combustible materials are sometimes passed through the incinerator. EA (2000) notes that during incineration of sewage sludge, metallic radionuclides tend to remain in the ash and 'volatile' radionuclides such as iodine, carbon and hydrogen pass up the stack (in general it is common for incinerator ash to be relatively highly contaminated with non-oxidisable compounds and solid oxides). It is expected therefore that NORM scale, if incinerated e.g. in an oily mixture, would largely remain in the ash. Lead and polonium NORM is unlikely to arise in a form suitable for incineration, because it mainly plates onto metal surfaces.

Another oxidation method is described by Titmas (1993). Supercritical wet oxidation has been trialled as a method of destroying organic contaminants (e.g. oils) while precipitating NORM metal oxides and concentrating them into a small volume for disposal. This is undertaken down a water-filled well at high hydrostatic pressure and high temperature with oxygen injection. The water is recirculated and insoluble NORM oxides precipitated and disposed of as a concentrated solid.

Pros.

- Effective for small volumes of NORM-contaminated combustible materials

Cons

- Secondary wastes generated
- Radioactive emissions to air from incineration
- Transport of NORM to a central facility
- Not really suitable for predominantly mineral wastes e.g. scale

Applicability for UKCS NORM

It is believed that the only real incineration outlet in the UK would be the Shanks incinerator at Fawley. This is understood to have an authorisation of 60 MBq/year for alpha emitters (the most limiting criterion for oil industry NORM) (UKAEA, 2002). It is not certain how this is calculated, but it will be a small fraction of the estimated annual 6 GBq/year (total activity) arising from terminal decontamination alone (the most likely waste stream to be incinerated due to its oil content).

Supercritical oxidation could in theory take advantage of existing oilfield infrastructure but it is not thought to have been attempted in the UKCS, or developed commercially worldwide.

Suitability: not a principal disposal route disposal for oilfield scale but appropriate for small volumes of PPE and some oily NORM wastes.

5.2.11 Disused mine workings

Description:

Disused mine working offer two possibilities for NORM disposal; either underground storage of cemented conditioned NORM wastes i.e. using the disused workings as a repository, or the use of NORM slurry cement for structural infill and shoring.

Cemented power station fly ash (PFA) which contains NORM nuclides is reportedly disposed of as part of cementing /shoring up operations (BGS pers comm.). PFA cement is used to stabilise old workings where there has been subsidence, and this has not been viewed as ‘waste disposal’, bringing licensing advantages.

Pros

- Many potential sites
- Simple existing technology

Cons

- Potential lack of containment leading to aquifer contamination, leaching,
- Public/NGO opposition,
- Potential costly re-engineering of old workings
- Difficulties with licensing as waste disposal sites etc
- Insufficient volume of oil and gas NORM waste to warrant starting this up unless part of a larger LLW disposal.

Applicability for UKCS NORM:

There is some precedent for this disposal route in the UK (for non-oilfield wastes) and the UK has a large number of disused underground workings.

Disused gypsum mines in Cumbria were investigated 10 years ago for conversion to solid hazardous waste storage/disposal (BGS pers. comm.). It was noted that all the risk assessment/ public consultation costs were far in excess of the engineering costs.

It might be possible to obtain the necessary authorisations but this may well be a difficult and lengthy process if there is local resistance. There is a history of serious pollution problems from some disused mine workings and although the NORM waste disposal may be safe it may be associated with these problems.

Oil and gas NORM waste could be combined with other wastes e.g. PFA for disposal to make the exercise more cost-effective. This would have the advantage of immobilising the NORM waste. In any case, it is likely that any oil contamination, if present, would have to be removed first.

Suitability: de-oiled solid NORM.

5.2.12 Disposal in salt caverns

Description

In a USA study Veil *et al* 1998 investigated the technical feasibility and likely exposure risks of NORM disposal in salt cavern in the US. Salt caverns resulting from solution mining of salt in salt domes and to lesser extent from traditional salt mining were investigated in Oklahoma, Louisiana, Texas, New Mexico and Mississippi. There were not considered to be legislative issues as the states participating already had legislation in place permitting re-injection of NORM down designated disposal wells and salt caverns were considered equivalent.

Pre existing caverns can be used or new ones created by solution mining using relatively simple techniques. Once created, the caverns are initially brine-filled and as waste is injected, the brine is withdrawn either up the injector well annulus/tubing or up a separate well. As the slurry is injected, the cavern acts as a separator with heavier solids sinking to the bottom of the cavern and hydrocarbons collecting at the top. As the cavern fills the removed brine become increasingly full of suspended material and when this becomes a mechanical problem (pump blockage) the cavern is considered full and is sealed up (Veil et al. 1998).

The method can involve some risk of the contents escaping depending on the nature of the salt deposit.

This disposal method is also used in Gemany in Lower Saxony e.g. the Asse mine is used for LLW disposal (not specifically NORM) and in France (Thoms and Gehle 2000). The NORM disposal in the US was directly into solution mining cavities in salt domes. A variation is described in a patent Snow (US patent Appendix 2 Phase 2 report) where NORM disposal is carried out using a pair of wells drilled into a salt formation.

Pros

- Utilises simple, tried and tested technology
- Existing structures exist and new structures are relatively simple to make
- Reasonable cost (150 \$US/bbl) (Veil *et al* 1998)
- Very high degree of isolation. Long term monitoring for leakage in US (after nuclear testing) has shown no nuclides escaping from the salt containment.
- Suitable for disposal of oily NORM wastes

Cons

- Seal failure from dissolution and cracking, leakage via non-homogenous, horizons and limestone non salt layers- loss to exterior migration of contents, with potential for aquifer contamination
- Risk to integrity from flooding, i.e. must ensure no access to groundwater
- Prone to “cavern creep” depending on the depth loss of significant volumes of storage. Rheological modelling is required to establish risks.
- Damage to injection equipment, loss of integrity due to cavern roof falls.

Applicability for UKCS NORM

Veil et al (1996) mentions an investigation in the UK about waste disposal (not particularly NORM) in salt caverns. There was a proposal to use some of 21 salt caverns off Teesside for hazardous waste disposal sites and they could also be considered for NORM LLW (Denholm Industrial Services pers comm.). Planning permission was investigated but the enterprise did not have sufficient financial backing.

In early 1980s BGS looked at salt structures in the UK for potential for hazardous waste disposal and identified several options, both onshore and offshore (see Phase 2 report).

This could be considered as a NORM disposal route as potentially suitable sites exist. Some salt caverns are currently used for underground storage in Cheshire (Deepstore -Northwich).

Salt caverns have been used more for gas storage in the UK which earns revenue. Onshore there would be concern over potential for aquifer contamination. While technologically simple, the main costs would be in obtaining consents (public consultation and potential resistance), which could be prohibitive if other options exist.

Suitability: operational NORM and other NORM that can be removed from equipment and slurrified or liquefied (including scale and metallic NORM).

5.2.13 Sewer

Description

The guide to the administration of the 1960 Radioactive Substances Act (1982), which has not been superseded, states that disposal to sewers should be considered as a disposal option for radioactive waste. Under section 18 of RSA93, the relevant Environment Agency may authorise disposal to sewer of small amounts radioactive material from non-nuclear organisations if the radiological risks are small and the disposal route is considered to represent BPM (EA, 2002). If the Agency considers that the disposal is likely to require special precautions to be taken by the water company [in England and Wales, or corporation in Scotland, or agency in Northern Ireland], then they must be consulted, but they do not have control over the discharge. It is not normal practice in the water industry to monitor influents, effluents or sludges for radioactivity. Most sludges in the UK are applied to agricultural land or incinerated, i.e. the public would be exposed to any radionuclides present.

EA *et al* (2002) states that the disposal to sewer route is under review, however, following the 1998 ban in disposing of sewage sludge to sea (implying that sea disposal is a relatively low-risk disposal route). The radionuclides discharged to sewer are almost always low toxicity beta or gamma emitters, although it is reported that very occasionally 'alpha emitters except natural uranium and natural thorium' are authorised.

NRPB (2004) discussed *inter alia* doses to sewage workers and to the public from radionuclides via sludge disposal. It concludes that small users (which term includes the oil and gas industry) may give rise to doses via sludge in agriculture that may be 'a few microsieverts'. This relies on decay in the period between discharging the radionuclides and the public eating crops. The document does not consider radium isotopes that have relatively long half-lives so it is conceivable that doses from NORM discharges to sewer could be non-trivial.

More widely, the disposal of sewage sludge has already suffered from adverse media attention and it is very unlikely that increasing the radioactivity in sludge, however slightly, would be welcomed.

Pros

- Minimum investment
- Widely available

Cons

- This is clearly a 'dilute and disperse' option
- Dose to wastewater operatives
- Discharge to nearshore
- Challenges in the available and acceptable routes for the disposal of sewage sludge

Applicability to UKCS NORM

Realistically, not applicable for bulk disposal of NORM solids onshore. Possibly suitable for small-scale disposal of laundry water from contaminated PPE to promote reuse and avoid incineration.

Suitability: not suitable

5.2.14 Export

Description

The Export option could entail any of the above options or combinations thereof but would be subject to the provisions for the transboundary movement of radioactive wastes, i.e. that the receiving country must have facilities, monitoring regulation etc. to deal with the waste adequately. It may be attractive in certain circumstances, e.g. on decommissioning if contaminated equipment is sent abroad for dismantling. This has occurred in the past with facilities taken to Norway (Brent Spar and Phillips Maureen) although the radioactive waste (as defined by the Norwegian limits) has been returned to the UK.

Some specific options involving export are described below as they have either been undertaken for oilfield NORM, seriously investigated or appear practically feasible. This is not intended to be exhaustive; other options, such as using disposal facilities in other EU countries (which are numerous), may well be equally viable. Representatives in Norway, the Netherlands and Denmark (as OSPAR countries with oil industries) were contacted, two of which indicated that radioactive waste may be imported under certain (commercial and regulatory) conditions. Denmark indicated that it was unlikely to import radioactive waste.

Norway - Disposal facility

Norway handles a large volume of UKCS decommissioning business. In Norway, onshore NORM waste is disposed of to repositories/landfill. Until recently this was to Himdalen, the national repository near IFE in Kjeller, however this facility has capacity issues. NORM waste is now in temporary storage at coastal bases up the west coast of Norway awaiting final disposal. New dedicated disposal facilities have been proposed, one in the South of Norway at Sokndal and one on the west coast at at Slovåg in Gulen. At the time of writing the Gulen facility (see below) had just received its authorisation and it may be the only facility that is permitted.

Netherlands - Disposal facility

In the Netherlands there is a central repository for radioactive waste at Bosele in Zeeland. It is run by COVRA (the central organisation for radioactive waste) and accepts NORM from the oil and gas industry. Disposers of radioactive material in the Netherlands are required to use this facility which has treatment and storage facilities for all levels of waste. Currently only companies holding a licence in the Netherlands under the Nuclear Energy Act (similar to a UK RSA disposal authorisation) may dispose of material to COVRA. However this could apply to several major operators on the UKCS who have facilities on and offshore in the Netherlands.

Germany - Smelting (Seimplekamp)

As Section 4.2.9, Seimplekamp has smelted NORM-contaminated steel imported from the oil and gas industry in the Netherlands, although it has not been ascertained how they would view imports from the UK.

USA - Reinjection and Landfill

The possibility of exporting NORM to the USA for disposal has been considered in the past by some operators. There are several offsite NORM disposal contractors in the USA, two with reinjection facilities and two with LLW landfill sites. One US-based company, MB Energy is reported (DTI 2003) to be authorised to import oilfield wastes, including NORM, to the USA for ultimate disposal into salt cavern. MB Energy is working with Denholm Industrial Shipping in Aberdeen to further this option. At the time of writing this project is in abeyance (pers comm. Denholm Industrial Services) pending resolution of shipping liabilities. MB Energy is currently obtaining export permits from a Norwegian operator who has in excess of 30 tonnes NORM stored on open ground.

Pros

- Makes best use of international experience and facilities, i.e. overseas options potentially ALARA compared to UK alternatives for some wastes
- Relieves pressure on UK disposal outlets e.g. Drigg
- Currently takes place in oil and gas and other industries

Cons

- Not in accord with proximity principle
- Exposure risks in transportation
- May be seen as not taking responsibility for own radioactive waste
- UK policy on exporting radioactive waste unclear
- Availability not guaranteed and may be conditional e.g. on decommissioning contracts

Applicability for UKCS

Export of oil and gas NORM wastes might be a viable option if there is no reasonable alternative in the UK. This would be subject to discussion with the regulators on a case by case basis.

5.3 Disposal method risk ranking

In order to rank the potential options a set of criteria was developed to allow options to be ranked in terms of the following criteria.

- Health and safety risks, radiological aspects
- Environmental impacts
- Generation of secondary wastes
- Technical availability/track record
- Cost/extra infrastructure
- Legislative implications
- Long term viability

The UKOOA risk assessment matrix was applied to identify tolerable and intolerable risks to screen out the options with intolerable risks. None of the options, however, presented an intolerable HSE risk according to the matrix criteria. Accordingly, the HSE risks, particularly the radiological risks, are also assessed to see if they are ALARA.

All the other criteria which pertain to suitability and sustainability are ranked according to professional judgement. Sustainability covers a wider range of issues dealing with the long-term future of the option these are dealt with in the long-term viability ranking but the following points were considered.

- Regulatory pressures and trends.
- Overall Management.
- Financial stability.
- Reputation Issues.
- Long-term capacity constraints.
- Ability to expand or accommodate change.
- Security and future of outlets for secondary wastes.

The ranking aspects are discussed in detail in the Phase 2 report. A summary table of overall ranking based on the criteria above of disposal options is shown in **Table 5-3**.

These risk rankings are, of necessity, generic, the aim being to give a broad comparison of disposal routes. For any particular disposal facility, a detailed site-specific risk assessment would be required. The ranking for each aspect is discussed in the Phase 2 report.

Although a number of waste reduction methods and NORM prevention methods are described in this report they are not included in this disposal option ranking. Those already practised are subject to HSE and SEPA/EA regulation and will be carried out under site Local Rules and procedures with the relevant risk assessments in place and it is to be assumed that the HSE risks are ALARA. Those in the developmental stage will have to be subject to the above regulation when ready for use. These pre-disposal stages are not included in the risk ranking above.

5.4 Doses

Radiological exposure was considered, both in terms of occupational exposure and public/ involuntary exposure.

Table 5-3. Summary of disposal option ranking

Option	Acceptability
Sea disposal offshore discharge	Good
Re-injection	Good
In situ downhole abandonment	Good
Sea disposal nearshore discharge	Fair
Encapsulation and downhole disposal	Fair
Onshore built disposal facility	Fair
Onshore landfill	Fair
Smelting	Fair
Disposal in salt caverns	Fair
Export	Fair
Landspreading	Unacceptable
Incineration	Unacceptable
Disused mine disposal	Unacceptable
Sewer	Unacceptable

All of the disposal methods will entail occupational NORM handling and it is assumed that this will be carried out under IRR 99 Local Rules and with appropriate risk assessment and risks should therefore be ALARA. The occupational exposure risks are identified as:

- External radiation (off and onshore workers).
- Inhalation (off and onshore workers).
- Ingestion (off and onshore workers).

For each of the disposal options, public dose was considered as far as possible using published information, described in the Phase 2 report. While the results are necessarily generic and will vary according to actual circumstances, the following broad conclusions are made:

- Doses for all offshore disposal options are negligible[1].
- Doses for reinjection options are negligible[1], although onshore options would require more justification due to proximity of aquifers.
- Doses for nearshore disposal are negligible[1].
- Doses from landfilling, incineration and smelting are uncertain, and although they may well be trivial, a site-specific assessment would be recommended.
- Doses from landspreading and sewer disposal are unacceptable unless there is no other option available.

[1]Public dose values below the environment agencies 20 μSv 'level of optimisation', the 10 μSv that is potentially 'of no regulatory concern' (Cm2919) and the IAEA triviality level of 'tens of microsieverts', with the possible exception of landfill depending on specific site conditions. EA (2002) states that calculated average annual individual doses for a population group in the nanosievert (nSv/y) range or below should be ignored in the decision making process. Therefore, although dose does differentiate between the main disposal options, it is arguable whether any of the doses calculated here should be a key factor in deciding preferences in disposal routes.

6 CAPACITY VS ARISINGS

The capacities of the different disposal options for solid NORM waste are discussed in **Table 5-1** below. The key areas where there are significant capacity issues are:

- Disposals to Drigg; the capacity for oilfield NORM is uncertain.
- Landfill capacity for non-exempt LLW is currently zero in Scotland and very small in England and Wales.
- Onshore decontamination has sufficient capacity under current arrangements but is effectively limited to one discharge point.
- Incineration capacity in the UK is very small, although this is not a route much used by the oil and gas industry.

'Capacity' is dependent on disposal routes being, and continuing to be, authorised. Any disposal of non-exempt radioactive waste can only be done under RSA authorisation. Such disposals are therefore subject to regulatory policy for radioactive waste disposal, which continues to be under review at a UK level and a SEPA/EA level. Further, some options discussed here have never before, or never recently, been authorised and it is cannot be stated whether authorisation would be forthcoming in a particular case. None of the options below is ruled out, however, by current radioactive waste legislation and policy. It is therefore for operators to discuss disposal options with the regulator in all cases, and it should be noted that the premise of this study is that the *status quo* is not necessarily the preferred solution in all cases.

For example, disposal of radioactive waste by landspreading or to sewer has virtually unlimited capacity, but these are options unlikely to obtain authorisation or be acceptable in a wider sense.

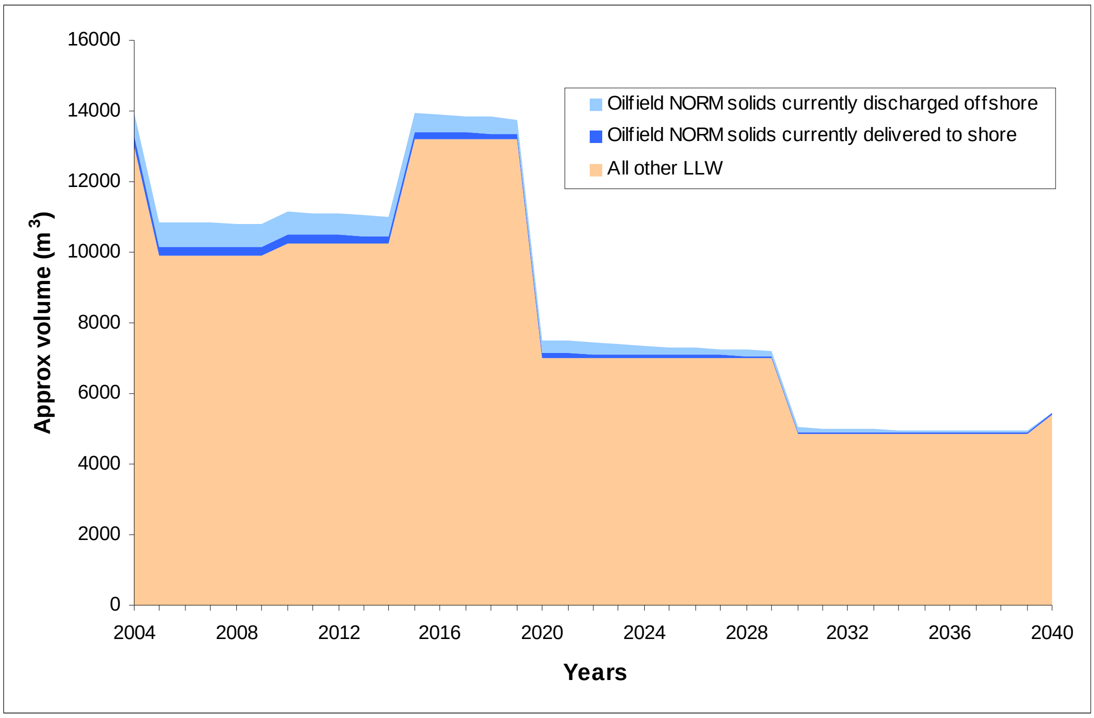
New capacity can also be made, and several contractors were identified in this study that had an interest in developing solutions that would include oilfield NORM. Where the construction of new/amended landfill and disposal facilities is concerned, NORM from the oil and gas industry cannot be considered in isolation as it is a relatively small and unpredictable waste stream. There is a consensus that overall radioactive waste disposal capacity will soon be at an all-time premium and emphasis will go on dealing with intermediate and high level wastes first. Security of existing outlets for oilfield NORM is therefore very uncertain and may require positive intervention from the industry.

The scale of the overall issue can be seen by examining the quantities of oilfield NORM in relation to other low level radioactive wastes. **Figure 6-1** shows the relative contribution of oil and gas industry LLW to the UK total LLW inventory (DEFRA 2001, UKRSR 07 Phase 1 report 2004). Solid NORM arisings that are currently generated onshore or arrive onshore are listed separately as it is assumed that offshore disposal for these arisings is effectively unavailable. It can be seen that these are a very small proportion of the total UK arisings. If offshore solid arisings are added (e.g. in the unlikely scenario that all offshore solids had to come onshore), the proportion is more significant but still less than 10% of the total.

Table 6-1. Summary of capacity issues

Option	Capacity	Comments
Sea disposal - offshore discharge	Effectively no limit under current regulatory regime	May be subject to a policy of reducing consents in line with OSPAR and UK strategy. EU/OSPAR aspiration to limit to 'background' levels by 2020.
Re- injection	Current limited only by the capacity of re-injection equipment, e.g. for drill cuttings. Some sites may not be suitable.	Unlikely to be installed purely for NORM disposals if sea discharge is permitted. Inter-field transfer potentially a solution if permitted
In situ down hole abandonment	Limited volume per well.	Disposal route for tubulars on decommissioning/abandonment. Waste avoidance, no radiological exposure.
Encapsulation and down hole disposal	Limited volume per well.	Potentially of use for decommissioning. Not certain that this would be authorised.
Sea disposal - nearshore discharge	Current routes limited by authorised activity: - Scotoil - Winfrith* - Terminals* *only available to specific operators New consents may be granted.	May be subject to uncertain public perception and regulatory policy issues. No predicted capacity problem unless sea discharge of solids NORM phased out, but reliance on few outlets.
Onshore built disposal facility	Existing facility (Drigg): in theory, has capacity for all current arisings brought onshore (Drigg annual $^{226}Ra/^{232}Th$ limit is 30 GBq vs 1.1 GBq oilfield arisings) but in practice may be zero due to other wastes. New facility: Effectively no limit.	Longevity of Drigg dependent on expansion plan that is not yet approved. Drigg is a disposal route of last resort. New facility could be authorised, but oilfield NORM not of sufficient volume to justify business case on its own
Onshore landfill	Exempt LLW: unlimited Non-exempt LLW: none in Scotland and very little in England & Wales.	Exempt LLW is treated as ordinary waste. Non-exempt LLW can only be disposed via SPB with authorisation requiring additional monitoring
Smelting	Limited to high quality NORM-contaminated steel e.g. tubulars.	Feasible, at trial stage in the UK, practised in Germany. May be more attractive following rise in steel prices. May be combined with recycling of decommissioned components.
Disposal in salt caverns	Currently not available in the UK, but potentially large capacity solid NORM disposal.	Feasible both onshore and offshore. May require significant investigation depending on degree of isolation.
Export	Potentially unlimited depending on destination. Several outlets potentially viable.	Has been undertaken during decomm-issioning although later returned to UK. Radioactive waste export policy unclear.
Landspreading	Zero due to unacceptable doses	
Incineration	Currently very limited in UK as a whole (30 MBq at Fawley). Unsuitable for mineral scales.	A solution for small quantities of combustible wastes e.g. PPE and some oily wastes.
Disused mine disposal	Potentially large volume but case dependent	Significant problems with lack of containment
Sewer	Not viewed as an acceptable solution; non-trivial doses.	

Figure 6-1. Volume of oilfield NORM compared with other LLW



Source: This study (for oilfield NORM) and The 2001 Radioactive Waste Inventory (DEFRA, 2002e)

Clearly, the onshore disposal issue would be greatly exacerbated if offshore NORM solids had to be disposed of via onshore outlets, and existing capacity would not be sufficient to meet such a challenge. Offshore disposal is currently viewed as acceptable and presents a trivial dose risk, but the UK policy is to reduce discharges to sea in line with and OSPAR and EU marine strategy.

Reinjection could be used to reduce discharges to sea, although it could still constitute 'discharges to the OSPAR area' under OSPAR definitions (Article 1 OSPAR Convention 1992). Reinjection could have a large capacity (especially if inter-field transfer is permitted), but where cuttings reinjection equipment is not already installed, requires significant capital and operational expenditure with associated fuel use and atmospheric pollution, and it is not clear that this is preferential to the discharge of NORM to the sea.

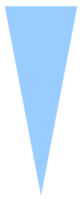
Exporting radioactive waste is another solution that could be expanded and outlets are currently available. Although it is permitted within the law (and may be authorised under RSA) it contravenes the proximity principle and it is not clear how it would be viewed in the international community, or whether this view is important.

7 CONCLUSIONS

7.1 NORM origins and occurrence

1. The origin of the radionuclides in NORM is well known and documented as progeny of the primordial ^{238}U and ^{232}Th decay series.
2. The vast majority of NORM occurs in oil production infrastructure. The main areas where NORM accumulation is encountered are locations where there is oil and water and where physical conditions change, e.g. in the well itself, in separators, degassers, heat exchangers and in water or hydrocarbon storage vessels.
3. Mineral scales and sludges containing radium isotopes account for the vast majority of oilfield NORM by mass.
4. Metallic NORM (as a thin metallic film or a black deposit in sludges) from gas and condensate process equipment contains ^{222}Rn daughters ^{210}Pb and ^{222}Po and is of very low mass in comparison with mineral scales but can be of locally high activity. There is very little volumetric data for these deposits. They do not usually interfere with production but may present an exposure risk on dismantling or decommissioning.
5. It is also reported that there is a third type of NORM (also containing ^{210}Pb and ^{210}Po) resulting from direct deposition of ^{210}Pb transported in solution.
6. The following broad ranking of NORM activities is made, but there are exceptions:

Higher activity	Downhole scale
	Topsides scale
	Separator sludges
	Storage vessel sludges
	Produced sand
Lower activity	Pigging wax



7. Most occurrence offshore is in the form of mineral scale. Most occurrence onshore is in the form of terminal sludges.

7.2 NORM quantification

8. Current NORM arisings from the UKCS upstream oil and gas industry have been estimated and forecast to 2040. See Sections 3.4 and 3.5.
9. There is considerable variation between facilities and it is apparent that meaningful trends would only be evident if several years' records from a selection of platforms were analysed.
10. The largest arising of solid NORM occurs through offshore decontamination.
11. Terminal vessel sludges and pigging waxes account for the bulk of NORM solids dealt with onshore.
12. The masses of solid NORM arisings from onshore decontamination and decommissioning are small in comparison to offshore decontamination and decommissioning.
13. The activity discharged in produced water is estimated to be around 200 times the activity occurring in NORM solids.

14. While offshore and onshore decontamination operations appear to be relatively steady in quantity over time, decommissioning arisings and terminal arisings may vary widely from year to year, largely due to a much smaller number of facilities.
15. It is predicted that the activity discharged in produced water, from the sum of existing and future platforms, will decrease to approximately one tenth of its current value by 2040.
16. The generation of NORM solids is expected to increase slightly to 2010 and then decrease by around 50% to 2040.
17. Arisings other than decommissioning are predicted to decrease from the current level in line with the number of facilities in the UKCS.
18. Arisings from decommissioning, less than 10% of the total arisings, are predicted to increase to a plateau between 2012 and 2025 in line with predictions for platform decommissioning.

7.3 Prevention, minimisation, treatment and removal

19. There are many techniques available for NORM prevention, minimisation, treatment and disposal, from proven and widely used techniques to novel and developmental techniques. These are summarised in Section 4 and apply to different circumstances and different NORM types.
20. The appropriate combination of techniques should form part of a facility-specific NORM management plan.

7.4 Disposal options

21. None of the disposal routes appears to present a significant occupational or public radiation exposure risk apart from landspreading. Onshore disposal options, however, would require a site-specific assessment to demonstrate this.
22. Options involving investment from contractors (e.g. onshore disposal facilities) are unlikely to be economic based solely on oilfield NORM given the small and unpredictable volumes. Securing onshore disposal facilities may require positive action by the oil and gas industry, i.e. the free market cannot be relied on to provide a solution.
23. No single disposal option is seen as the sole solution for the variety of NORM types and circumstances experienced in the oil and gas industry. Conclusions for each disposal option are as follows.
24. **Sea disposal offshore discharge**
    - While discharge of alpha emitters has become a reputational issue via Dutton *et al* (2002), the data in this report and in NRPA (2005) suggest that emissions are significantly lower than estimated in the 'Marina II' study.
    - Sea discharge in the long term (2020) may need to be curtailed to meet OSPAR and EU aspirations (and UK policy) to reduce radioactive discharges to sea, although by this time discharges will have reduced in line with UKCS activity and reinjection.
    - The effects on marine biota are not well understood.
25. **Sea disposal via a nearshore discharge**
    - Currently there is only one onshore decontamination facility (security of supply risk).
    - Relatively simple to permit new discharges e.g. from terminals.
26. **Re-injection**
    - Re-injection offshore to the deep subsurface has distinct advantages over all the other options due to degree of isolation and minimisation of handling and transportation.

- Significant investment unless cuttings re-injection equipment is already present.
- Increased fuel use and atmospheric pollution.
- Centralised reinjection has attractions but legal basis would need affirmation.

27. In situ downhole disposal

- High degree of isolation.
- Occurs at present.
- Permitted under UKOOA Well Abandonment Guidelines and approved under decommissioning plans.
- No exposure risk.

28. Encapsulation and downhole disposal

- High degree of isolation.
- Legality of depositing containers uncertain.
- Possibly useful for disposing of contaminated tubulars avoiding the exposures associated with decontamination.

29. Onshore built disposal facility

- Some onshore disposal facility capacity is essential for non-exempt NORM that cannot be disposed of elsewhere (e.g. at present, onshore arisings from decommissioning).
- Drigg capacity for oil and gas NORM wastes is uncertain as it is constrained by radium and thorium activity limits plus the current capacity limits might be fully taken up by other wastes.
- Public resistance to new radioactive waste disposal sites although perceptual advantage of being "natural"
- Economics militate against construction of a oilfield NORM-only facility
- Several contractors have interest or plans but are reluctant to invest without some guarantee of revenue.
- Shared facility may bring unwanted associations - reputational issue.
- If this is to continue to be the main disposal route onshore for non exempt NORM waste for the UK some assurance should be sought by the regulators that oil and gas NORM waste will continue to be accepted.

30. Onshore landfill

- Exempt NORM waste may continue to go to conventional landfills and this is an important route e.g. for occasional large volumes of terminal wastes.
- Special precautions burial appears to be a diminishing practice.
- There are no sites that receive non-exempt LLW in Scotland, few in England and Wales and limited interest from waste contractors due to controversial nature of waste. The proximity principle and differences in regulation north and south of the border are arguments for a greater number of sites, but this is a matter for the open market.
- Additional leachate monitoring required for non-exempt waste.
- Doses from landfill disposals are uncertain.
- Non-exempt NORM waste is not WFD waste and in the absence of special precautions burial requires a RSA authorised disposal facility, discussed above.

31. Landspreading

- Not considered a viable option.

32. Smelting

- Smelting is a potential outlet for used tubulars, but not suited to loose NORM.
- Relatively high doses (although probably still trivial).

33. Incineration

- May give rise to a non-trivial dose depending on circumstances.
- Very little capacity in the UK.
- Not really suitable for non-combustible wastes.
- Secondary waste - ash containing radioactivity.

34. Disused mine disposal

- Used in some other NORM industries.
- Potential to combine oilfield NORM with existing materials e.g. PFA.
- Containment difficult to guarantee and some existing mine discharges are very polluting, i.e. there are real and reputational pollution risks.

35. Disposal in salt caverns

- Possible to demonstrate good containment.
- Isolated from public.
- Potential sites have been investigated in the UK.
- Some technical (and potentially licensing) challenges so long lead-in time.

36. Sewer

- Not considered a viable option.

7.5 Capacity issues

37. Short-term capacity issues are in the disposal of NORM brought onshore. Longer-term issues are in the disposal of NORM to sea.
38. The capacity for oilfield NORM at the Drigg disposal facility is uncertain.
39. Landfill capacity for non-exempt LLW is currently zero in Scotland and very small in England and Wales.
40. Onshore decontamination has sufficient capacity under current arrangements but is effectively limited to one discharge point.
41. Incineration capacity in the UK is very small, although this is not a route much used by the oil and gas industry.
42. New facilities may be authorised to deal with NORM brought onshore although consent processes may be extensive, both in time and cost, to take public consultation into account.
43. Export options appear available under the existing legislation but would require approval on a case by case basis from the regulators. Export routes would also require justification with respect to the proximity principle.

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