Phase II Technical Report **Project UKRSR07**

Identification and assessment of alternative disposal options for radioactive oilfield wastes.

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1 EXECUTIVE SUMMARY

This report addresses Naturally Occurring Radioactive Material (NORM) arising from the oil and gas industry in the UK, covering the UK Continental Shelf (UKCS).

This report is the deliverable for Phase 2 of the SNIFFER project UKRSR07 Identification and Assessment of Alternative Disposal Options for Radioactive Oilfield Wastes. It addresses NORM prevention, removal and waste reduction. Existing disposal methods and other potential disposal routes are reviewed for use for UKCS NORM waste. Capacity issues are included in this report however the combined technical report (deliverable 3) will contain the main waste volume/capacity discussion.

There are pressures on existing disposal outlets, both offshore and onshore, that could cause significant problems in the medium and short term if not actively addressed. There are also reputational and public perception issues associated with NORM disposal as it is a radioactive waste, regardless of the actual risks. This report is an investigation of potential solutions.

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 are 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 to along with an indication of regulatory support.

The predicted amounts of NORM arisings for onshore disposal under the current regulatory regime, even at the peak of decommissioning, are unlikely to justify development of a dedicated disposal facility in the UK

None of the disposal routes appear 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 and the table below shows a summary of the results. This is based on an overall assessment of the following ranking criteria (Section 11).

Risk ranking 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

Assessed as good (pale blue)/fair (mid blue)/poor/unacceptable (dark blue)

Summary disposal option ranking based on all criteria

Disposal option	**Ranking**
Sea disposal offshore discharge	
Re-injection	
In situ downhole abandonment	
Sea disposal nearshore discharge	
Encapsulation and downhole disposal	
Onshore built disposal facility	
Onshore landfill	
Smelting	
Disposal in salt caverns	
Export	
Incineration	
Landspreading	
Disused mine disposal	
Sewer	

There do not appear to be any insurmountable legislative hurdles to development of the preferred disposal routes, but changes to legislation such as exemptions could be pursued to simplify current arrangements.

2 GLOSSARY AND ABBREVIATIONS

Absorbed Dose	The ionising radiation energy absorbed in a material (tissue) per unit mass of that material. Unit=gray (Gy) measured in J/Kg
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
Capex	Capital expenditure
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
CT	Coiled Tubing
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, one of the regulators for radioactive waste management in England and Wales. EA's powers are provided under RSA93. 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.
EJC	European Court of Justice
EEMS	Environmental emissions monitoring
EHS	Environment and Heritage Service of Northern Ireland (the radiological regulator)
Effective Dose	The sum of equivalent doses from internal and external radiation in all tissues and organs of the body taking into account tissue weighting factors. Unit =seivert (Sv) normally mSv or μSv.
EPA90	The Environmental Protection Act 1990; legislation that, among other things, made changes to the management and regulation of waste management
Equivalent Dose	The absorbed dose in a tissue/organ weighted using the radiation weighting factor. Units are Sieverts.
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.
GBq	$1x10^9$ Bq
G o M	Gulf of Mexico
GRA	Guidance on Requirements for Authorisation (for Disposal Facilities on land for low and intermediate level radioactive wastes), EA guidance for assessing RSA applications for LLW disposal sites
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
LET	Linear energy transfer
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)
Man Seivert	Effectively the individual dose (Seiverts) multiplied by the number of people exposed
MBq	$1x10^6$ Bq
MIC	Minimum Inhibitor Concentration
MOD	Ministry of Defence
MOL	Main Oil Line
MWD	Mining Waste Directive
NEA	Nuclear Energy Act (Netherlands)
NGEO	Natural Gas Exemption Order 2002, exempts most North Sea gas in terms of radon content , from the requirements of RSA.
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)
Opex	Operational expenditure
OSPAR	Oslo and Paris Commission for the protection of the marine environment of the North East Atlantic
PFA	(Power station) Pulverised 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
Radiation Weighting Factor	Factor used to weight absorbed does to a tissue or organ according to the type of radiation exposure. Normally :α particles = 20, ß particles and γ photons =1
RAM	Risk assessment matrix
RCL	Radioactively Contaminated Land
RPA	Radiation protection advisor
RPS	Radiation protection supervisor
RSA 93	Radioactive Substances Act 1993 (as amended by the Environment Act 1995). 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 Scottish Ministers and the departments and staff of the devolved administration in Scotland. The Scottish Executive is responsible for most aspects of environmental protection policy in Scotland

	under devolution arrangements
SEPA	Scottish Environment Protection Agency, reports to the Scottish executive on radiation matters.
SI	Scale Inhibitor
Sievert (Sv)	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*
TBq	$1x10^{12}$ Bq
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

3.1 Overview

Naturally Occurring Radioactive Material (NORM) is an unavoidable by-product of oil and gas production. There are a number of technical, radiological and practical management issues associated with NORM, together with wider issues of stakeholder perception and corporate reputation that exist under an umbrella of national and international regulation on NORM disposal.

This report is the deliverable from Phase 2 of the SNIFFER project UKRSR07 "Identification and assessment of alternative disposal options for radioactive oilfield wastes".

In this report, methods of NORM/scale prevention, NORM waste minimisation and NORM disposal options are discussed. 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. The main discussion of likely future disposal capacity compared to predicted NORM arisings from the Phase 1 report is in the Technical Summary Report.

The development of appropriate and sustainable NORM handling, treatment and disposal requires the integrated and active involvement of the oil and gas industry and the Regulators. It is important for the industry as a whole to move from a reactive position to a proactive, forward planning approach.

3.2 The Phase 1 Report

Phase 1 of this project examined the origins of NORM in the upstream oil and gas industry (i.e. extraction offshore and onshore and the immediate handling and processing of hydrocarbons at Terminals). Reference should be made to the Phase 1 report as it provides important context for this report.

A full synthesis of Phase 1 and Phase 2 findings will be made in the Final Technical Report. Nevertheless it is useful to include the summary findings of the Phase 1 study here as these help determine the relative importance of each disposal outlet, and technical details such as specific activity from different waste streams affects the choice of treatment and disposal outlets.

The capacity of the disposal routes is addressed in part in the option section of this report but will be more fully addressed in the final technical report (Phase III).

Table 1. Estimated current annual arisings of NORM from the upstream oil and gas industry

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

*Exempt/non- exempt from the disposal requirements of the Radioactive Substances Act (ref. page 6)

3.3 Consultations for Phase 2

A data-gathering exercise was undertaken for Phase 1 including contacting all oil and gas operators via a questionnaire but also by telephone and email to discuss particular points arising. While this was primarily for quantification purposes it also yielded useful information on prevention, minimisation, treatment and disposal options.

The members of the Steering Group (SEPA, EA, EHS, DTI, SE, UKOOA, Shell, and BP) have also provided valuable information and views.

In addition to this, a wide range of bodies has been contacted for their views and information specifically for the Phase 2 report. These are listed in **Table 2** below, and reference is made to their comments throughout the report. Where circumstances permitted, consultation was made in person.

Table 2. Bodies contacted for Phase 2 report

Organisation contacted	Notes
Aberdeen University Department of Medical Sciences	RPA for several companies on oil industry NORM issues
ALCO Waste Management Limited	Disposal facility for exempt LLW with proposals for non-exempt disposals
British Geological Survey	Advisors on geological radioactive waste disposal routes, geological evaluation of potential routes.
BNFL (Drigg)	Managers of the only UK LLW disposal facility
Coflexip Stena Offshore (Technip)	Logistics company occasionally involving NORM waste
COVRA	Manager at COVRA disposal LLW facility
Danish regulator	Danish radioactivity regulator
DEFRA	Contingent at OSPAR Reykjavik plenary session agreeing NORM reporting procedures
Denholm Industrial Services	NORM decontamination contractor
Enviroco	Waste disposal contractors involved in oil industry
Environment Agency	Radioactive waste policy and latest developments relevant to non-nuclear industry. NORM arisings at Terminals. Drigg authorisation.
EXCAL	Scale and metallic film dissolution methods
MERPRO	Water treatment and solids removal process designers and suppliers
Norse Decon A/S	NORM decontamination and radium concentration services; links with consortium proposing to construct NORM disposal facility
NRPA	Norwegian Radiation Protection Authority (Statens Strålevern)
OLF	Oljeindustriens landsforening (Norwegian UKOOA equivalent)
PSL Energy Services	Offshore decontamination services and well support services
Rigblast	Offshore decontamination contractor
RWE Solutions	NORM decontamination services for onshore field
Scotoil Services	Onshore decontamination contractor
SEPA	Landfill policy and practice
SFT	Statens Forurensning Tilsyn (Norwegian Environmental Regulator)

Shanks Chemical Services	Waste disposal contractors involved in oil industry
Shanks Waste Solutions	Waste disposal contractors involved in oil industry
SSI	Swedish radiological protection agency
Tracerco	RPA for several companies on oil industry NORM issues (also member of project team)

4 REGULATORY FRAMEWORK FOR NORM DISPOSAL

4.1 Overview

A summary of the main legislation affecting the accumulation, transport and disposal of NORM in the UK is shown in **Table 3**.

The UK's regulatory regime exists within a European and international framework of controls and policies on radioactivity, although it pre-dates many of them. Although these policies have broadly the same aims, they differ in some details. The key bodies involved in policy on radioactivity are the European Union, the International Atomic Energy Authority (IAEA), the International Commission on Radiological Protection (ICRP) and OSPAR (the Oslo and Paris Commission for the Protection of the Marine Environment of the North East Atlantic).

Most of the legislative requirements relating to NORM waste in the UK stem from the Radioactive Substances Act (RSA) 1993. This regulates the management of materials and wastes that contain radionuclides at levels of activity greater than those listed in Schedule 1 of RSA. The Schedule 1 activity limits (measured in becquerels per gram or per metre cubed) are based on conservative assumptions about dose (measured in sieverts) (DEFRA, 1999), i.e. it is very unlikely that activity levels below the Schedule 1 limits could ever give rise to a significant dose. A more detailed explanation of dose is given in Section 10.

The keeping of radioactive materials and the accumulation and disposal of radioactive waste is regulated under RSA 93 and permitted under authorisation from the Scottish Environment Protection Agency (in Scotland), the Environment Agency (in England and Wales) and the Environment and Heritage Service (in Northern Ireland) who are the competent authorities in the UK. They are responsible for the regulation of radioactivity both onshore and offshore.

Amounts of radioactive disposals authorised under RSA are reported to the competent authorities annually. The Environment Agency is consulting on replacing the current voluntary reporting scheme with a compulsory scheme. Separately, the UK government reports offshore radioactive discharges to OSPAR.

There are exemption orders that introduce levels higher than Schedule 1, below which radioactive wastes are exempt from most of the requirements of RSA 93. For NORM, the most important exemption order is the Radioactive Substances (Phosphatic Substances, Rare Earths, etc.) Exemption Order 1962 (the PSEO). These apply to certain elements, normally naturally occurring elements, and are particularly relevant here. If a substance is above the Schedule 1 limit it is "radioactive", but if it is below the exemption order limit it is effectively exempt from regulation.

The International Atomic Energy Authority (IAEA) has published International Basic Safety Standards for Protection Against Ionising Radiation and for the Safety of Radiation Sources (IAEA 1996). This recommends a limit of one millisievert per year (1 mSv/yr), above background, for average doses received by a critical group as a result of practices involving radioactive materials.

Table 3. Summary of legislation that may be relevant to NORM disposal

Legislation	**Description (regulator)**
Primary legislation	
Radioactive Substances Act 1993	Legislation controlling the keeping and use of radioactive materials and the accumulation and disposal of radioactive waste. (SEPA/EA)
Exemption orders made under RSA 93 including: • Substances of Low activity, SI no. 1002, 1986 and amendment SI No. 647, 1992 • Phosphatic Substances Rare Earths, etc. SI 2648, 1962	Statutory instruments that exclude some materials, activities and premises from certain provisions of RSA 93. Of relevance to NORM /LSA disposals and wastes. (SEPA/EA)
Euratom Basic Safety Standards Directive 96/29 13 May 1996	Basic radiological protection criteria and definitions accepted by the UK. Most if its provisions are addressed in the Ionising Radiations Regulations 1999 (below), RSA 93 and related directions.
Health and Safety at Work Act 1974	Legislation requiring employers to ensure safety at work for their employees. (HSE)
The Ionising Radiation Regulations (IRR 99) SI 1999/3232	The principal safety legislation controlling work with radiation and radioactive materials. (HSE)
The Radioactive materials (Road Transport) Regulations 2002	Includes definitions of how materials (including wastes) must be packed and labelled for transport and what paperwork must accompany consignments
TS-R 1 (ST1 revised) 2001 IAEA Safety Standard	IAEA requirements for the safe transport of radioactive materials
The Transfrontier Shipment of Radioactive Waste Regulations 1993	Implement Council Directive 92/3/Euratom on the supervision and control of shipments of radioactive waste between Member States and into and out of the Community;
Additional legislation (Potentially influencing NORM disposal routes)	
The Special Waste Regulations 1996	Conditions by which a radioactive waste may also be a special waste, conditions for handling
Waste Incineration Directive 2000/76/EC	Council Directive 2000/76/EC to prevent or limit as far as is reasonably practicable negative effects on the environment, in particular pollution by emissions into air, soil, surface water and groundwater, and the resulting risks to human health, from the incineration and co-incineration of waste
Water Frame work Directive 2000/60/EC	Council Directive 2000/60/EC establishes a community framework for the protection of inland and surface waters, transitional waters, coastal waters and underground waters in order to prevent and reduce pollution, promote sustainable water use, protect the aquatic environment, improve the status of aquatic ecosystems and mitigate the effects of floods and droughts

The International Commission on Radiological Protection (ICRP) recommends a maximum dose of 1 mSv/year over background and 100mSv over 5 years for radiation workers with a maximum of 50mSv in any one year.

The Euratom Council directive 96/29 was adopted by the Council of the European Union in 1996. The Directive sets out basic safety standards (BSS) for the protection of the health of workers and the general public from ionising radiation and EU member states were obliged to implement the directive in their legislation by may 2000. The Euratom BSS applies to all practises involving a risk from ionising radiation emanating from an artificial or from a natural source, in cases where naturally occurring radionuclides are processed. They also apply to work activities.

Workplace exposure to ionising radiation is regulated in the UK under the Ionising Radiation Regulations 1999 (IRR 99), which incorporates the main tenets of the Euratom directive.

The aim of the following sections is to discuss how the following classifications of wastewater, wastes, radioactive wastes and exempt radioactive wastes apply to typical oilfield scales (mineral or metallic) and produced water. The effect of the classifications on available disposal routes is discussed. Issues relating to triviality, proposed revisions to exemption orders and transboundary issues are discussed, as these may reduce or expand the available disposal routes.

4.2 UK radioactive waste categories and NORM

Solid radioactive waste is normally defined as either high level waste (HLW), intermediate level waste (ILW) or low level waste (LLW) depending on its characteristics. These categories were derived primarily for the nuclear industry. With very few exceptions, all NORM from the oil and gas industry falls into the LLW category. The accepted categories are expanded in **Table 4**.

NORM is categorised according to the activity concentration of RSA 93 Schedule 1 elements it contains, *e.g.* solid waste with over 0.37Bq/g of elemental radium is classed as radioactive (**Table 5**). The limits for Schedule I elements are different for gaseous and liquid and solid wastes. For liquids the limit for radium is 0.00037Bq/g, which puts most of the produced water from offshore installations into the radioactive category (see produced water section of Phase 1 report).

If solid NORM is radioactive as defined above then it may be exempt under the PSEO if the elemental activities of the Schedule 1 elements are under 14.8 Bq/g.

The waste category to which NORM arisings belong is derived from the total activity of Schedule 1 elements. This is calculated from an agreed formula and almost all is LLW. Radium is normally the critical element as it has the most restrictive limit for solid wastes. It is routinely measured in oilfield NORM analyses. The formula is an approximation based on steps in the ^{238}U and ^{232}Th decay series and assumes that there is no loss of radon.

As shown in **Table 4**, there are therefore two categories of solid NORM waste.

1] Radioactive but exempt *i.e.* between 0.37 and 14.8 Bq/g for radium
2] Radioactive and not exempt *i.e.* over 14.8 Bq/g for radium

From the analyses available, total activity for NORM wastes from the UKCS ranges from below regulatory limits to several thousand Bq/g with most wastes in the units and low tens of Bq/g.

Table 4. Categories of radioactive waste for naturally occurring radioactive material

Category	Definition	Application to NORM waste
"Radioactive"	Defined by the activity from Schedule 1 elements.	*e.g.* >0.37 Bq/g radium in NORM.
Radioactive and exempt	Radioactive but with elemental activities lower than those specified in The Phosphatic Substances and Rare Earths etc. Exemption Order	e.g. 0.37Bq/g -14.8 Bq/g radium in NORM
Radioactive and non-exempt	Radioactive and with an activity concentration greater than the limit in the relevant exemption order	e.g. over 14.8 Bq/g radium in NORM
VLLW	"dustbin disposal" may be disposed of with ordinary refuse as long as each $0.1m^{-3}$ contains less than 400 kBq of beta/gamma activity in a single item containing less than 40kBq activity beta/gamma	Not normally accepted as a route for alpha emitters such as oilfield NORM
LLW	Wastes other than those suitable for disposal with ordinary refuse but not exceeding 4GBq/tonne (4,000 Bq/g) for alpha and 12GBq/tonne for beta and gamma (12,000 Bq/g)	All NORM falls into this general category but may be exempt or non-exempt under RSA 93 as described above
ILW	Wastes exceeding the upper boundaries for LLW but which do not need heat to be taken into account in the design of storage facilities	Not applicable to NORM
HLW	Wastes in which the temperature may rise significantly as a result of their radioactivity.	Not applicable to NORM

Table 5. Schedule 1 elements RSA limits

Element	Activity (Bq/g)		
	Solid	Liquid	Gas
Actinium	0.37	$7.4x10^{-2}$	$2.59x10^{-6}$
Lead	0.74	$3.7x10^{-3}$	$1.11x10^{-4}$
Polonium	0.37	$2.59x10^{-2}$	$2.22x10^{-4}$
Protactinium	0.37	$3.33X10^{-2}$	$1.11x10^{-6}$
Radium	0.37	$3.7X10^{-4}$	$3.7x10^{-5}$
Radon	-	-	$3.7x10^{-2}$
Thorium	2.59	$3.7X10^{-2}$	$2.22x10^{-5}$
Uranium	11.1	0.74X10	$7.4x10^{-5}$

4.3 Definition of waste

It is important to define whether substances come within the scope of the Waste Framework Directive (WFD), as they will then also come within the scope of daughter directives such as the Landfill Directive and Hazardous Waste Directive. The Waste Framework Directive sets out a general definition of waste:

> Article 1
> For the purposes of this Directive:
> (a) "waste" shall mean any substance or object in the categories set out in Annex I which the holder discards or intends or is required to discard.

This is immediately qualified by:

> Article 2
> 1. The following shall be excluded from the scope of this Directive:
> (a) gaseous effluents emitted into the atmosphere;
> (b) where they are already covered by other legislation:
> (i) radioactive waste;
> (ii) waste resulting from prospecting, extraction, treatment and storage of mineral resources and the working of quarries;
> (iii) animal carcases and the following agricultural waste: faecal matter and other natural, non-dangerous substances used in farming;
> (iv) waste waters, with the exception of waste in liquid form;
> (v) decommissioned explosives.

Produced Water

For produced water, the WFD distinguishes between wastewater (which it outside its scope and consequently not defined as waste) and waste in liquid form. It does not define wastewater. Some other sources do define wastewater, e.g. the Urban Waste Water Framework Directive defines 'industrial waste water' as any wastewater which is discharged from premises used for carrying on any trade or industry, other than domestic waste water and run-off rain water.

For produced water to be exempt from the WFD, it must be covered by other legislation. The UK's view has been that the term 'already covered by other legislation' refers to (a) EU and national legislation already in force prior to 18 March 1991 (the date the amended WFD was adopted); and (b) consolidating or amending legislation which consolidates or amends a legal framework that was in force prior to 19 March 1991 - provided that the changes do not involve any reduction in the level of environmental protection and such legislation provides an effective means of fulfilling the aims of the WFD (Scottish Executive, 2003). In an ECJ ruling of September 03, which followed a request for a preliminary ruling on interpretation of Article 2 of the WFD, the Court stated that "national legislation must be regarded as other legislation within the meaning of Article 2(1)(b) of that directive covering a category of waste mentioned in that provision, if it relates to the management of that waste as such within the meaning of Article 1(d) of Directive 75/442, and if it results in a level of protection of the environment at least equivalent to that aimed at by that directive, whatever the date of its entry into force".

The regulation of produced water discharges will shortly be via The Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2004. This will apply to discharges to sea and to discharge streams that are injected or re-injected beneath the seabed, i.e. produced water re injection. This amends the legal framework of the Prevention of Oil Pollution Act 1971 (i.e. that was in place before 19 March 1991).

Produced water from terminals is discharged to controlled waters, in the same manner as industrial and municipal wastewaters. It is covered via discharge consents under the Control of Pollution Act 1974 as amended in Scotland, the Water Resources Act 1991 in England and Wales and The Water Act (Northern Ireland) 1972 in Northern Ireland; it is not classed or treated as a waste. It may contain permitted levels of oil and solids as well as dissolved salts. It is DEFRA's view (2002a) that such wastewaters are outwith the scope of the WFD.

Sand and scale

The discharge of sand and scale offshore is controlled by an exemption from Section 3 of the Prevention of Oil Pollution Act 1971. On-site injection of drilling discharges (e.g. cuttings and associated chemicals) is covered by Section 15 of the Schedule to the Deposits in the Sea (Exemptions) Order 1985 (SI 1985 No.1699). Off-site injection requires a licence under the Food and Environment Protection Act (FEPA) 1985, Part II Deposits in the Sea (As Amended).

General

The dumping of waste at sea is banned via the OSPAR Convention. Annex III (On The Prevention And Elimination Of Pollution From Offshore Sources) Article 3 states:

> "…Any dumping of wastes or other matter from offshore installations is prohibited…
> …This prohibition does not relate to discharges or emissions from offshore sources…"

The latter statement is commonly referred to as 'operational discharges' and includes drilling discharges, production chemicals, mineral scale, sand and many other discharges and emissions.

The DTI website states that conventional processes undertaken by the oil and gas industry for the recovery of hydrocarbon products are not covered by the Waste Framework Directive and will therefore not fall under the scope of the Landfill Directive. "This includes such processes as re-injection of produced water; injection of liquids such as acids, surfactants, biocides, and corrosion inhibitors for reservoir management and well maintenance; use of drilling muds, cleaning fluids and cuttings re-injection."

In principle, the oil and gas industry could claim exemption from the WFD for much of its waste as 'resulting from prospecting, extraction, treatment and storage of mineral resources and the working of quarries'. As above, this appears valid provided that it is covered by other controls and arisings are deposited in a manner preventing environmental pollution or harm to human health. This exemption will soon be covered by the proposed Mining Waste Directive (MWD). The MWD acknowledges that the Landfill Directive is not an appropriate instrument for dealing with mineral wastes, and seeks to lay down specific rules under Article 2(2) of the WFD which are better suited. The MWD excludes excavation voids into which waste is replaced after extraction of the mineral, which would appear to cover re-injection, but in any case waste from the offshore extractive industries is excluded from the proposal "because the nature of the operations, which are designed for the land-based industry, makes the technical measures contained in the proposal impractical to apply" (Scottish Executive, 2003). The MWD is still in the amendments stage but appears close to finalisation.

4.4 Definition of radioactive waste

In the UK, the definitions of 'radioactive material' and 'radioactive waste' are contained in the Radioactive Substances Act 1993 (RSA 93) and judged by reference to specific activities of certain radionuclides and different thresholds exist for solids, liquid and gases. For solids containing principally radium, for example (as in oilfield scale), the limit is 0.4 Bq/g of elemental activity, which in effect counts the activity of ^{226}Ra plus two times the activity of ^{228}Ra, but usually a more onerous standard is for polonium which is counted as 2 times the activity of ^{226}Ra plus 1.7 times the activity of ^{228}Ra.

Much NORM scale is 'radioactive waste' and subject to the various requirements of RSA 93, and similarly much produced water is above the limits for liquids and is classed as radioactive waste. RSA 93 defines ' radioactive waste' as:

- a) a substance which, if it were not waste, would be radioactive material or
- b) a substance or article which has been contaminated in the course of production, keeping or use of radioactive material, or by contact with or proximity to other waste falling into this or category a) above.

RSA 93 further defines "waste" as:

- including any substance which constitutes scrap material or an effluent or other unwanted surplus substance arising from the application of any process.
- including any substance or article which requires to be disposed of as being broken, worn out, contaminated or otherwise spoilt..

The latter definition would include *inter alia* contaminated tubulars, processing and production equipment which are not intended for reuse as radioactive waste.

The definition is different to the WFD and having material classed as 'radioactive waste' under RSA does not necessarily make it 'waste' under the WFD.

The EURATOM Directives provide little definition of what is a waste. Directive 96/29/EURATOM (basic safety standards) defines 'radioactive substances' as substances which contain radionuclides, the activity of which cannot be disregarded for radiological protection. In other words, the definition of a radioactive substance is based on dose, and although unit or specific activity thresholds are put forward, member states may override these if the critical dose is less than 10µSv or the collective dose less than 1 man-Sv per year.

Directive 93/3/EURATOM (transportation) defines radioactive waste as any material which contains or is contaminated by radio-nuclides and for which no use is foreseen. In the context of transportation therefore, produced water may be a radioactive waste, unless it has a foreseen use e.g. reservoir pressure maintenance, in which case it would not be waste under this Directive.

DEFRA (2000) states (as a consultation viewpoint) that it is the Government's view that radioactive waste is already covered by Council Directive 80/836/Euratom and the Radioactive Substances Act 1993, and is therefore outside the scope of both the Waste Framework Directive and the Landfill Directive.

4.5 Exemptions and Disposal

There are 16 exemption orders that exempt certain radioactive materials and radioactive waste from RSA 93 registration and authorisation requirements, subject to certain conditions. Pertinent to the oil and gas industry is The PSEO. This in effect exempts elemental activities of schedule 1 elements at levels below 14.8 Bq/g. Below this level, they do not have to be reported to the regulator and do not require an authorisation, but they remain classed as 'radioactive'.

Radioactive waste is excluded from the scope of the WFD, and consequently the Landfill Directive, and the HWD as a result of the exemption provided by Article 2 set out in Section 4.3. This applies irrespective of whether the waste has hazardous properties in addition to its radioactivity.

Consequently, exempt radioactive waste can, in theory, currently be disposed of without control (i.e. without RSA authorisation and without EPA90 waste controls); e.g. on an onshore site it could be landspread on the site where it is collected or it can be sent to a landfill for non-hazardous or inert waste. Waste management controls such as duty of care and waste transfer notes do not apply to the waste.

However, the Special Waste Regulations apply to radioactive waste subject to:

- radioactivity in itself is not relevant for determining whether the waste is a special waste or not;
- other properties over and above the waste's radioactivity are relevant for determining whether a waste is a special waste or not.

The Special Waste regime is being revised to bring it in line with changes made at EU level and to modernise the monitoring process. DEFRA recently consulted on a number proposed changes and on draft regulations.

One change proposed is that radioactive waste which is exempt from RSA93 requirements by virtue of Exemption Orders will be subject to the requirements of the new hazardous waste regulations if it has hazardous properties over and above radioactivity. Other proposed changes include:

- replacing the (UK) term "special" with (EU) "hazardous"
- a wider range of wastes classed as hazardous (implementing the revised EU Hazardous waste List) a requirement on the Agency to inspect producers of hazardous waste who need to register with the Agency
- an end to the requirement for the Agency to be pre-notified of movements

The proposal is that these regulations will be made by April 2005, coming fully into force from July 2005.

According to the WFD, radioactive waste is only excluded if it is covered by other legislation, meaning equivalent protection of the environment. If it is not covered by any controls, then it automatically falls back within the WFD, and requires waste management licensing, duty of care, etc. to be applied as necessary, meaning that landspreading or *in situ* burial, for instance, would be classed as landfill and require a PPC permit, i.e. a highly engineered site may be required dependent on the properties of the waste – if 'inert' it would not need to be 'highly engineered']

Exempt radioactive waste may also be incinerated without RSA authorisation. Non-exempt radioactive waste may be incinerated under an RSA authorisation at an appropriate site. Radioactive waste for incineration need not be combustible, although if a high proportion of non-combustible solids are present (e.g. scale) then much of this will presumably remain in the ash and may require disposal as non-exempt waste, i.e. incineration may not be an efficient means of converting the waste to gaseous form.

For non-exempt low level waste (referred to as 'low level waste' or LLW but also including the category of 'very low level waste' or VLLW) disposed to landfill, the person disposing of the waste must be authorised under RSA. For LLW, disposals may be authorised for disposal at a named landfill site. For VLLW, the landfill site is not specified. In both cases, the landfill site itself does not require authorisation, although this may change in the future. The policy and practice of this is discussed further in Section 8 (land disposal).

LLW may be disposed of to a disposal facility, where the producer and the repository hold appropriate authorisations under RSA. The only such facility in the UK that is currently open is the Drigg facility operated by BNFL in Cumbria.

4.6 Proposed changes to thresholds and exemptions

DEFRA (1999) states that the concentrations for liquids in RSA Schedule 1 were based on one tenth of the most restrictive maximum permissible concentrations (MPC) in air or water, as appropriate in Publication 2 of the International Commission on Radiological Protection. The concentrations corresponded to the concentrations at which continuous exposure for 168 hours per week and 52 weeks per year (i.e. all the time) would give rise to the, then applicable, annual dose limit for workers. For present purposes, the dose limit for workers at that time can be taken as being equivalent to an annual effective dose of 50 mSv and so the Schedule 1 values were those for which continuous exposure would lead to an annual effective dose of about 5 mSv. This exposure scenario is clearly far removed from the practices surrounding the treatment of NORM in the oil and gas industry.

The above DEFRA document recommends a revised limit of 0.001 Bq/g for radium and polonium in liquids. This is 27 times higher than the current limit for radium and 4.5 times higher than the current limit for polonium.

DEFRA (2002b) discusses research into the revision of all RSA exemption orders except the Substances of Low Activity Exemption Order (SoLA). It is proposed that various NORM exemption orders, including the PSEO and the NGEO, would be amalgamated into one NORM EO with specific activity limits that are more in line with EURATOM reporting limits (i.e. higher than RSA 93), typically 10 Bq/g elemental for solids. This would be titled The Naturally Occurring Radionuclides Exemption and Generic Authorisation Order.

According to those proposals, exemption from registration would be granted for any volume of liquid in which radionuclide concentrations do not exceed specified levels, conditional on the premises being unconditionally exempt from authorisation for disposal of liquid and airborne wastes containing naturally occurring radionuclides, and producing less than 10 tonnes per year of bulk solid waste containing such radionuclides.

Although radon in natural gas is discussed, there is no mention of produced water. Under the proposed generic NORM exemption order, liquids under 10 Bq/g would be exempt but not if the 'premises' also gave rise to 10 tonnes of non-exempt solid radioactive waste of the same nature. Oil platforms give rise to the vast majority of produced water, and oil platforms routinely give rise to more than 10 tonnes of solids per year; consequently this proposed

NORM exemption order might have almost no application to offshore produced water. Alternatively, if the offshore solids are not interpreted as waste, or as 'bulk solids' (e.g. if macerated), it would apply, although they are currently authorised as radioactive wastes. The use of the word 'premises' throughout also suggests a terrestrial bias.

4.7 Triviality

Reference is sometimes made to 'trivial' doses of radioactivity and to *de minimis* levels. According to IAEA (Basic Safety Standards) and ICRP, these terms refer to two situations:

- any exposure that is unamenable to control should be excluded from regulatory control, regardless of magnitude (e.g. cosmic rays where it is not feasible to move cities from high altitudes)
- where doses arise from a 'practice' which is justified and
    a. where individual and collective doses are small in both normal and accident conditions, *or*
    b. no reasonable control procedures can achieve significant reductions in individual and collective doses.

Because of their minimal or trivial doses, these situations are candidates for exclusion or exemption from regulatory control respectively. Situations that are candidates for exemption because of 'triviality' still require an exemption to be written into national law before they can be exempted from control.

IAEA, jointly with the OECD's Nuclear Energy Agency, set out the following principles for exempting a practice:

i. individual risks must be sufficiently low as not to warrant regulatory concern;
ii. radiation protection, including the cost of regulatory control, must be optimised; and
iii. the practice should be inherently safe.

IAEA has concluded that a level of dose of some tens of microsieverts a year could reasonably be regarded as trivial by regulatory authorities, i.e. could be a case for exemption. IAEA also recommends the use of a 10 µSv per year dose criterion for the derivation of exemption levels, and ICRP states 'of the order of 10 µSv per year'. IAEA also states that a collective dose of around 1 man-Sv per year would be low enough to permit exemption without more detailed consideration of other options (implying that a higher level might be appropriate according to the options available). The ICRP also indicated that there is "… a logical basis for exemption of sources that cannot be exempted solely on the grounds of trivial doses, but for which regulation on any reasonable scale will produce little or no improvement."

IAEA and ICRP recommendations are not binding, but are repeated in national guidance, e.g. the EA *et al* (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 as the associated risks are minuscule and the contribution to total doses to individuals will be insignificant. Higher annual doses, up to say a few microsievert (µSv/y) can be considered trivial but may require some consideration particularly if at the higher end of the range. Calculated annual average individual doses in excess of these values should prompt careful consideration of the discharge options being considered.

EA *et al* (2002) recommend a simple and cautious assessment of the critical group dose (i.e. conservative assumptions are used to ensure the chance of actual doses being higher than predicted is very low). If the results of this indicate that the critical group dose is less than the threshold dose of 0.02 mSv/y then no further assessment would be warranted for the purpose of authorising the discharge of radioactive waste to the environment. If the dose is above 0.02 mSv/y then a detailed more site specific assessment would be required. 0.02 mSv/y can be broadly equated to an annual risk of death of about one in a million per year.

The Environment Agency and SEPA have been directed, when exercising their functions under RSA 93, to ensure that doses to members of the public from discharges of radioactive waste are limited to 1 mSv per year for England, Wales and Scotland. Equivalent legislation is being developed for Northern Ireland.

4.8 Radioactive waste policy

The Euratom Basic Safety Standards Directive provides for the implementation of the 1990 recommendations of ICRP within the European Union. The Directive's provisions with respect to the control of radioactive waste have been implemented within England, Wales and Scotland through Regulations amending RSA 93 and Directions to the Environment Agency and SEPA. Regulations to implement the Euratom Basic Safety Standards Directive are currently being made in Northern Ireland. The principal aims of the Directions are to require the Environment Agencies to ensure, when exercising their duties and functions under the RSA 93, that:

- All public ionising radiation exposures from radioactive waste disposal are kept ALARA.
- The sum of the doses arising from such exposures does not exceed the individual public dose limit of 1 mSv a year.
- The individual dose received from any new discharge source since 13th May 2000 does not exceed 0.3 mSv a year.
- The individual dose received from any single site does not exceed 0.5 mSv a year.

The dose constraint of 300 µSv per year and the threshold for optimisation of 20 µSv per year apply to individual practises. An example of this is the disposal of radioactive waste to sewer, discussed in EA (2000a). This notes that doses received during the treatment of sewage containing radionuclides do not need to be considered for optimisation if the doses from the individual sources (e.g. each hospital or laboratory) were less than 20 µSv, even if the cumulative dose was higher. EA and SEPA guidance states that a maximum constraint of 300 µSv/y (dose to members of the public) should be used when determining applications for discharge authorisations from a single new source, defined as "a facility, or group of facilities, which can be optimised as an integral whole in terms of radioactive waste disposals". The logical application of this offshore would be to a single facility (e.g. a platform or FPSO), or to a group of facilities that produce via a common 'hub' facility, where controls can be most easily applied.

In addition to the Euratom commitments and the text of RSA93, the UK Government's position on radioactive waste policy in the UK was last stated in 1995 in Cm2919. Since then, no formal changes have been made to this policy although it has been reviewed by RWMAC in some detail. RWMAC's conclusion on radioactive waste policy is that

> "The 1995 policy statement [Cm2919] has been overtaken by various events which leave current UK radioactive waste management waste policy – in respect of both solid wastes and discharges – uncertain. In particular, it is difficult for anyone outside Government to be clear on which particular elements of Cm2919 continue to apply and which do not."

Cm2919 does not discuss the policy of 'dilute and disperse' versus 'concentrate and contain', although it notes that different approaches may be adopted for solid wastes versus gaseous and liquid wastes. The guide to the administration of the 1960 Radioactive Substances Act (HMSO, 1982), which has not been superseded, seems to imply that 'dilute and disperse' is acceptable - "Where it can be done safely it is desirable to use conventional methods of waste disposal such as discharge to sewers or disposal on local authority refuse tips". The terms 'special precautions disposals', and 'local disposal' (aka trench burial at Drigg) and 'sea disposal of solid waste' appear as valid disposal routes in the 1982 guide, although the latter has since been discontinued as unacceptable and its function has been replaced by the vaults at Drigg. Cm2919 (1995) states that controlled burial should continue for non-nuclear wastes. It implies that the sites should have good containment characteristics and states that such disposal should be accompanied by radiological analysis of the leachate. RWMAC (2003) states, however, that this guidance is now very dated (demonstrated by its reference to sea disposal as an option) and new guidance for waste disposal should be made.

The House of Lords Select Committee on Science and Technology (1999) heard evidence on radioactive waste disposal and noted that Cm2919 did not encourage greater use of the VLLW disposal route because of opposition from local authorities, environmental groups and members of the public. They noted continuing, strong opposition from local authorities to the disposal of nuclear industry LLW to landfills (although not necessarily NORM LLW). They recommended that the Government reviews alternative disposal routes to landfill, in order to produce an accepted national policy rather than leaving matters almost entirely to local negotiations.

It is difficult to draw any conclusion from this for oilfield NORM wastes, other than that new LLW disposals to existing landfills is likely to be controversial and will impose an additional monitoring burden.

Some of the work of RWMAC in developing policy ideas has now passed into the auspices of CoRWM while RWMAC is in abeyance. CoRWM is currently in a startup phase and its first priorities will be high level and intermediate level waste. It is therefore unlikely that new government guidance on low level waste will be made in the short term (next two years).

For applicants for new LLW landfills, there is guidance in the form of "Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Guidance on Requirements for Authorisation", commonly referred to as "the GRA" (EA *et al,* 1997) The GRA contains guidance on the principles and requirements against which the Agency will assess any application for authorisation of waste disposal under RSA93. These are

1. Independence of Safety from Controls (non-reliance on future generations)
2. Effects in the Future (health impacts in the future will be no greater than the present)
3. Optimisation (doses to the public as low as reasonably achievable)
4. Radiological Protection Standards (source-related and site-related dose constraints met)

The GRA explicitly does not cover the disposal of LLW by controlled burial with other waste at non-specialised landfill sites.

Best Practicable Means (BPM) is a term used in Radioactive Substances Act 1993 and specified in authorisations. Within a particular waste management option, the BPM is that level of management and engineering control that minimises as far as practicable, the release of radioactivity to the environment whilst taking account of a wider range of factors including cost-effectiveness, technological status, operational safety, and social and environmental factors.

It is interpreted as including the following requirements:

- Take all reasonably practicable measures in the design and operational management of their facilities;
- Minimise discharges and disposals of radioactive waste, so as to achieve a high standard of protection for the public and the environment.

Note that BPM is *not* a tool to decide the preferred waste management option, and in theory several waste management options may be authorised for the same waste, as long as each one is conducted via the Best Practicable Means.

In determining whether a particular aspect of the proposal represents the BPM, the Inspectorates [the forerunners of EA, SEPA and EHS for radiological protection] must not require the applicant to incur expenditure, whether in money, time or trouble, which is disproportionate to the benefits likely to be derived (HMSO, 1995).

The use of BPM means that radiation risks to the public and the environment will be As Low As Reasonably Achievable (ALARA), which takes into account, cost benefits and associated risks including those to people. There is no specified protocol for use in BPM assessments. SEPA has commissioned a study to advise small users on BPM for the disposal of LLW.

DEFRA (2000b) sets out the following principles for radioactive waste. These are for nuclear licensed sites, i.e. not NORM, but are informative nonetheless:

- **Waste minimization.** The creation of radioactive waste (whether in solid, liquid or gaseous form) should be minimized. Discharge of radioactivity into the environment that is unavoidable should be subject to stringent numerical limits.
- **Best Practicable Environmental Option (BPEO).** Radioactive discharges may arise in different physical forms, but need not necessarily be discharged in the form in which they arise. The Agency, before granting discharge authorizations, needs to be clear that alternatives, where they exist, are properly evaluated and the choice is made that will have a low environmental impact i.e. that the Best Practicable Environmental Option is chosen.
- **'Concentrate and Contain' vs 'Dilute and Disperse'.** The alternative to discharging gaseous or liquid radioactivity into the environment, the so-called "dilute and disperse" approach, is to trap it before it can escape from the plant, and then to concentrate and immobilise it, before storing the solid wastes which would be created in containers, either indefinitely, or until they can be disposed of safely in the future. This is the so-called "concentrate and contain" approach. Each case will need to be evaluated on its merits, but where possible "concentrate and contain" should be the preferred option.
- **Decay Storage.** Due to the long half life of the main contributors to activity from NORM waste this is unlikely to be appropriate for oilfield NORM disposal.

It should be noted that BPEO is not mentioned in RSA and exists in legislation only in the Integrated Pollution Control regime, which is being replaced by Pollution Prevention and Control, which does not mention BPEO. It is nevertheless a widely quoted principle (as above), developed by the Royal Commission on Environment and Pollution (1988) that seeks to make judgments between impacts in different media. In discussing ILW and HLW disposal, DEFRA (2002c) states that it is ‘commonplace’ to adopt the principle.

4.9 Transboundary issues

4.9.1 Transboundary movement of wastes

In general waste policy there is an overarching 'proximity principle'. It is not named as such in the WFD but it is a requirement that 'the network [of disposal installations] must enable waste to be disposed of in one of the nearest appropriate installations, by means of the most appropriate methods and technologies in order to ensure a high level of protection for the environment and public health' (Article 5(2)). Additionally, minimising the movement of waste is an aspiration. Transboundary movement should therefore be a last resort.

In the context of NORM wastes, there are two sets of transboundary movement legislation that may apply; the transboundary movement of hazardous waste (e.g. for oily exempt NORM wastes) and the transboundary movement of radioactive wastes. The former is implemented under the Basel Convention and for transboundary movement requires, *inter alia*, that the country of origin *cannot* manage the waste adequately and that the destination country *can*. The corresponding legislation for radioactive waste under Euratom is less onerous; in comparison it only requires that the country of destination can manage the waste adequately.

In practice, sites such as Drigg that receive radioactive waste are usually managed to preserve their capacity for as long as possible; consequently they would not normally accept radioactive wastes from another country that could be disposed of in that country. If transboundary *reprocessing* options are available, however, then transboundary movement may be more desirable. Any outlet for UK radioactive waste must be named in an RSA authorisation and this requires demonstration that the solution is the BPM, which would require demonstration that transboundary movement provides the highest level of radiological protection versus options in the country of origin.

The transboundary movement of non-hazardous and non-radioactive waste has less onerous requirements (although regulation, such as duty of care requirements, still applies and the proximity principle still applies).

Notwithstanding the above, the most recent stated policy on transboundary movement of radioactive waste is given in Cm2919 (1995). This states policy on the import and export of radioactive waste is that there should broadly be a presumption of self-sufficiency and that export should not be authorised except in the following circumstances:

- Where the prime purpose is to recover reusable materials
- For treatment of waste from developmental processes that will make its storage and disposal more manageable
- For treatment waste of such small quantities that it is not practicable to treat it in the UK

Since NORM waste is not reusable and since treatment technologies are available in the UK, this suggests that the export of NORM waste would be contrary to government policy.

With regard to decommissioning, it has been the case that radioactive substances associated with some offshore facilities have been moved transboundary (UK to Norway). The decommissioning plan, which must be approved by the DTI and on which the relevant Environment Agency is a consultee, will normally address the issue, and an authorisation may be necessary. In at least two cases (Brent Spar and Phillips Maureen, both decommissioned in Norway), radioactive waste (i.e. above the Norwegian threshold of 10 Bq/g) was returned to the UK for treatment and disposal. It is understood, however, that the current view is that radioactive and hazardous wastes, once moved transboundary, should not normally be returned to the UK.

A potential complication arises where the originating country has a lower threshold for classification as 'radioactive' than the destination country (as in the UK versus most of the rest of Europe). It is possible that the country receiving the waste may not classify the waste (or all of the waste) as radioactive, and the waste may therefore receive a lower standard of disposal than it would otherwise have in the originating country, e.g. UK NORM decommissioning wastes disposed of in Norway. It is not clear how this is dealt with in terms of the transboundary regulations or whether it is seen as a difficulty.

4.9.2 Espoo Convention (transboundary impacts)

The Espoo Convention (UNECE, 2004) requires that there must be environmental impact assessments for certain projects that are likely to cause a significant adverse transboundary impact, and potentially affected countries notified. The projects include installations designed solely for the final disposal of radioactive waste or solely for the storage (planned for more than 10 years) of irradiated nuclear fuels or radioactive waste in a different site than the production site.

This could be interpreted as applicable to some NORM disposal options. The key test is 'significant adverse transboundary impact'.

4.10 European policies

4.10.1 Habitats Directive

There has been recent EA guidance on application of the Habitats Directive to radioactive discharges (EA 2002a). Appropriate Assessments are to be carried out in regard to Natura 2000 sites. The EA guidance includes a method for assessing radiological impact on biota (rather the past practice of assuming that if the risk to people is acceptable then the risk to the environment is also acceptable). Further international research is underway to refine such methods of assessment.

4.10.2 OSPAR

OSPAR's Radioactive Substances Strategy (OSPAR, 2003) has very similar aspirations to the EU Marine Strategy (below). It declares that by the year 2020 the Commission will ensure that discharges, emissions and losses of radioactive substances are reduced to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero.

A response to this is contained in the UK's Strategy for Radioactive Discharges (DEFRA, 2002d). This notes the current position regarding oil and gas NORM but does not set any discharge profile or targets. It contains a presumption that these discharges will continue to be tightly controlled and reduced wherever practicable.

"The Government considers that, by using Best Practicable Means (BPM) to reduce discharges so that public exposure to ionising radiation arising from such discharges is As Low As Reasonably Achievable (ALARA), it will achieve the objective of the OSPAR Strategy, to the extent set out in the timeframe for 2020."

4.10.3 EU Marine Strategy

Objective 6 of the EU Marine Strategy (EU, 2002) is to prevent pollution from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim to reach concentrations in the marine environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. This objective should be achieved by 2020.

4.11 Conclusions for oilfield NORM

There is no simple way to summarise all of the implications of the above legislation. The following points are therefore paraphrased and not exhaustive, but are relevant to oilfield NORM. It is assumed that the reader is familiar with the requirements of RSA93 and these are not repeated.

- Radioactive waste is excluded from the provisions of the WFD. Under the WFD, produced water is wastewater and is not waste. Under RSA93, produced water is radioactive waste if above the Schedule 1 limits for liquids.
- NORM discharges offshore are treated as operational waste by OSPAR
- The discharge to sea of radioactive scale or produced water should be authorised under RSA93.
- Solids exempted under RSA93 can be disposed of to landfill according to their non-radioactive characteristics (inert, non-hazardous or hazardous).
- Non-exempt solids (i.e. LLW) are not WFD waste unless they are also hazardous e.g. by virtue of oil content. Following treatment, disposal must be either to a LLW disposal site (currently Drigg, in which case any hazardous characteristics must be treated, or a site overseas) or possibly incineration. Disposal to a landfill other than Drigg can be authorised under RSA.
- Radioactive wastes may be moved transboundary, under TFS authorisation and with accompanying international documentation, if the receiving country can adequately manage their disposal. This may be, however, contrary to government policy and in practice, due to general pressure on repository capacity, there would have to be a strong reason for not disposing of it in the country of origin.
- A case could be argued to bring in an exemption for produced waters of certain activities and possibly for scales discharged to sea on the basis of trivial dose and/or the inability of regulation to bring significant improvement; the opportunity to include this properly in DEFRA’s proposal for a generic NORM exemption order should not be overlooked.

From the discussion above, it would seem that further elucidation of these legislative aspects, in particular the interactions between the various pieces of legislation, with the relevant regulatory and government bodies would be beneficial.

5 NORM PREVENTION

5.1 Preventing NORM exiting the reservoir

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 but no practical details of trials or applications of these have been identified.

5.1.1 Downhole removal of NORM nuclides in the reservoir

Groundwater Services Inc has developed a system for depositing a solid sorbent for specific radionuclides in the formation near the well bore. The solid sorbent is precipitated in the reservoir matrix by the reaction of two carrier fluids or it can be emplaced by high pressure slurry injection. No details are available on effectiveness, how long it lasts, effects on production amount or degree of NORM nuclide removal. Some of the sorbents listed include: barium sulphate /carbonate (presumably to precipitate out any radium), iron oxides and hydroxides, zirconium, antimony, tin and titanium oxides. This would seem a very attractive solution to NORM prevention but no further information was available and none of the operators contacted had attempted this. A concern would be that the near well bore formation could be damaged and operators will be very reluctant to use a process which might interfere with production or damage the formation.

A 1994 US patent (Hrachovy 1994) describes a similar process but gives no details of the "nucleating agent capable of reducing the concentration of scaling ions including NORM present in aqueous subterranean fluid".

5.2 Preventing and minimising NORM solids

5.2.1 Overview

Recent developments in more efficient scale inhibition, both downhole and in topsides processing, have already helped to prevent the traditional problems associated with mineral scales and have reduced the volumes of NORM solids requiring disposal.

NORM scale prevention methods have been summarised below. These have been included in this report as, in view of the limited disposal options currently available for UKCS NORM wastes, primary waste prevention is a preferred option. Some of these are well known and widely used in the UKCS already, some are more experimental and still at the pilot stage.

As was discussed in the Phase I report the main factors contributing to scaling are:

- 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 barium, strontium, calcium and radium are leached from the formation and are present in soluble form in the produced water. When scaling occurs this radium co-precipitates with the other Group II metals barium or strontium.

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.

5.2.2 Scale inhibitors

Scale inhibitors are designed to interfere with the processes of scale mineral nucleation and/or restricting crystal growth (poisoning). Scale inhibition is the most widely used method of NORM scale prevention and there are a large number of chemicals, often very similar, marketed under proprietary names. These are under continual development as new compounds are found and old ones modified for greater efficiency. Common scale inhibitors are phosphate esters, polycarboxylates and phosphonates. Their effectiveness in scale inhibition is affected by temperature and by the ionic concentration and composition of the formation water. Very high salinities can cause precipitation of some inhibitors and reduce their efficacy. Effectiveness of inhibitors can also be severely affected by the presence of other production chemicals and by corrosion products and these issues have to be considered as part of any scale management plan.

Scale inhibitors can be broadly classified as:

- **Threshold inhibitors** (used in low concentrations typically 2-20ppm) that work on the principle of nucleation prevention, i.e. preventing ion clusters from reaching the critical size for nucleation to occur. The inhibitors diffuse through the brine disrupting ion clusters and they also act through crystal growth disruption by adsorbing onto the growth faces. These are typically polyacrylates and phosphonates.
- **Dispersants** prevent scale particles from agglomerating and reduce pipe wall deposition and sludge formation, e.g. polyacrylates
- **Complexing agents**: bind the scale-forming cations in stable water-soluble complexes e.g. EDTA, NTA, DPTA.

Effectiveness is checked by standard tests (dynamic tube blocking, static bottle test) carried out by the vendor or by the Operator's production chemists. The optimal scale management solution can be very site-specific and good scale management can bring result in much lower concentrations being required. Threshold (effective working) dosage levels in production lines are usually 5-25 mg/l but with very scale-prone brines up to 200mg/l may be needed. Extra dose may be added to cover for sudden compositional changes in brines due to injection water breakthough or bringing new wells on stream.

Scaling tendencies are checked prior to bringing wells into production and sophisticated modelling of compatibility of water from different reservoir compartments and with injection water is undertaken.

It is operationally advisable to apply the inhibitor as far upstream as possible. In production wells this is usually at the wellhead. There can also be continuous downhole application via narrow bore treatment strings and/or use of periodic scale squeezes (forced injection of scale inhibitor into the reservoir close to the well), repeated when inhibitor returns fall below a certain level. Squeeze effectiveness is increased by use of surfactants injected before the scale inhibitor, which facilitate retention of the inhibitors on the formation and increase the lifetime of the squeeze treatment two to four times.

Scale inhibitors are not thought to have significant long term environmental impacts and are generally of low toxicity. They are water soluble and are discharged to the environment with the produced water and rapidly dispersed in the marine environment. Discharges are made under an Offshore Chemicals Regulations permit and must meet a 'no effect' concentration.

Applying these techniques significantly reduces NORM scale deposition and thus solid NORM waste requiring disposal, by keeping the NORM nuclides in the water phase. The total activity of the NORM nuclides produced form the subsurface and discharged is not reduced but is discharged in the much larger (i.e. dilute) volume of the produced water

5.2.3 Sulphate removal

Seawater is commonly reinjected into reservoirs in order to maintain the pressure as hydrocarbons and formation water are removed. Seawater contains relatively high levels of sulphates that can lead to the formation of sulphate scales if and when the seawater migrates to production wells. This 'breakthrough' of seawater has sometimes caused catastrophic losses of production due to rapid scaling

This issue can be avoided by reinjecting aquifer water, i.e. water drawn from a well that is drilled into a low-sulphate water-bearing stratum in the vicinity of the production facility. This is not, however, an option that is available, economic or reliable at all sites.

A proven method of reducing production of sulphate scale related to seawater injection is to eliminate the sulphate ions by treating the injection water. A number of treatment methods are available (Sinclair and Weston, 1996):

Reverse osmosis: This can produce water with near zero sulphate but has a low productivity of 30% (30l of treated water for every 100l passed through). It is used for potable water production offshore but is not suitable for production of the large volumes required for injection. Fine filtration is needed upstream of the unit.

Distillation: Either by thermo compression distillation or mechanical vapour compression. This is unsuitable for offshore use due to high power requirements and the weight of the units.

Nanofiltration: This is a membrane process which selectively removes sulphate ions. The process has a good productivity of 75% and has been utilised in several North Sea fields where there is a high sulphate scaling potential e.g. the Brae and Tiffany facilities.

Ion exchange: This is used widely in desalination in the Middle East. It could be used to remove sulphate ions by passing seawater through ion exchange resin cartridges. The resin requires regeneration, however, after it becomes saturated which takes time and a suitable regeneration fluid which would need to be manufactured offshore. It is an efficient method with a 75% productivity. This is not currently considered to be suitable for offshore UKCS use due to the logistics of resin regeneration.

Microbial sulphate reduction: this remains at the pilot scale using sulphate reducing bacteria to remove sulphate ions from seawater.

Other:

<u>*Salt precipitation*</u>*:* Use of barium chloride solution to precipitate out barium sulphate. However this is unsuitable for the large volumes of water required for seawater injection projects and could result in a considerable volume of precipitate to be shipped to shore for disposal.

<u>*Electrodialysis;*</u> This is still in development. This method uses multi-compartment cells with alternate cation and anion exchange membranes. The process requires a 3MW DC power supply and is reportedly expensive.

5.2.4 Electrochemical

A downhole plating method for removal of metallic NORM has been patented (Keatch 1998 Appendix 2). The method involves installation of a sacrificial metal surface on which to plate out metallic ^{210}Pb. The plate can then be removed for disposal. This is effectively concentration and removal of metallic NORM. This has been trialled onshore in the UK but is not reported to have found wide commercial application in NORM prevention. In any case it will produce a secondary waste in the form of contaminated plates which must be decontaminated (liquid waste) or disposed of as solid waste.

Another method of metallic NORM prevention is applying a small potential across the well tubulars to keep Pb^{210} in solution in the produced water. This may have an effect on other parameters such as corrosion prevention.

5.2.5 Engineering solutions

Scale management is recognised as a particular technical and economic problem. Scale management is increasingly being considered pro-actively at the FEED stage of oil and gas production facility design rather than reactively once production problems have been encountered (Collins *et al* 2004). This is especially true of deepwater projects where it is technologically and financially challenging to carry out well interventions. The following aspects can be included.

- Inclusion of sulphate removal at design stage.
- Optimisation of scale inhibitor system and injection points to ensure constant effective scale inhibitor concentration.
- Process optimisation to minimise areas where there is pressure drop, turbulent flow and temperature change. In practice, however, optimisation to maximise production takes precedence.
- Design of plant for handling fluids with scaling potential - minimisation of internal irregularities, constrictions and rough surfaces that can act a substrate for scale formation e.g. installing glass linings on separators
- Routing of incompatible waters through separate separation systems. This is a common solution on platforms receiving hydrocarbons and water from multiple wells with incompatible waters.
- Minimisation of downhole equipment - installed pumps etc. tend to become severely scaled.

For an existing facility, engineering modifications are likely to require shutdown of production, which is very costly, and are only carried out when there is no other solution.

5.2.6 Other methods

The following are methods that have been reported in the literature. They are not currently commercially available, with the exception of magnetic fluid conditioning, which has been installed on at least one platform on the UKCS.

Magnetic scale inhibition

Magnetic fields are believed to disrupt nucleation and existing scale crystal structure, softening it so it can be removed by fluid movement. Some studies have reported alteration of hydration states in crystal nuclei in high magnetic fields (pers. comm.). It was also reported that the effects were short term and that it moved the scaling problem elsewhere (pers. comm.). The method is typically advertised for water treatment for carbonate scale removal but may also be effective for other types of scale.

This has been used by a major operator on one North Sea platform. ‘Linear Kinetic Cells’ have been installed on water outlets from the separators and on the discharge line of the degasser pump. It is understood that performance has not been monitored, however. The same platform also has a set of magnetic rings clamped around the discharge line of the hydrocyclone pump but again there is no monitoring of effects. The consensus from literature and Operators is that there is currently insufficient hard evidence that the technique works to justify investment, but that anecdotal evidence, vendor claims and some laboratory evidence suggest that some effect exists. It is not currently considered as a reliable substitute for chemical scale inhibition.

There appears to be an example of effective use by Petronas in the South China Sea in the Tinggi field which has a history of severe scaling problems (Rahim 2002). The system used was APS Scale-X™. The facility suffers from a predominantly carbonate scale with some barite. The facility has had some acute failures with scale inhibitors (e.g. 400% increases in barite scaling seen) but reported 100% removal of scale by the magnetic fluid conditioner. The mechanism is not discussed in detail.

Another magnetic fluid conditioning system mentioned in the literature is Oilfield Equipment Services System™ “pumpmaster” for low cost scale treatment developed for onshore pumped wells. There are no details on any offshore use. The system consists of stainless steel units that are screwed to the base of the pump so no dismantling is required.

Microbial NORM removal CP

Chem™ (2002) in the US have reported testing microbial methods for prevention of scale formation in the formation and in equipment that utilise microbial biosurfactants naturally produced by bacteria which live on hydrocarbons. These are effective for all forms of mineral scale as they work by coating surfaces and preventing attachment of growing scale crystals and by preventing clumping of scale crystal nuclei. This technique is only at the experimental stage at the moment.

A key difference with microbial techniques is that the bacteria can mobilise themselves within the reservoir, whereas chemical treatments rely on fluid movement in the reservoir.

5.3 Preventing NORM in produced water

As discussed, produced water contains NORM and unless the NORM is deposited somewhere in the process it will exit with the produced water discharge. The objective of chemical scale inhibitors is to prevent the deposition of mineral scale in production and process equipment by keeping the scaling ions (including NORM radionuclides) either in solution or in suspension as fine precipitates in the produced water.

It is possible to prevent or minimise the discharge of the NORM present in the produced water using a number of techniques for removing metal ions. In general these include:

- Precipitation by chemical dosing
- Physical removal of fine precipitates by more or less sophisticated methods, e.g. hydrocyclones, ultrafiltration, etc.
- Nano-filtration (ion removal)
- Ion exchange, similar to that described for sulphate removal in 5.2.3

Depending on how much of the radioactivity is due to the presence of fine particulates (phase 1 section 4, table 5) some bulk filtration method might be effective in removing NORM from produced water. For example the Merpro Filtore™ which is used at Wylfa nuclear power station in Wales to remove fine particulates from coolant water. The filter medium is backwashed and reused so the only waste produced is the filtrate. A concern would be NORM nuclides remaining in solution although these could be precipitated by addition of sulphates e.g. from seawater which would be readily to hand. Some operators have considered filtration of produced water for reduction of oil in water which would also remove particulate NORM but this creates an oily radioactive waste requiring land disposal. Non-oily filtrate could be discharged to sea but then there is no reduction in overall activity discharged to sea from produced water and chemical scale inhibition would be just as effective.

Due to the large volumes of produced water, any NORM removal methods applied to it would be at significant expense and associated use of fuel, chemicals and creation of emissions. Although methods such as nanofiltration are applied offshore e.g. to remove sulphates for seawater reinjection, they are expensive, require much fuel to operate and are only used where they can be justified by substantial benefits in production. NORM removal from produced water at the point of discharge would not bring any production benefit.

The common characteristic of such options is that while they reduce the activity discharged to sea in the produced water they create a secondary waste that contains the same NORM nuclide activity and can also incur major expense, resource use and emissions. If this waste is then disposed of onshore or to the sea, it is difficult to see that any benefit has accrued (Section 10 discusses doses for releases to different media). Even if wastes are reinjected, the benefit in dose avoided is trivial. Further discussion on reinjection is given in Section 7.4.

NORM removal from produced water, while possible in principle, is therefore not seen as a realistic proposition.

An alternative approach would be to avoid producing water to the surface by using downhole oil water separation (DOWS) with reinjection. This has been trialled by some operators but is not reportedly in use in on the UKCS. It would not be suitable for all facilities. Its primary function is to reduce water produced to the surface and the reduction in NORM would be an incidental bonus.

5.4 Removing NORM deposits

However effective the use of scale inhibition and other techniques, in most oil and gas production facilities there will be some build up of scales and sludges containing NORM nuclides that must to be removed to prevent interference with production and on decommissioning. In this context, NORM removal becomes synonymous with NORM solids removal. Although the primary aim of almost all the techniques is to prevent or rectify loss of production, they also remove the NORM present.

Where lead and polonium films occur, primarily in gas and gas/condensate facilities, production is not usually affected but there radiological, exposure and radioactive waste issues for maintenance, re-use or decommissioning.

For each method, a description is given below including where it is employed onshore or offshore, the pros and cons and its applicability to UKCS operations. Where methods are still under development this is indicated.

5.5 In situ chemical dissolution

Description

Scale removal techniques that do not require removal and dismantling of equipment are obviously attractive. Mineral scales can be softened or dissolved by use of suitable scale dissolvers (Tailby et al. 1999). Their use is common for the removal of carbonate scales but less so for removal of the more insoluble sulphate scales. There are also some patented chemical methods for the removal of NORM-containing deposits from gas processing and production equipment (Keatch 1998 patent, Rootham 1998 patent, James 1992 patent Eylander *et al*. 1998).

Scale dissolvers are also used to ‘soften up’ scale prior to removal by mechanical means. There is extensive literature on their use, e.g. Jordan *et al.* (2000). Scale dissolvers have also been used to remediate losses of production due to scaling in the near well formation, by forced injection into the near bore formation.

Rootham 1998 patent also describes using mechanical pressure pulses in a chemical cleaning agent to aid dissolving, dislodging and fluidizing sludge and corrosion products. It is not recorded whether this has found a use in the oil and gas industry.

Pros

- Chemical removal methods are less expensive than mechanical methods and require less equipment.
- Can help to remove scale from the near well bore formation, improving production.
- They offer the possibility of effective removal of NORM contaminated scale from complex equipment offshore without dismantling.
- The chemicals used are generally of low toxicity and are suitable for sea discharge under an Offshore Chemicals Regulations permit.

Cons

- Can be slow and only partially effective on sulphate scales
- NORM nuclides are transferred to another medium
- Forced injection of scale dissolver to remove sulphate scale in the formation around the wellbore can cause irreparable formation damage (Jordan *et al.* 2000) leading to loss of production as severe as the losses originally caused by the scaling

Applicability for UKCS

There are companies marketing scale dissolvers in the UK for all types of scale and also metallic (gas) deposits. Some products are claimed to be effective in removal of barium sulphate scale but few operators report these being used. Some offshore cleaning contractors have reported using chemical removers for sulphate scale to “soften up” the scale to increase the effectiveness of subsequent mechanical scale removal. They were said to be effective for this purpose but not as the primary method of scale removal.

It is understood that they are more widely used for removal of carbonate scale and dissolution products and waste chemicals are discharged to sea with produced water.

Under the recent OSPAR reporting procedures the activity of discharges from chemical dissolution will have to be reported for the first time (OSPAR 2004a).

5.6 In situ mechanical removal of scale

Description

In situ descaling of tubulars can be carried out as part of a workover using coiled tubing operations (Latos, 1994). This is beginning to be widely employed in the US and middle east and is becoming more common on the UKCS. Various proprietary tools and attachments can be employed to descale downhole avoiding the need to pull production tubulars saving production time and expense. The methods range from running wire brushes on lines to full well workover, the latter being the most expensive and least desirable.

A number of proprietary products can be attached to coiled tubing e.g. high pressure (HP) water jetting with/without abrasives, rotary mills and reaming devices, rotating wire brushes and high pressure application of scale dissolvers in combination with the tools above. A large number of permutations are possible and can be tailored to suit local conditions. Technical details are proprietary however some examples are given below.

Jetting and coiled tubing

Rotary jetting using the BJ NOWSCO Rotojet system is described in Crabtree (1999) and Latos (1994). These use multiple jet orifices to ensure full wellbore coverage. One problem with earlier HP devices was that the jet became trained on one area of tubular leading to severe erosion where abrasives were used (Courville et al, 2000). Use of rotary jets prevents this. HP rotary jets can be used in conjunction with chemical washes. Water jetting is effective on soft scales and on debris but is less effective for calcium and barium sulphates.

The mechanism of scale removal involved in water jetting is cavitation. Bubbles of water vapour form as the jetting fluid passes through the jetting nozzle and these bubbles collapse on impact with the scale with explosive and erosive effect This cavitation effect is severely reduced at higher hydrostatic borehole pressure (Crabtree et al, 2003) and it becomes necessary to use abrasive slurries. Companies such as Schlumberger have experimented with different sizes, shapes and compositions of cleaning particles. Shlumberger Cambridge Research have produced “sterling beads” for use as an abrasive, which are as abrasive as sand but less erosive of the steel tubulars. Systems can be customised to suit the degree of scaling. Small diamond bits can be attached to cut through scale bridges (total blockages).

Adams Coiled Tubing Inc. has a glass bead jetting system with 8 stationary nozzles, although it is understood that this can cause some metal fatigue (ACT 2004). The first use of this tool with coiled tubing intervention in the North Sea (Tailby, 1999) was to remove barium sulphate scale from in situ gas lift valves. It has also been successfully used downhole in Gabon, West Africa. Other examples incluse the BJ Services Vortex Wash Nozzle™ with 4 tangentially offset nozzles, suitable for non-barite scale, and the Trican “Hydromill Tool” for removal of heavy scale deposit and scale bridges.

Combined High Pressure jetting and chemical removal

The Schlumberger Jet Blaster™ is an example that was used in the BP Ula field in Norway, which has a high scaling potential. Acid injection and slickline brushes were unsuccessful in removing the scale from downhole safety valves and tubing, but the Jet Blaster was successful in a single run taking 3 hours and using 12 m^3 of hydrochloric acid. The device has 2 radial jets and one downward jet and uses software to optimise the nozzles.

Percussion methods - explosive

A novel method was used in the Norwegian Statfjord field using small explosive charges. Due to delivery problems with coiled tubing equipment a wireline solution was used (Børeng *et al.* 2004) for downhole scale removal. After wireline tractor milling failed to remove barite scale it was removed using explosives. A string of small shot charges was detonated over the scaled interval, removing barium sulphate scale effectively. There was no mention of tubular damage. The shattered scale was circulated up the hole and collected for disposal.

Percussion methods - mechanical

Scale Savage™ is a proprietary percussion device from the USA but no details could be obtained. It is reportedly very effective at removing thick barium sulphate scale. It is reported to be able to completely clean 200-300 feet of tubing in situ per hour without tubing damage. It is described as "impacting and pulverising" the scale, particles of which are then circulated to the surface for separation and disposal

Pros

- Avoids having to remove and replace production tubulars and downhole equipment.
- Avoids risks associated with transport of contaminated tubulars.
- Avoids risks associated with offshore cleaning of removed tubulars/handling

Cons

- Expensive and only done as part of well intervention
- Production has to stop for well in question.
- These techniques still produce NORM waste to be disposed of e.g. by maceration and sea disposal.

Applicability to the UKCS

Coiled tubing (CT) intervention is widely used onshore in US and Middle East. It is sometimes used in the UKCS but many production platforms have inadequate craneage to lift the equipment needed to carry out well interventions, requiring a drilling rig which is expensive, or the CT has to be reeled off onto the platform from a supply vessel or used via a modular crane, which are both cost- and time-consuming. One contractor is examining CT intervention from a floating vessel. This was developed for offshore West Africa (Arangath 2003) but could be useful for UKCS and for fields where production is from a floating production vessel.

Coiled tubing operations have been carried out in Forties field wells using downhole motors, bits and underreaming (Brown *et al.* 1991).

Percussion removal methods appear to be effective and attractive in some circumstances and should be considered further for use in the UKCS.

5.7 Offshore NORM removal from opened/dismantled equipment

Description

Vessel Sludge removal

Removal of sludges from process vessels is undertaken using jetting and suction devices or manually after vessel entry. All of the major offshore cleaning contractors offer some type of NORM sludge removal service. None of them is understood to have an RSA authorisation to dispose of the material onshore and all such material is usually macerated and discharged to sea under the host facility RSA authorisation. Oily NORM contaminated sludges which cannot be de-oiled offshore will have to be authorised by the regulator for onshore disposal.

Offshore descaling of dismantled equipment

This is carried out wherever feasible to avoid costs and transport issues. Tubulars and simple equipment that does not require expert dismantling can be cleaned offshore. A large range of mobile jetting and reaming equipment can be deployed depending on which cleaning contractor is engaged.

The NORM waste is macerated and discharged to sea under the facility RSA authorisation. Decontamination contractors offer mobile HP jetting units with and without use of abrasives.

Deck space often restricts the use of offshore descaling equipment. In the past several innovative solutions for offshore cleaning were put forward by cleaning contractors including a vertical tubular cleaning assemblage (AEAT 2001) and a mobile RSA authorised decontamination vessel (Denholm Industrial Services pers comm.) The former did not receive sufficient operator support and development of the latter was stopped due to vessel owner reputational concerns (discharging radioactive waste).

Pros

- Flexible and available on demand.
- Variety of equipment available.
- Contractors can provide oil removal, mobile macerator and weighing units for sea discharge.
- Reliable method with minimal handling and transportation issues.

Cons

- Tubulars may have high activity NORM present especially from the producing section and there may not be suitable storage areas for these on the platform.
- Can be limited by deck space on offshore facilities.
- Costs can be similar to onshore decontamination.
- Not all contractors have de-oiling equipment and some asphaltic deposits can be very difficult to remove.
- Oily wastes may have to go onshore for disposal

Applicability for the UKCS

This is currently the most widely used NORM removal method on the UKCS.

5.8 Onshore NORM removal

5.8.1 Mechanical removal

Description

Dismantled equipment sent onshore is decontaminated. Scale that has been removed by high pressure jetting with water and salt abrasive and by reaming is ground to <242µm and discharged (after oil removal) into a nearshore disposal line (ref. section 7.3)

Pros

- Uses tried and tested technology, efficient infrastructure in place
- Is the current method of cleaning smaller and complex NORM contaminated equipment in the UK

Cons

- NORM waste is created onshore for disposal
- Exposure risk associated with transport of contaminated equipment
- Transport as radioactive waste creates secondary waste in form of contaminated packaging

Applicability for the UKCS

There is one onshore facility in Aberdeen, Scotoil services which effectively carries out all of the decontamination of equipment sent onshore from the UKCS Scotoil Services, Aberdeen is now the major disposal contractor for NORM in the UK and takes NORM from both the Scottish and English sectors of the North Sea.

Scotoil receive NORM from many UK sites and the material is transported by road to its Aberdeen facilities. Scotoil has invested heavily in a new building in Aberdeen which will contain all its NORM treatment facilities. This building should be completed by mid 2004. This enclosed site will ensure the containment of all NORM washings *etc*.

RWE-Nukem has commissioned its LSA cleaning/treatment facility in Winfrith (Dorset) and is accepting LSA-contaminated downhole pumps, tubulars etc. from BP's Wytch Farm site. There is a backlog of material requiring treatment from BP which could take up to two years to clear. RWE-Nukem expect to produce about one drum of radioactive waste per month which it will pass to the UK Atomic Energy Authority (UKAEA) who are also on the Winfrith site. It will then be shipped to Drigg along with other waste produced from the overall decommissioning of Winfrith. It is not clear whether they will be accepting waste from other operators after the initial startup period and backlog is cleared.

5.8.2 Chemical decontamination

Description

There are a large number of commercially available scale dissolvers for all chemical types of scale including numerous proprietary sulphate scale dissolvers. These are routinely used for the removal of carbonate scales, but for sulphate scales the chemicals, although effective, are usually slow and are often used in conjunction with mechanical cleaning methods (see section 5.6).

For the ^{210}Pb and ^{210}Po NORM deposits associated with gas processing equipment, chemical decontamination can be the most effective removal method and is less damaging to equipment than jetting. These metallic deposits are effectively plated to the equipment.

Pros

- Less equipment required than for mechanical removal.
- Can allow the decontamination of complex equipment without dismantling.

Cons

- Slow and only partially effective for sulphate scales
- Onshore this creates a secondary waste requiring a disposal route.

Applicability for UKCS

A UK company has successfully removed ^{210}Pb and ^{210}Po contamination using proprietary dissolvers (UDD 2003). Lead and polonium contamination (and mineral scales) were removed from tubulars and downhole pumps using a proprietary chemical dissolution/ chelation system. The process is patented (Keatch, Appendix 2), equipment is immersed in bath of proprietary solvent to remove iron oxides then immersed a second, patented solvent bath to remove metallic NORM. Removed NORM was re-injected along with slurrified cuttings at a UK onshore field under the field operator's RSA authorisation. The unit activity concentration of the spent chemical containing the removed NORM was below 14.8 Bq/g and therefore exempt from RSA under the PSEO. Another chemical cleaning patent is Snyder (Appendix 2).

5.9 Acoustic removal

Description

Work has been carried out at the Argonne National Laboratory (Illinois USA) on mineral scale removal using sonification (Wilkey *et al* 2000). Acoustic cavitation (sonification) involves application of high intensity sound waves to a liquid phase. Microbubbles are formed which grow to a critical size (few Ǻ) then implode. At the collapsing bubble interface temperatures reach 5000 K and pressures reach 500 to 1000 atmospheres but the bulk solution stays at ambient pressure and temperature. It can be a very effective cleaning method for industrial equipment. It can be enhanced by other advanced oxidation techniques e.g. ozone injection, vapour stripping and /or use of hydrogen peroxide.

The laboratory study used $BaSO_4$ as a substitute for normal scale. Results showed up to 90% removal of scale after 15 minutes' sonification of coatings up to 5/8 inch thick. Solid lumps of scale were shattered.

Pros

- Could be carried out down hole. (minimal interruption to production)
- No requirement to remove tubulars for decontamination
- No chemicals are involved.

Cons

- The method requires good access to scaled areas of equipment.
- Still have scale to dispose of and, if carried out in situ, may disperse scale particles around the process.
- Commercial availability is uncertain.

Applicability to the UKCS

The cost is questionable when other methods are available and it is not clear if this method is commercially available. From discussions with offshore cleaning contractors this method is not currently used in the UK offshore.

This study has not found any example of commercial application of this method and none of the operators consulted had used such methods.

5.10 Other methods at developmental stage

5.10.1 Microbial Scale Removal

Description

There is a project underway at the University of Oklahoma (Krumholz, 2000) to design an anaerobic microbiological treatment that will specifically dissolve radium sulphate that has precipitated onto equipment in contact with production water. The system will selectively remove radium by reducing sulphate to sulphide and drawing the Ra^{2+} ions into solution. The solution will then be transferred to another vessel where the radium will be re-precipitated and disposed of. This is a concentration method.

This will not reduce the overall amount of scale but will control where it builds up and save costly items of equipment from the scrap yard or smelter.

Pros

- Concentrates the radium NORM
- Potentially Low energy/resource use

Cons

- Potentially slow due to insolubility of barium/radium sulphate

Applicability to the UKCS

This method is at the developmental stage and it is not reported to be used by anyone on the UKCS. If viable, it may be worthwhile for expensive items of equipment e.g. pumps.

5.10.2 Liquid nitrogen

Description

Immersion of scaled equipment in liquid nitrogen and subsequent impacting of the equipment to remove the scale has been suggested (Decook 1995 patent). The success of this is not reported but it might be an effective means of removing layered scales containing napthenates and asphaltenes. There is a potential for equipment damage as this will also be made more brittle by the liquid. It is also presumed that the cooling demand for a large tubular would require a very large amount of liquid nitrogen or a significant power input for re-cooling the nitrogen, which would be expensive and logistically difficult offshore.

Pros

- More effective removal of problem deposits e.g. asphaltenes

Cons

- Probable health and safety issues around use of liquid nitrogen
- May be resource intensive

Applicability to the UKCS

This method is at the developmental stage and it is not reported to be used by anyone on the UKCS. If viable, it may be worthwhile for expensive items of equipment e.g. pumps.

6 NORM WASTE REDUCTION

6.1 Introduction

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.

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 above (Section 5). 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 needing to be sent to landfill, 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 but is not suited to scrap steel or wastes that are predominantly minerals. Wastes must be dry and oil-free before supercompaction.

6.2 Chemical segregation/Dissolution and separation

Description

Radium can be extracted from barium sulphate scale using a combination of physical and chemical treatments (Varskog, 2003). The scale is separated into oil components, heavy metals, barite and a radium concentrate. After oil removal, the radioactivity-containing waste is dissolved and heavy metals are removed. The solution is precipitated into a radium-rich fraction and a radium-depleted fraction. Typically the radium-rich fraction contains 50 % of the barium mass and more than 95 % of the radium. The process is run until the radium content in the rich fraction has reached 0.1% and further enrichment is performed by column chromatography. The radium-depleted fraction is produced to be below free-classification limits. This waste fraction consisting mainly of barium sulphate may be reused or disposed of as non-radioactive waste.

Starting with LSA scale with a radium activity of 60 Bq/g, over 90 % of the initial mass can be decontaminated for reuse or ordinary waste handling after 4 dissolution and precipitation cycles. The enriched fraction will reach activity concentrations suitable for LLW repository storage (4000 – 10 000 Bq/g) after 6-7 cycles. In this latter case more than 99 % of the initially mass has been taken out of the system as non-radioactive

A mobile unit for NORM waste processing is described by Capone (1998) who achieved a volume reduction of 67% on oily sludge and 90% on dry granular sulphate scale. The steps in the process are de-oiling, dissolution of scale using proprietary scale dissolvers and injection of the aqueous solution into a suitable formation.

The whole process can be mounted as a mobile unit. The process is designed for use in the US onshore fields however mobile units are already employed by offshore cleaning contractors on UKCS.

Pros

- Satisfies principles of waste minimisation and ‘concentrate and contain’
- Reduces final volume for disposal as LLW

Cons

- May be unsuitable for offshore use
- May be unsuitable for large quantities - further evidence required
- Designed for radium and might be less effective on ^{210}Pb and ^{210}Po. ^{210}Pb can be transported in solution and is not always supported by ^{226}Ra.

Applicability to the UKCS

Norse Decom A/S operates a commercial process in Norway involving extraction of radium from barium sulphate scale as described above. The method could be applied to the UKCS. Given the plant requirements and radiological analysis necessary, this is probably limited in practice to onshore treatment and may be suitable for decontamination wastes and decommissioning wastes, particularly if their final disposal is as non-exempt LLW to a land-based facility.

6.3 Selective nuclide removal - ion exchange media

Description

Technology for the selective removal of radionuclides using ion exchange media has been developed for processing of uranium mine tailings in Germany, USA and Australia.

Smith (1992) discusses the Argonne Laboratory that has developed a ion exchange treatment resin to remove selected radionuclides from waste water. The “Diphonix” resin is commercially available and can be regenerated for reuse. It has not yet been tested for radium removal and there is a concern that the effectiveness of the resin will be affected by the hardness of the water as Ra and Ca show chemically similar behaviour.

In general, after use, ion exchange resins will either need to be regenerated or to be disposed of and replaced when spent. Either route produces a more concentrated secondary waste to be disposed of.

Pros

- Satisfies principles of waste minimisation and ‘concentrate and contain’
- Reduces final volume for disposal as LLW

Cons

- May be unsuitable for offshore use
- Not proven on radium wastewaters

Applicability to the UKCS

This technique is only applicable to liquids e.g. produced water. As discussed in Section 5.3, it is not clear that transferring the radionuclides to another medium that then requires handling and disposal, incurring use of fuel and raw materials, is worthwhile in terms of dose avoidance.

This may be a valid technique for onshore decontamination/decommissioning activities that generate wastewaters.

6.4 Waste segregation/dewatering

Description

Simple physical processes can significantly reduce total wet volume by removal of oil and water from sludges. It should be noted, however, that drying out NORM contaminated wastes can increase the dose risk via inhalation of dust.

Mechanical volume reduction for NORM contaminated sludges can result in 75-80% volume reduction (Smith 1992) using chemical demulsifiers, oil removal and segregation on size. Radioactivity is reportedly concentrated in the finer silt and clay fraction.

Bush (Appendix 2 - patents) promotes the dissolution of the finer fractions using sulphate scale dissolver and reinjection of the resultant solution. Mason (Appendix 2 - patents recommends producing a NORM slurry and separating off the <80µm fraction which will contain most of the NORM, a form of gravity segregation).

Oily NORM-contaminated sludges are a problem where no offshore de-oiling capacity is available. Some cleaning companies offer an offshore oil decontamination service, otherwise such wastes have to be drummed and sent onshore for treatment and disposal.

Pros

- Satisfies principles of waste minimisation
- Reduces final volume for disposal as LLW or hazardous exempt waste

Cons

- Not always suitable for offshore use - depends on facility and contractor
- Drying can increase dose risk from dust

Applicability to the UKCS

Segregation and dewatering techniques are currently used on offshore facilities provided there is sufficient deck space, power etc. and the techniques are used whether NORM is present or not. Similar treatment can and should be applied to onshore wastes under the Landfill Directive requirements for pre-treatment of hazardous wastes.

Waste segregation and dewatering should be an element of any NORM waste management plan at an appropriate point in the treatment and disposal chain.

7 NORM DISPOSAL

7.1 Introduction

In the following section, methods of NORM disposal on and offshore from around the world are discussed. The disposal of NORM waste is already heavily regulated in the UK (ref Section 4) and some of the following may not be considered suitable for NORM disposal on the UKCS or UK onshore. Nevertheless the project scope is to examine all potential solutions even if they could require legislative changes to proceed.

Some solutions can be contemplated which are theoretically possible, but not realistic for NORM wastes. These include, for example, options considered for intermediate and high level wastes disposal (DEFRA, 2002c), which are not considered further, such as disposal in ice sheets, subduction zones, space or a purpose-built geological repository.

Deliberate incorporation of NORM into products has been investigated. There is a patented process for using radium contaminated barium sulphate scale as a weighting agent in drilling mud (Scotoil, Appendix 2) diluted below regulatory limits with “clean” barium sulphate. There are examples of NORM recycling into building materials such as plasterboard, cement and building blocks but their use is problematic due to the raised public dose from long term close exposure. There are also increased occupational exposure risks from processing, manufacture and installation of these products. Overall these are not considered to be viable options for UK NORM disposal and are not considered further in this report.

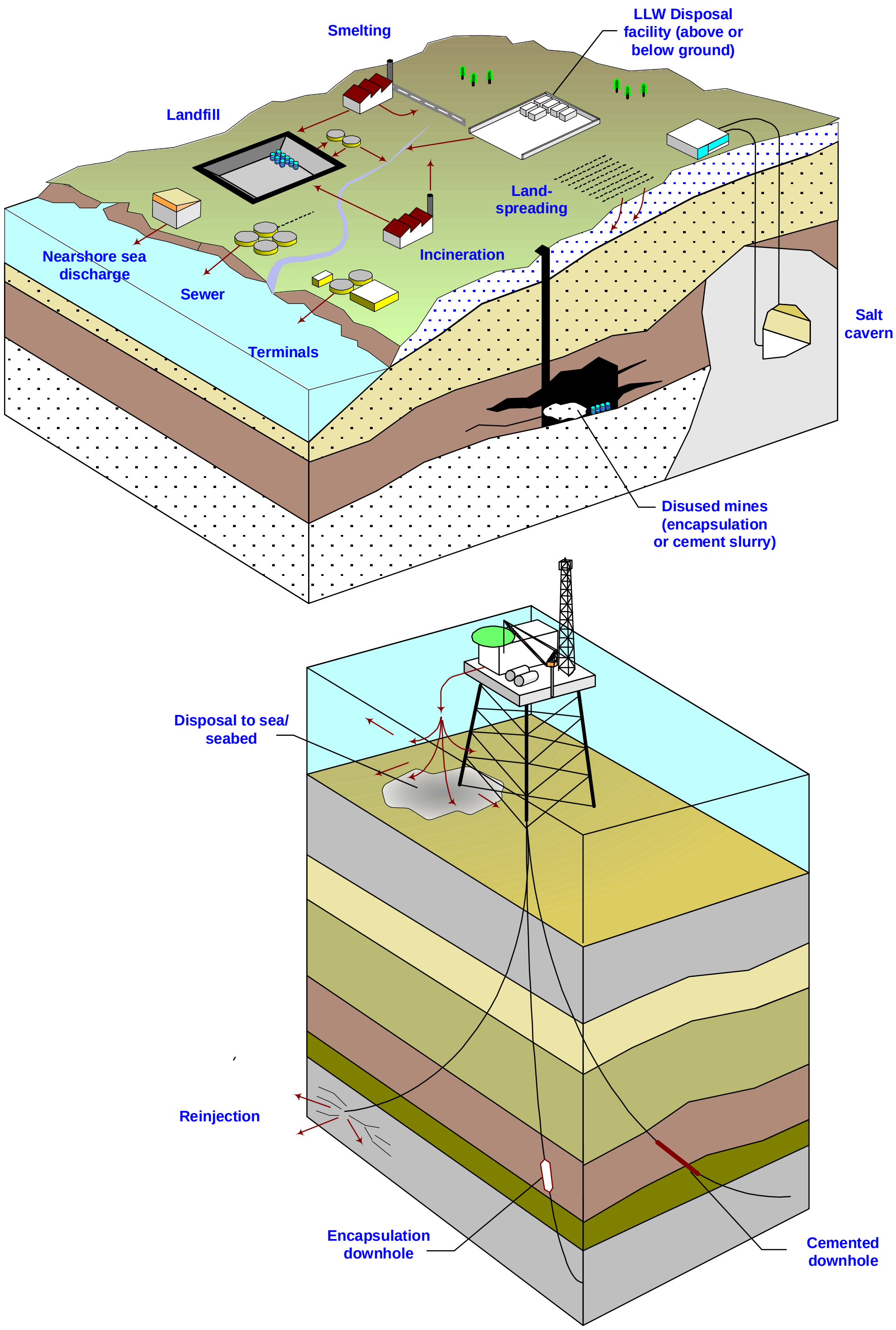
The methods that are considered as having some application to oil industry NORM are given in **Table 6** and illustrated in **Figure 1**.

Table 6. List of disposal options considered

Offshore*	Sea disposal offshore discharge
	Sea disposal nearshore discharge
	Re-injection of dissolved NORM
	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

Figure 1. Illustration of NORM disposal options



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

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

7.2 Sea disposal to sea from offshore installations (fixed or floating)

Description

This option includes produced water discharge and solid NORM.

The vast majority of produced water is discharged offshore with a small percentage being reinjected or being passed to terminals. Produced water, and the NORM within, is expected to disperse quickly and widely in the sea. On contact with seawater, most of the NORM is expected to form insoluble sulphates. It has occasionally been reported that a local scale build-up can form on platform structures near produced water discharges, which can be dislodged in rough weather.

Solid NORM arisings from offshore equipment descaling or from process and storage vessel cleanouts (sands, sludges) are macerated to 1mm and discharged to sea. Platforms may have fixed de-oiling and maceration equipment or this may be brought onboard by offshore cleaning contractors. Grinding to 1mm is a standard condition of platform RSA authorisations in the UKCS. This appears to be a historical condition and is presumably to promote dilution and dispersion, but the radiological merits of dilute and disperse are not clear. It is assumed that the NORM is rapidly dispersed in the water column by current action. There is no published data on whether it accumulates around the discharge point on the seabed in the North Sea, although anecdotal evidence in deeper parts of the North Sea suggests it may, and it is reported to do so in the Gulf of Mexico to a limited extent (Hart *et al.* 1995).

The same route can be used for disposal of sand that has been produced from the reservoir and that has been contaminated with radioactive scale.

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 given distance 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

- Not consistent with OSPAR stated aspirations to reduce radioactive discharges to sea for naturally occurring substances.
- 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 for operators as sea discharge (including produced water) from

the oil and gas industry accounts for a proportion of alpha activity discharge in the OSPAR area (although the dose is trivial, see Section 9).

Applicability to UKCS NORM disposal

Offshore scale 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’ that could travel to platforms and decontaminate NORM adjacent to the facility and discharge either under the facility’ authorisation or have its own RSA authorisation. This has a significant capital cost, however, and would require industry buy-in, and raises reputational concerns for the ship owner.

7.3 Discharge to nearshore via sea outfall

Description

NORM can be discharged to the nearshore via a pipeline where a suitable RSA authorisation exists or can be obtained This is the main disposal route for the UK for NORM from onshore decontamination. This outlet is mainly provided by one contractor (Scotoil). Scale that has been removed by high pressure jetting with water and salt abrasive and by reaming is ground and discharged (after oil removal) into a nearshore disposal line. The discharge is dispersed to sea by water movement. The discharge is regularly monitored by the cleaning contractor and no significant accumulation of NORM has been reported under this monitoring.

Some UK oil and gas terminals also have an authorised NORM sea discharge and RWE Nukem has a small facility in Dorset. One terminal in England (2002 authorisation) 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.
- Proximity to Aberdeen harbour (and to source for the terminal discharges) removes the requirement for transporting NORM waste (with attendant exposure risks) to another disposal site.

Cons

- Potential reputational vulnerability
- Inconsistent with OSPAR aims of reducing radioactive discharges to sea
- Monitoring costs requirement due to proximity to public areas.
- Possible impacts on Habitats Directive site
- As currently practiced reliance 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.

Scotoil 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. The application of the Habitats Directive may affect the continued feasibility this nearshore disposal as it discharges adjacent to the River Dee candidate Special Area of Conservation.

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

Based on Phase 1 estimates, the capacity at Scotoil should be sufficient to cope with future decommissioning demand from the UKCS.

7.4 Re- injection

***Description*:**
Produced water is already reinjected in many UKCS fields, some of which is 'radioactive' under RSA Schedule 1 limits. PWRI is expected to increase to meet OSPAR targets for reducing the amount of oil in produced water discharged to sea. There is a presumption that all new facilities will have produced water reinjection unless there is a strong argument against this. The practice may lead to increased power emissions.

Solid NORM may be finely ground and mixed as a water based slurry that can then be re-injected into a suitable subsurface formation by hydraulic fracturing. Cuttings re-injection equipment may be used where present. Baker.*et al.* (1999) describes the process used in Louisiana onshore for disposal of historic NORM waste accumulations. In this case a purpose-designed disposal well was drilled and water supply for slurrification was needed, as this was an historic accumulation. This would not be the case for offshore NORM disposal on the UKCS where produced water or seawater would be available.

In Norway BAT must be applied to PW disposal, which excludes the generation of secondary hazardous wastes i.e. 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 as an irreducible waste.

Reinjection is used more widely offshore in the US (Smith *et. al.* 1996) and is dependent on the availability of a suitable formation i.e. thick, high permeability and preferably sealed by impermeable horizons above and below.

Pros:

- This has distinct advantages for oil and gas NORM disposal as the 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, financially or in emissions.
- It utilises tried and tested technology.

Cons:

- Onshore, it must be demonstrated that there is no potential for aquifer contamination.
- If a facility does not already have cuttings re-injection equipment installed there would be a high capital cost for disposal of a relatively small volume, which would make it hard to justify in a situation where discharge to sea was already permitted.
- The power consumption of slurry pumps is relatively high and would mean increased power generation emissions.
- There has to be a suitable disposal well in the field, or intra- or inter-field transport for disposal would have to be investigated (intra- and inter-field transfer of cuttings for re-injection is permitted for example with conditions).

Applicability for UKCS NORM
This disposal method has obvious potentially 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.

On the Norwegian Shelf, 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 believes that it is permissible to reinject NORM 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 interfield transport is not undertaken in Norway. Several platforms, with cuttings re- injection facilities already installed, are currently re-injecting NORM including Statfjord and Gullfaks (Statoil pers comm.). Another Norwegian operator has applied to re-inject NORM from offshore decontamination (BP Norge pers. comm.). Where there is no capacity for re-injection e.g. at the floating installations, NORM waste is shipped to shore. Unlike the UK, discharge to sea is not an approved disposal route.

NORM reinjection has been successfully used onshore 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 CO_2 emissions weigh against its use. Currently 12 facilities in the North Sea have cuttings re-injection equipment installed according to responses to the Phase 1 Questionnaire.

It is anticipated (Section 4) 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. The interfield movement of NORM waste for re-injection may require further investigation, but inter-field cuttings reinjection is permitted with conditions. No operators in the UKCS have yet notified an intention to carry out NORM re-injection.

Historically, containment has been a concern with the disposal of radioactive waste by subsurface injection. For offshore NORM re-injection, however, the nature of the subsurface in the disposal areas offshore is very well known from 3D seismic data and drilling activity and re-injection will be into the deep subsurface a long distance offshore and unlikely to present risk of aquifer contamination or of seepage to surface. The situation is analogous to cuttings disposal where the reinjection horizons are chosen to have the requisite properties of high permeability and good fracturing and sealed by impermeable zones.

Onshore re-injection
The method has been used in the US onshore to dispose of historic accumulations of NORM waste (Smith *et al*. 1996, Reed *et al*. 2001) with the proviso that baseline and post disposal monitoring are carried out and that there will not be any aquifer contamination. It is unlikely that any risk assessment would support the transport of UKCS NORM waste onshore for disposal when it could be re-injected offshore at source. In the UK, oil and gas NORM arisings onshore are limited to arisings from decontamination facilities and terminals that currently have other NORM disposal routes to Drigg and to nearshore. Even if these routes were to be discontinued the low relative volume and activity would make it unrealistic to justify a dedicated onshore NORM re-injection facility. This disposal route was considered for disposal of nuclear LLW in the past but met with public and NGO resistance. A multi-industry LLW reinjection facility would potentially bring associations with the nuclear and defence industries, which are unlikely to be welcomed.

7.5

7.6 Downhole abandonment in situ

Description:

The production string is left in place downhole on well abandonment. It is necessary to seal all the producing zones to avoid the risk of future hydrocarbon contamination. This can be done 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). Production tubing in each well was left in the wellbore and used to conduct all downhole cementing operations. Once cementing was completed a crane removed sufficient production tubing to place a cement plug near the surface. This is not waste disposal per se but abandonment in situ. No transport of waste is entailed. The cost of a workover rig/vessel can be avoided.

Pros

- Reduces abandonment costs/ decommissioning costs
- Avoids NORM decontamination and disposal to nearshore land.
- NORM on tubulars is permanently isolated from the environment
- This avoids having to remove transport, and decontaminate production tubulars and associated exposure risks
- Is compatible with current well abandonment guidance (UKOOA, 2001)

Cons

- Not current practice on the UKCS
- Cannot deal with large volumes of NORM waste
- Not all wells will be suitable (case by case basis).
- Potential for loss of containment

Applicability to UKCS NORM

The NORM in producing zones of wells is usually the most radioactive in a facility. There is 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, there is no fixed requirement to remove downhole tubulars and equipment 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.

7.7 Encapsulation and downhole disposal

Description

NORM waste is placed into sections of tubular (or some other container), sealed in and deposited down the well bore.

Scaife *et al*. (1994) give some examples of this in practice from the US. One disposal was carried out offshore (Gulf of Mexico) as NORM 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

- Works well for NORM disposal however could only be used for small volumes of NORM.
- When containerised prior to disposal, this provides permanent isolation from the environment and very small exposure risk

Cons

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

Applicability for UKCS NORM disposal

For the UKCS the transport of NORM waste back offshore for disposal is likely to raise difficult licensing issues. As the vast bulk of it is generated offshore, however, this method might be of use during decommissioning where relatively small volumes of NORM are present and could be disposed of prior to well abandonment and capping.

7.8 Onshore built disposal facility/repositories

These are discussed separately in Section 10. A summary only is included here.

Description

NORM waste is conditioned in situ by cementing into drums. These are placed in concrete lined open vaults either as they are or grouted into ISO containers. 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.

Pros

- Established disposal route
- Simple technology
- Currently in use

Cons

- Cost
- Containment of leachate
- Monitoring costs
- Requires land transport of NORM wastes

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.

If this is to continue to be the main disposal route onshore for non-exempt NORM waste for the UK some assurance may need to be sought by the regulators that oil and gas NORM waste will continue to be accepted.

7.9 Landfill

Landfill is discussed separately in Section 10. A summary only is included here.

Description

Waste is deposited loose into a lined, excavated cell and mixed with other wastes with similar properties. When full the cell is covered with topsoil or granular material and ultimately the whole site is capped.

Pros

- Simple, existing technology
- Current method for exempt wastes

Cons

- Lack of capacity in current landfills
- Lead time to regulate and open new facilities
- Lack of financial incentive to open new facilities
- Public opposition

Applicability to UKCS NORM

Landfill is currently in use for disposal of exempt NORM wastes. 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.

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.

7.10 Landspreading

Description

This is 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 in the US. The EPA report 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 is 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.

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 microganisms and can pass into the food chain. Dose estimates for landspreading were non-trivial (section 9).

Pros

- Cheap
- Low technology

Cons

- Not the EA /SEPA recommended method of 'concentrate and contain'
- Lack of suitable remote land area to carry this out
- Potential public/NGO opposition (reputation)
- Risk of groundwater contamination
- Lack of control over exposure to public from windblown NORM
- Required transport of NORM from site of generation.
- Exposure risks to public - ingestion and inhalation (windborne)

Applicability to UKCS NORM disposal

Most oilfield NORM is produced offshore. This disposal route would entail transporting it to land with attendant exposure risks. There may be complications in authorising such a disposal routes, i.e. in demonstrating that this is the Best Practicable Means to minimise public exposure, or if the waste is exempt, obtaining a PPC authorisation under the Landfill Regulations. This is very unlikely to be considered suitable for disposal of UKCS NORM and is now largely discontinued in US due to risk of radiological exposure, contaminated land issues and need for remediation.

7.11 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 smelted 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 in the UK. There may be more interest from UK steel producers now that the price of steel has increased as offshore equipment represents a known source of high quality steel. There should be no particular impediment to shipping the 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 carefully 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 and partition to the slag phase and activity of the slag calculated (it would not be desirable to end up with a large amount of non-exempt slag which would have to be disposed of as LLW.) However when the tubulars were cut up to be put into the furnace, a random check by the attending HMIPI inspector showed some non-exempt activity levels and the trial was stopped. 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 the smelting option was not pursued further by the operator.

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. It is probably not the best option for contaminated tubulars as they are often high activity and large volume (and new technologies exist to clean them offshore).

Probably not an option for large volumes of non-exempt scrap as it may generate large volume of radioactive slag although this may be exempt in which case it can be disposed of to landfill. In Germany the slag from smelting was of sufficiently low activity to be used as road metal. It is likely that furnace operators today would be interested in high quality steel from a known source especially as the price of steel has now increased.

7.12 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 (2000b) 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 containing 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 main 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 tiny 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).

This is not seen as suitable as a principal disposal route for oil field NORM waste but it is appropriate for small volume of exempt PPE and some oily NORM wastes.

7.13 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 (i.e. not waste disposal).

Pros

- Many potential sites
- Simple existing technology

Cons

- Potential lack of containment leading to aquifer contamination, leaching,
- Potgential public/NGO opposition
- Potential costly re-engineering of old workings and
- 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.. The UK has a large number of disused underground workings. 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.

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 resistance.

There is likely to be an insufficient volume of oil and gas NORM waste requiring onshore disposal) to justify a dedicated facility. Association with other radioactive waste (including nuclear) at a general facility might be a reputational issue for some operators, especially if there was a high profile public consultation.

7.14 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. Legally, this practice was considered equivalent to reinjection.

Pre existing caverns can be used or new ones created by:

1. **Solution mining** where salt undersaturated water is injected into a salt deposit (of suitable thickness and homogeneity) and the resulting brine withdrawn.

2. **Direct circulation method**: Fresh water is injected through a tubing string from the surface and the brine withdrawn up the annulus between the tubing and well casing (the reverse can also be used with water injection down the annulus and brine withdrawal up the tubing string (Veil *et al* 1998).

The caverns are initially brine filled and as waste is injected the brine is withdrawn via a well. As the slurry is injected, the cavern acts as a separator with heavier solids sinking to the bottom of the cavern and free oil /HC's in the NORM slurry will collect at the top of the cavern. As the cavern fills the removed brine become increasingly full of suspended material and when this becomes a disposal and mechanical (pump blocking) problem the cavern is considered full and is sealed up. Potential risks of contamination were identified, namely:

- Inadvertent intrusion
- Release through the cavern seal
- Release of contaminated fluid though cracks
- Release of contaminated fluid via permeable interbeds/inhomogenous zones
- Cavern roof fall

This disposal method is also used in Gemany in Lower Saxony e.g. the Asse mine used for LLW disposal (not specifically NORM) and 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, Appendix 1) where NORM disposal is carried out using a pair of wells. NORM slurry is injected in a carrier fluid which dissolves out a salt cavern in which the NORM solids are deposited. The carrier fluid and brine from salt dissolution are then abstracted up the second well to be re-injected into a disposal well.

Pros

- Utilises existing tried and tested technology
- Can utilise existing structures or new structures formed using basic technology.
- Reasonable cost ($150 US/bbl) Veil *et al* 1998
- Very high degree physical and chemical of isolation. Long term monitoring for leakage in US (after nuclear testing) has shown no escape of nuclides.
- 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. Have to ensure no access to groundwater which could

cause salt dissolution leading to loss of integrity and leaching.

- Prone to "cavern creep" depending on the depth loss of significant volumes of storage. Rheological modelling is required to establish risks. The deeper and hotter the worse the creep.
- 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 the 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 in the UK and identified the following options.

Onshore:
Permian and Triassic salts in Cheshire Lancashire
North of the Humber (Whitby–Middleton strip of Permian Salt)
Coastal strip Tees to Humber, 1800m at the deepest part shallowing northwards to a few hundred metres. This is historically associated with underground storage.
Near Hornsea there are a cluster of salt caverns used for gas storage.
Planning permission has been granted for a deep gas storage site at Alborough (S. of Hornsea) at depth of over 1800m.

Offshore:
Permian salt structures in the Southern North Sea were investigated (BGS pers comm.) for creating solution cavities for radioactive and other hazardous wastes using conventional drilling techniques and pumping seawater down the annulus to dissolve out the salt. This required an environmental impact assessment for the concentrated brine discharge to sea. It was suggested that LLW waste should be injected as non-aqueous slurry then cemented in with clean cement with dye in it as a marker in case of future intervention, finally sealing the well below seabed level.

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 and this seems to be the preferred use. Onshore there would be concern over potential for aquifer contamination. Public/NGO opposition there might be insufficient NORM waste from UKCS to generate/warrant business interest for a NORM dedicated disposal facility so the site would have to be developed as a general LLW disposal facility with all the attendant public concern as it would then include nuclear LLW. Technologically simple, the main costs would be from obtaining consents (public consultation and potential resistance) which could be prohibitive if other options exist.

7.15 Sewer

Description

Under section 18 of RSA93, the relevant Environment Agency may authorise disposal to sewer of small amounts radioactive material from non-nuclear organisations provided that the radiological risks are small and the disposal route is considered to represent BPM (EA, 2002b). 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.

EA (2000a) states that the disposal to sewer route is under review following the 1998 ban in disposing of sewage sludge to sea. Of the 17 radionuclides considered as being discharged to sewer, only one is an alpha-emitter, Americium-241 (used in smoke alarms and possibly in research). The report could not find any data on the discharge of this radionuclide. The radionuclides discharged to sewer are almost always low toxicity beta or gamma emitters, although it is reported that occasionally disposal of 'alpha emitters except natural uranium and natural thorium' is authorised.

The NRPB (2004) discussed *inter alia* doses to sewage workers and to the public from radionuclides via sludge disposal. It concludes that small users may give rise to doses via sludge in agriculture 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.

Pros

- Minimum investment
- Widely available

Cons

- This is clearly a 'dilute and disperse' option
- Dose to wastewater operatives
- Discharge to nearshore
- Not normally used for alpha-emitters such as radium
- Challenges in the available and acceptable routes for the disposal of sewage sludge.
- Acceptability to public and NGOs

Applicability to UKCS NORM

None realistically for bulk disposal of NORM solids onshore. Possibly suitable for small scale disposal of washings from contaminated PPE to aid reuse and avoid incineration.

7.16 Export

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 is unlikely to be used as a preferred route for routine NORM disposal for the UKCS except in certain circumstances, e.g. it may occur during decommissioning if contaminated equipment is sent abroad for dismantling.

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, may well be equally viable if pursued further.

7.17 Specific export options

7.17.1 Land disposal facilities/repositories - General

Figure 4 shows the radioactive waste disposal sites in the EU and Norway (IAEA, 2004). It illustrates that the sites are numerous. Operators of the sites in Norway and the Netherlands were consulted as to their willingness and ability to accept NORM waste from abroad, as they are known to accept radioactive oil industry wastes and are the closest (proximity principle). The Danish regulator was also contacted and was of the view that the importation of oilfield radioactive waste would not be permitted.

7.17.2 Norwegian repositories

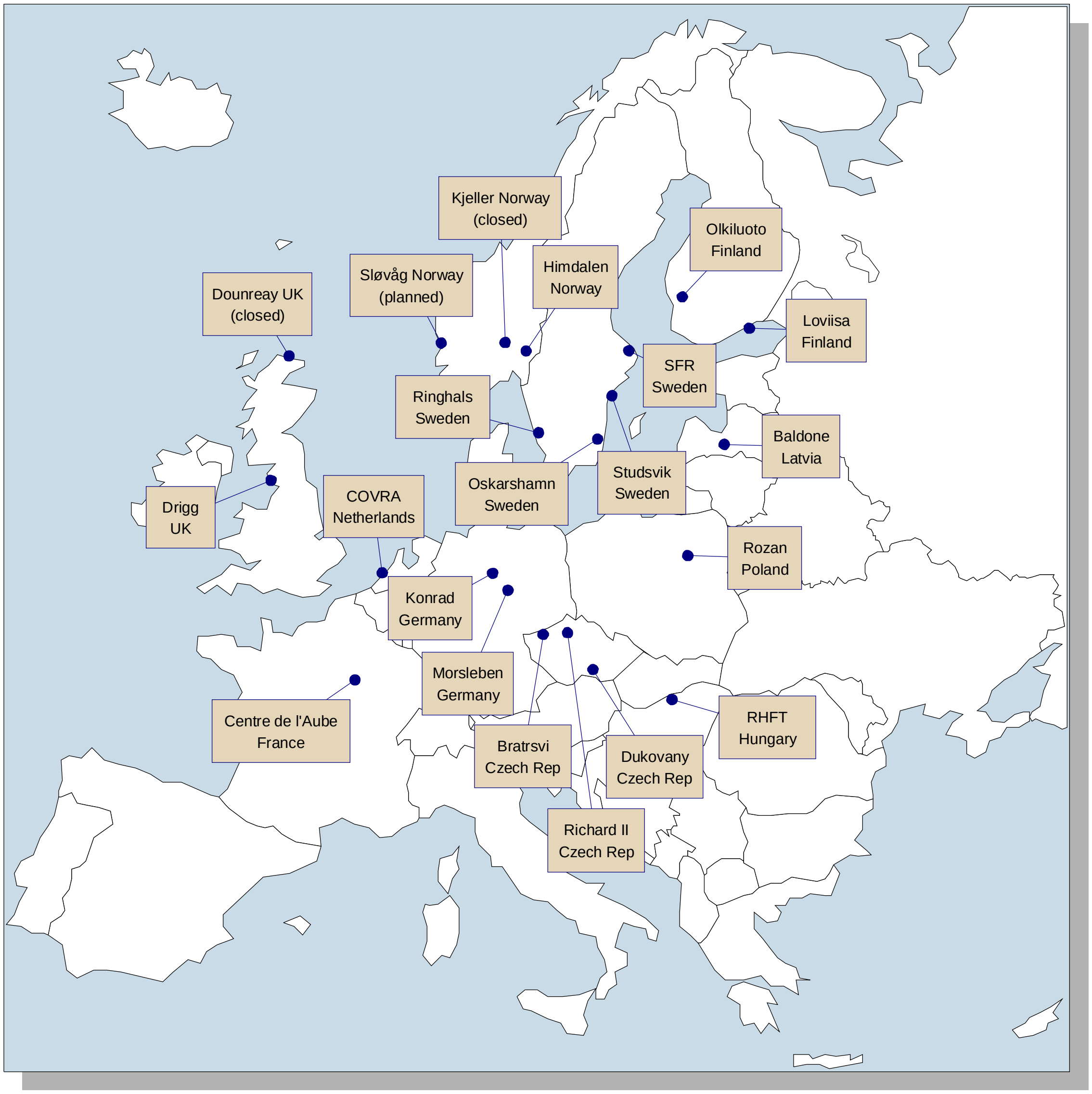
Because Norway has an oil industry with the same NORM issues as the UK, and because Norway handles a large volume of UKCS decommissioning business, it is a particularly relevant country to examine for UKCS NORM disposal.

Although Norwegian facilities have been used to decontaminate NORM from decommissioned platforms (Brent Spar and Maureen), the NORM (classified according to the Norwegian radioactivity limits) has been returned to the UK. It is understood that the UK regulators might not permit this in the future, i.e. if the waste has been sent to Norway it should remain there.

In Norway, onshore non-exempt* NORM waste is disposed of to repositories/landfill. Until recently this was to Himdalen, the national repository near IFE in Kjeller, however this facility cannot accept the NORM waste in its current form due to capacity issues. This waste is now in temporary storage at coastal bases up the west coast of Norway awaiting final disposal.

* In Norway the current regulatory limits are 10 Bq/g for each of ^{226}Ra, ^{228}Ra and ^{210}Pb; however these are being reviewed with an intention to reduce them and a “frank exchange of views” is anticipated between operators and regulators on this matter (pers. comm.).

Figure 2. Radioactive waste disposal sites in Europe



Notes
This map shows sites that are open and sites soon to open in the EU and Norway. Dounreay is also shown.
Of these sites, the following are known to have received oilfield NORM: Drigg, COVRA, Himdalen and Dounreay. Sløvåg is proposed to take oilfield NORM.
Some sites are referred to as repositories, others are referred to as disposal facilities.
Source: adapted from IAEA Bulletin 39/1

The Norwegian regulators and oil and gas industry have quantified existing amounts of NORM awaiting disposal and also the likely annual accruals from onshore decontamination and decommissioning. It is proposed to build one or two dedicated disposal facilities. One of these is 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 had just received its authorisation and it is currently understood that this will be the only facility.

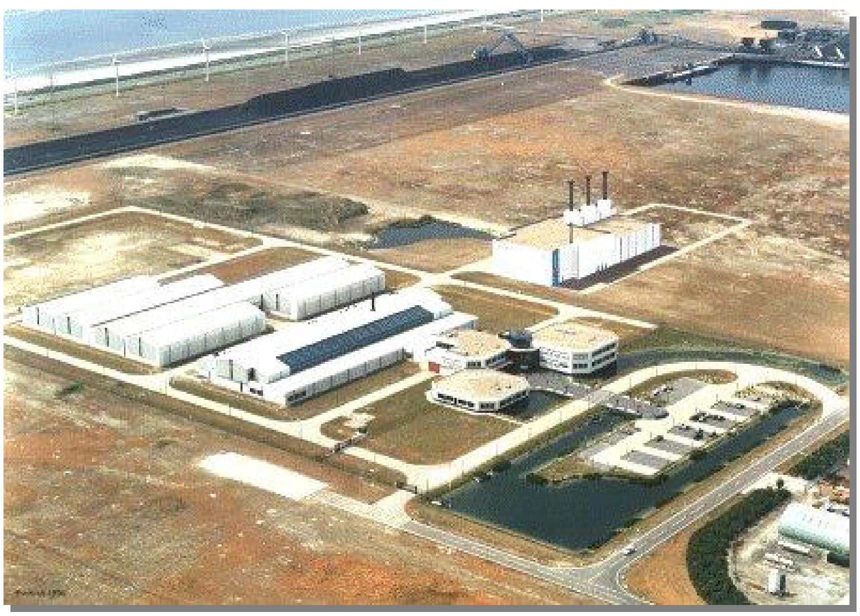
The disposal facility at Gulen will consist of a temporary storage facility, processing unit for de-oiling and conditioning the waste by cementing and a repository consisting of tunnels 5m wide and 4m high by 30-50m long running into the hillside (Norse Decom A/S 2003). The conditioned waste will have an average activity from ^{226}Ra of 5-7 Bq/g. Conditioned NORM waste will be loaded into concrete containers and these will be packed into the tunnels. When a tunnel is full it will be walled off and concrete will be pumped into the remaining void space. Total processing time is estimated at 4 weeks. The facility will be fitted with radon removal and a closed drainage system for recovering any NORM leachates. A workplace radiation monitoring system will be in place. The minimum distance between the tunnels and the surface will be 8 metres. On decommissioning of the facility the access tunnel will also be backfilled with concrete.

It is not clear whether the other proposed facility at Sokndal will now go ahead.

7.17.3 COVRA (Netherlands)

In the Netherlands there is a central repository for radioactive waste at Bosele in Zeeland (**Figure 3**). It is run by COVRA (the central organisation for radioactive waste) and accepts NORM from the oil and gas industry. This consists of a single 20 hectare site, near the docks at Vlissingen Oost. All users of radioactive material are required by law to use this facility which has treatment and storage facilities for all levels of waste. A dedicated building for treatment and handling of NORM wastes has been constructed and has been taking in NORM waste since 2000.

Figure 3. Site View of COVRA (Netherlands)



Oil and gas NORM waste is only a very small part of the intake (pers. comm. COVRA 2004). 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 several major operators who have facilities on and offshore in the Netherlands may also be able to utilise this facility under authorisation held by their Netherlands company. COVRA will also take waste generated in the Dutch sector of the North Sea from companies not registered in the Netherlands although they must apply for a Nuclear Energy Act (NEA) licence for disposal. Consequently this may be a potential disposal route for operators with operations in the Netherlands.

7.17.4 Germany - Smelting (Siempelkamp)

This is described in section 7.10. Siempelkamp has smelted NORM-contaminated steel from the oil and gas industry in the Netherlands, i.e. which has been imported, although it has not been ascertained how they would view imports from the UK.

7.17.5 USA

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. Deholm Industrial Services) as the proposed ship owner is concerned about the implications of shipping LLW. The option remains open for Denholm to use a third party shipper. MB Energy is currently involved in obtaining Export Permits from a Norwegian operator who has in excess of 30 tonnes NORM stored on open ground.

8 NORM WASTE LAND DISPOSAL FACILITIES

8.1 Introduction

Disposal of NORM into landfill, into a repository or into a land-based disposal facility is something that has occurred historically and which has particular implications in terms of licensing, government policy and available sites. Consequently it is discussed here separately to the other disposal routes, in some depth. Landfills that accept LLW have diminished in recent years, however, and it is understood that none currently exists in Scotland.

Although most NORM is disposed of offshore, and while re-injection of NORM waste offshore is attractive in many respects, there will always be cases where this is not possible for example due to physical impracticability at some facilities.

In NORM it is the alpha emitters which are the main barrier to disposals on land, due to annual disposal limits to Drigg and restrictions on alpha emitters in the VLLW category.

8.2 Special Precautions Burial and Controlled Burial

There is a subcategory of LLW which may be disposed of to landfill under the term ‘Special Precautions Burial’ (SPB) waste. This is referred to in Cm2919 as ‘controlled burial’. This is mainly used for small, irregular arisings such as from laboratories. There is reference to it also being used to dispose of power station fly ash, which is a much larger volume and activity (Nancarrow and White, 2003). This is a category described in the 1982 guidance to RSA 60; RSA 60 has been replaced by RSA 93 but the guidance is still extant. Under this guidance, which makes no distinction between naturally occurring and man made nuclides, LLW containing up to 40MBq activity from nuclides with half lives up to 365 days and 4 MBq activity from nuclides over 365 days may be disposed of to landfill using ‘special precautions’. Predominantly, the radionuclides in oilfield NORM have half-lives greater than 365 days (**Table 7**).

As an illustration, for a consignment of solid NORM having an activity of 100 Bq/g from radium isotopes, SPB would be limited to 400kg. What is not clear from the guidance is whether multiple batches can be employed in the same site, or at different times, etc.

Table 7. Main oilfield NORM radionuclides and half lives

Nuclide	Half life
^{226}Ra	1,620 years
^{224}Ra	3.66 days
^{228}Ra	5.75 years
^{222}Rn	3.82 days
^{210}Pb	22.3 years
^{210}Po	138 days

Note: for full decay series see the Phase 1 report.

SPB does not differentiate between alpha, beta and gamma emitters but is based solely on half life. The lower limit of 4MBq per container would apply to NORM because of the ^{226}Ra, ^{228}Ra and ^{210}Pb.

The ‘special precautions’ used in SPB disposal regarding packaging are “waste should be transferred to the disposal site in a plastic or multilayer paper sack” which forms part of the disposal license for the producer of the waste and is not a condition for the landfill operator. The sacks must be buried to a depth of around 2m in existing waste with immediate infilling of the hole. There is no reference to the total number of sacks that may be disposed of in one consignment. Most of the authorizations for SPB disposal were granted ten or more years ago and were granted to the waste producer not the landfill site operator, however the EA now prefers the landfill site operator to hold the authorisation with the waste generator having a separate transfer authorisation. This is in line with commercial incineration of radioactive waste. This means LLW producers will be reliant on landfill operators to ensure that this method of disposal is available. Enquiries made with some local authorities and with the landfill team at SEPA suggest that this is a rarely used disposal route and something of an anachronism relating to local authority landfills, of which there are now very few. It was not viewed as a preferred routine route for the disposal of oilfield NORM even if sites were available.

For high volume, less active sludges e.g. from terminal storage vessels such a disposal route might be an alternative to the very costly disposal to Drigg.

Cm 2919 states that controlled burial to be discouraged for the nuclear industry but to be available for small users. Potentially this would apply to one-off disposals from onshore terminals, but in any case disposals are subject to agreement of the landfill site operators. There had been a decline in number of landfill sites willing to take radioactive waste now that an authorisation is required, and there is a widespread hesitance to take radioactive waste for fear for future liability and public concerns over radioactive waste disposal (RWMAC 2003, Nancarrow and White 2003 and various pers. comm.).

8.3 Landfill sites for NORM waste

Exempt NORM waste may be landfilled without RSA authorisation, i.e. in the same manner as non-radioactive waste, and it is understood that this is common practice (various pers. comm.). The key issue is the disposal of non-exempt LLW (referred to here as ‘LLW’).

There are a limited number of RSA 60/93 authorisations in England that currently permit the disposal of solid LLW to landfill sites. These authorisations are granted to the owners of the premises generating the wastes, rather than to the sites receiving them for disposal. The authorisations are specific and only permit the disposal of specified wastes from specified premises to a specified landfill site in accordance with specified conditions. It is the intention (EA, 2003 and pers. comm. P. Merrill, EA) that licensing will shift towards the landfill site, and this may take the form of a disposal authorisation for the landfill site and a transfer authorisation applying to the producer.

In England and Wales, the number of landfill sites named in RSA authorisations for the disposal of LLW was 12 in 1997 (Hansard, 1997), 9 in April 2003 (Hansard, 2003) and seven in December 2003 (EA, 2003). It was projected that from April 2004 only six controlled burial authorisations would remain and these are included in the list in **Table 8** along with two others that no longer take LLW. There are a further three sites named in authorisations for the disposal of VLLW.

Table 8. Landfill sites in England and Wales taking radioactive waste

Landfill site	Landfill designation and timescales	Nature of Radioactive Waste	Comments
Arpley Landfill, Warrington	Interim hazardous, but likely non-hazardous Lifetime to about 2023	Small quantities of hospital waste, generally non-hazardous	No issues
Milton Landfill, Cambridgeshire	Interim Hazardous, but will be non-hazardous Lifetime to at least 2013	Important route for hospital waste, generally non-hazardous	No issues
Cowpen Bewley, Billingham, Cleveland	Non-hazardous Limited life – approx 9 years	Waste was disposed of from Tracerco, but is now sent to Shanks at Fawley	Controlled burials have ceased
Clifton Marsh, Preston, Lancashire	Non-hazardous, with mono-cell for some hazardous waste Lifespan 12 – 15 years	Important route for building waste and process wastes, some hazardous	Lined with leachate management.
Asham Quarry Beddingham, East Sussex	Non-hazardous 4 years maximum remaining life	University and lab wastes, generally non-hazardous	No issues
Hilts Quarry, Crich, Derbyshire	Non-hazardous Landfill will close from 9 April 2004	Disposals have ceased	No future issues
Magnesium Elektron Swinton, Greater Manchester	Non-hazardous	Magnesium hydroxide sludges with Th contamination, non-hazardous	No issues
Braziers Landfill Ware Quarry" Hertfordshire	Non-hazardous Life of site probably limited	Contaminated lab equipment	No immediate issues Decay store may be built when landfill closes

Note: 'hazardous' and 'non-hazardous' refer to the likely property if the waste was *not* radioactive.

In Scotland, 12 landfill sites were listed in 1997 as being named in RSA authorisations for the disposal of LLW. SEPA was contacted (pers. comm. S. Donaldson 2004) and believed that two sites continued to accept LLW, Melville Wood and Braehead. The operators of these sites were tracked down and it transpired that Melville Wood had been transferred from the local authority ownership to Viridor, and Viridor stated that radioactive waste would not be accepted. Braehead had closed with wastes being diverted to Dunbar landfill operated by Edinburgh unitary authority; Dunbar landfill stated that it took VLLW (specifically university gloves) but not LLW.

Consequently it is to be concluded that no landfill sites in Scotland currently take LLW. Given that most of the UK operators and service companies are based in Aberdeen, and that most of the NORM waste is generated from the Central and Northern North Sea (i.e. any wastes are likely to be landed in Scotland), this is an important shortcoming in terms of the proximity principle and also in terms of present and future differences in regulation north and south of the border.

8.4 Drigg disposal facility

British Nuclear Fuels plc is authorized to dispose of low level radioactive waste at a disposal facility on the Cumbrian coast near the village of Drigg, NW England, 6 miles south of BNFL Sellafield. The facility, known as 'Drigg' is currently the only onshore disposal facility for non-exempt NORM waste (LLW) in the UK other than from decontamination services. It is a disposal facility for radioactive waste; it is not a repository, i.e. waste may not be recovered or inspected once placed nor is it a 'landfill' as the waste is exempt from EPA 1990 and the WFD.

Drigg is authorised under RSA 93 by EA. The authorization is currently under review (as of September 2003) and no new authorization is likely to be granted before 2005. Additional disposal space is being applied for. It is currently estimated that Drigg will be in use until 2050 after which a permanent site cap will be emplaced

Drigg receives waste according to its Conditions For Acceptance (CFA) (BNFL, 2002a), which are expanded on in a Guidance Note (BNFL, 2002b). The CFA are numerous and include a requirement that waste will only be accepted if alternative means of disposal are not available, such as municipal landfill sites or Special Precautions Burial (SPB), i.e. the disposer must provide evidence that alternative options have been exhausted.

Drigg has been in use since 1959. Since 1995 LLW has been containerised and placed in an open concrete vault. Radioactive waste has to be conditioned (cemented) before Drigg will accept it according to its CFA. Leachate tests are run on the cemented product to check that no activity is escaping.

Drigg can accept LLW under its present authorization i.e. wastes that contain radioactive material with activity above regulatory levels but not exceeding 4 GBq/t alpha activity or 12 GBq/t beta/gamma activity. The authorization sets limits on certain radionuclide groupings including ^{226}Ra/^{232}Th which will affect how much NORM waste can be accepted. The <u>annual</u> limit activity from ^{226}Ra/^{232}Th is 30 GBq. These limits are not likely to be increased as they have now been included in the Drigg post closure safety case (BNFL 2002c), amendment of which would be present many difficulties.

The activity of current onshore oil industry arisings of non-exempt ^{226}Ra activity (onshore decontamination and decommissioning) are estimated at 1.1 GBq per year. Hence Drigg could in theory comfortably accept all non-exempt oilfield NORM that is returned to shore. In practice, however, many commentators speculate that the capacity may well be completely taken up with nuclear and MoD decommissioning waste, or at least reserved for that purpose and so not available. This is a key concern for the oil and gas industry, along with other small users, who are reliant on an outlet being available but who have relatively small volumes of waste.

Costs are understood to be in the order of £1,000-£10,000 per metre cubed (Nancarrow and White, (2003), British Nuclear Energy Services website and various pers. comm.) and this can vary widely depending on the nature of the waste and it's compactability.

8.5 Future landfill capacity

Clearly there is a dearth of landfill sites that receive LLW or VLLW. With the implementation of the Landfill Directive, the number of landfills in general is significantly reducing, especially hazardous waste landfills. Availability for NORM wastes is therefore rapidly reducing.

If it were to be decided that disposal of radioactive waste with other hazardous waste could not take place, unless dedicated landfill sites were designated, then all non-exempt LLW would have to be disposed of at Drigg. The future of VLLW (dustbin disposal) is also currently being reviewed, i.e. it is uncertain.

RWMAC has noted that there is increasing reluctance on part of landfill owners to take on radioactive waste for fear of future liabilities and because of potential adverse public reaction, and this has been confirmed through discussions for this study. If radioactive waste is disposed of to a landfill, most landfill operators are committed to public consultation even if its only VLLW and LLW. This is more likely to be the case for large companies where reputational issues are a major issue. Smaller concerns might be more amenable, but overall the private sector cannot be relied on to provide landfill capacity for radioactive wastes.

8.6 New facilities for LLW including NORM

8.6.1 General

There is the possibility of a new facility being planned to handle LLW from nuclear decommissioning. It is not considered economic just to take radioactive contaminated land waste so any facility will be open to other types of LLW. The timescale is for opening new facilities is relatively long: at least 2-3 years before a new facility would be ready for use.

Development of new facilities needs to be considered in the context of with the UK government's decision making plan on arrangements for solid radioactive waste which is to be completed by 2007.

NORM waste has the perceptual advantage of being "natural" and while economics militate against construction of a NORM-only facility public perception may not. The new Gulen facility in Norway (section 9.9.2) will only receive NORM. Much public concern over radioactive waste is a legacy of past practices of the MOD and nuclear industry that have now ceased. In addition some operators may have reputational reservations over association with a nuclear waste facility.

There is currently no disposal site in Scotland for non-exempt NORM waste, and a very small number in England and Wales. 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.

In general, it is understood that several companies have undertaken market research over the last 3-4 years with a view to entering the market for decontamination and NORM disposal services (Drain Brain, AEA Technology and the companies mentioned in the following subsections) and much of this interest is still current. The main barriers, however, were a combination of:

- High capital investment
- No guarantee of business
- Lack of information on the size of the market

Certain waste companies were consulted that were known to have a particular interest in NORM/LLW disposal and who were considered to be representative of the broader industry. Remarks made here about individual companies should not be taken as an endorsement or advertisement and there may be many other interested parties amongst the hundreds of waste contractors in the UK.

A key factor in any business case for such a facility is being able to forecast that revenues will provide an acceptable return on the investment, which includes construction costs but also the (probably) substantial public relations exercise and licensing discussions that will be required. Several contractors noted that business cases could not be made unless there was some guarantee of waste quantities and charges.

8.6.2 ALCO Waste Management Ltd.

ALCO is a waste management company with a landfill site in Cumbria. They are actively considering applying for an RSA authorisation to be able to take non-exempt LLW and have had positive discussions with the EA. ALCO states that Drigg has also encouraged them to take oilfield NORM. They have designed a cell set in self sealing boulder clay for this waste. They have carried out the "Regulation 15" risk assessments under the Groundwater Regulations (now part of PPC permitting). Around 4 years ago ALCO approached North Sea operators in Aberdeen with their alternative to current arrangements but received little interest, and the project was shelved because of the lack of a reliable market. They report that the plan will require substantial investment to obtain permission (in addition to construction). ALCO has recently been re-consulting on the issue and are waiting to assess the size of the NORM disposal market.

Current exempt waste intake is unknown.

8.6.3 RWE Nukem

RWE Nukem is a company specialising in radioactive wastes and advisory services. It has been planning to open a NORM decontamination and disposal facility at a site in the North of Scotland. This has been on hold, however, subject to discussions with the regulator that an application would be acceptable in principle before proceeding further.

8.6.4 Shanks Waste Services

Shanks Waste Services expressed interest in developing a LLW disposal site and stated that they had been following the market for some years. They believed that the landfill disposal of oil industry NORM was a real possibility but that it would require significant investment from the industry and/or guarantees of income due to the reputational risks involved. Shanks were consulted as being representative of the major waste companies and other companies may well have a similar outlook.

8.6.5 Denholm Industrial Services

Denholm Industrial Services is a waste contractor specialising in the offshore industry and has had serious discussions about securing salt caverns for hazardous waste disposal and potentially NORM disposal. This possibility has not progressed, however, for precisely the reasons given in 8.6.1.

8.7 Discussion - Exempt NORM waste

Disposing of exempt NORM waste to a conventional landfill is permitted (Section 4.5) and takes place at present. Many landfill operators, however, may prefer not to handle even exempt radioactive waste for public liaison reasons. The site operator would require proof from the waste producer that it was exempt and there have been reported incidents where non-exempt material has turned up in batches of exempt waste for which a disposal route had to be sought. This places an onus on both the producer and the receiver to sample and analyse comprehensively. This requirement will increase via new characterisation rules being brought into place in 2006 via the Landfill Directive.

Nevertheless the continuing disposal of exempt LLW to landfill is viable.

8.8 Discussion - Non-exempt NORM waste

Currently there is only one facility in the UK authorised for final disposal of non-exempt LLW and that is Drigg. There are restrictions on capacity, and although most of the current onshore NORM production could be accommodated (in theory) at Drigg, it would not be able to take all NORM waste produced on the UKCS if sea disposal was to be stopped. This assumes that the entire Drigg capacity for radium-containing wastes is available for the disposal of NORM waste, when in fact MoD and nuclear industry wastes may take precedence. It is reported that Drigg is not likely to increase the radium/thorium limit as it is understood that this would necessitate changes in the Post Closure Safety Case which has now been accepted (pers. comm. 2004).

It would be advisable for the UK government and regulators to obtain assurance from Drigg as to the volume and activity of UKCS NORM waste that they will accept into the future.

There remains a significant quantity of NORM waste stored at Dounreay from the AEAT NORM decontamination operation which ceased in December 2002. Discussions over the fate of this material are understood to be ongoing. Although it is not explicitly mentioned in the 2001 UK Radioactive Waste Inventory (DEFRA, 2002e) there is reference to 1,400m^3 of LLW at Dounreay that is unsuitable for disposal at Drigg. Mention has been made of proposals for a LLW disposal facility at Dounreay (for nuclear decommissioning) but no details are available and even if it is a possibility it may well not accept non-nuclear wastes.

The ALCO proposal appears to be well advanced but requires some financial commitment from potential users for it to go ahead. It is understood that some operators are currently having discussions with ALCO. RWE NUKEM has investigated a decontamination facility and permanent storage facility in the North of Scotland but has not begun seeking approval for this. As most of the NORM waste is produced offshore Scotland and is landed at Aberdeen or Peterhead it would seem expedient to have a facility for non- exempt NORM waste disposal in Scotland to avoid transporting waste around the UK. The plans of other interested waste companies are perhaps less advanced, although investigations for this study were not exhaustive.

The current situation in Scotland is that Scotoil's nearshore discharge pipe is the disposal route for all* NORM waste from onshore decontamination. There is speculation over how much longer, in the light of increased OSPAR and public interest in radioactive discharges, the regulator can allow this disposal route to operate even though available dose risk modelling shows no significant risk to the general public.

*A small amount of NORM is removed from Wytch Farm equipment at Winfrith by RWE NUKEM.

9 DOSES

9.1 Introduction

An important, although not the only, factor in determining preferences in disposal options is the (involuntary) dose to the public that is caused by the waste. This is a key element of determining the Best Practicable Means for a waste disposal option under RSA authorisations. This is usually distinct from the occupational dose to workers, which is monitored and controlled by working practices under IRR99 and which is a voluntary risk.

Existing assessment methods and standards for radiological impact assessment focus mainly on measures for human radiological protection and do not specifically address risks to the environment. This is based in the ICRP assumption that measures to protect human life are sufficient to protect the environment. Dose optimisation has been based on the principle that human exposure should be kept As Low As Reasonably Acceptable.

This section discusses attempts to quantify relative doses for different disposal pathways. General background on the effects of radiation, potential impacts and exposure pathways for NORM discharged into the environment are included in Appendix 1 along with further background to the dose estimates presented in this section.

9.2 Dose information for waste disposal options

There are number of proprietary models which calculate dose to critical groups by calculating the partitioning of nuclides between surface sediments and overlying water mass. The more sophisticated of these (box models) subdivide the area into compartments and look at partitioning of nuclides between compartments as well as between water and sediments.

Discharge to sea is currently the main disposal route for solid oilfield NORM and NORM in produced water on the UKCS. There is currently no requirement from the regulator to carry out a radiological environmental impact assessment for these offshore discharges although the nearshore discharge is subject to more scrutiny. For this reason there is very little available baseline data on NORM nuclides from the UK sector.

A recent, and detailed, analysis of doses from NORM wastes from the non-nuclear industries, including oil and gas, is given in Chen *et al* (2003). This is a major study into doses from NORM industries in the EU funded by the European Commission and includes modelling of doses from individual radionuclides and their progeny released into different media. The study examines doses into the marine environment, rivers and the atmosphere. The dose coefficients arrived at in the report are used here as a basis for comparing different disposal options and the relevant radionuclide series (or sections thereof). This process arrives at an indicative dose that is sufficient to distinguish between options; it is not a detailed dose calculation of the kind that would be required to justify an authorisation per EA *et al* (2002).

The dose coefficients used are given in Appendix 1

The coefficients in **Table 10** may be applied to the current annual arisings of NORM from the oil and gas industry as noted in Section 3.2. The 'total activity', however, cannot be used to calculate the dose, and it is necessary to specify the concentrations of ^{228}Ra, ^{226}Ra, ^{210}Pb and ^{210}Po for each disposal stream. To do this, data from Phase 1 has been analysed to arrive at average concentrations for each disposal stream. These are summarised in **Table 10**. Note that there is relatively little data on ^{210}Pb and ^{210}Po, and values have been assumed based on these radionuclides being in equilibrium and ^{210}Pb being in proportion to ^{226}Ra using the values for ^{210}Pb analysis from the offshore NORM dataset.

Table 9. Typical NORM characteristics used to estimate doses

		^{226}Ra	^{228}Ra	^{210}Pb	^{210}Po
Produced water	Sample size	86	86	0	26
	Average Bq/g	0.0028	0.0022	0.0001[1]	0.0001
Scale removed onshore	Sample size	898	898	287	287
	Average Bq/g	29.4	13.3	13.0	12.6
NORM removed offshore[2]	Sample size	333	333	8	0
	Average Bq/g	1.8	0.9	0.9[3]	0.9
Solid scale removed offshore	Sample size	14 years[4]	14 years[4]	0	0
	Average Bq/g	8.6	5.8	4.2[5]	4.2[6]
Decommissioning sludges	Sample size	6	6	0	0
	Average Bq/g	4.4	2.8	2.2[5]	2.2[6]

NOTES:

All averages are mass-averaged, i.e. the sum of the activities (Bq) divided by the sum of the masses (g), rather than the average of the sampled specific activities (Bq/g).

1. Unknown; assumed equal to ^{210}Po
2. Includes scale, sludges, sand, wax
3. Based on 'less than' values, i.e. an overestimate
4. These are averages of 14 years' totals from an oil platform; the number of samples is not known
5. Unknown; set in proportion to ^{226}Ra using 'NORM removed offshore' data
6. Unknown; assumed equal to ^{210}Pb

The results of the dose calculation are given in **Table 10** and illustrated in **Figure 4**.

Re-injection can be included in the assessment by assuming a zero dose, corresponding to an assumption that no material escapes from the re-injection stratum.

Chen *et al* (2003) neglect, however, to consider doses from disposals to land (e.g. landfill) from the oil and gas industry despite this being commonly used, especially for terminal wastes. Doses from disposal to sewer are discounted as being not relevant to the NORM industries as the sewer is not suited to the waste characteristics. Consequently it is extremely difficult to come to a conclusion on how the land-based disposal options for oil and gas NORM, of which there are several (in particular, landfill), compare with the aquatic and atmospheric routes.

Exempt radioactive wastes disposed of in a landfill that is compliant with the Landfill Directive requirements (which will shortly equate to all landfills) may dissolve into the leachate, particularly in the acid conditions that prevail in many landfills. The landfill will have a properly engineered containment system and virtually all the radionuclides should remain in the leachate, although a very small amount may escape to groundwater. Leachate must be treated and may only be released to surface waters in compliance with a consent, and Cm2919 (1995) states that controlled burial of radioactive waste in landfills should be accompanied by radiological analysis of the leachate, although it is not clear how the results should be acted upon. Once the landfill is completed and capped, the amount of leachate will be small. The implication of this is that some of the radioactivity remains in the landfill, some is discharged to surface waters and a very small amount discharged to groundwater. The proportions of radionuclides over time that will pass into the surface water and groundwater depend entirely on site-specific issues such as the chemistry inside the landfill (which in turn depends on the type of waste, gas extraction, leachate system, age, etc.) and the physical form of the radioactive waste deposited (e.g. in bags, containers, cement-conditioned), amongst other factors. Even in a specific site this may be very uncertain due to inhomogeneity of the waste.

The situation is slightly different for a LLW disposal facility regulated under RSA. Such facilities are outwith the Waste Framework Directive and do not have to comply with the Landfill Directive requirements. Consequently the containment and drainage arrangements may be quite different, subject to a radiological risk assessment. For example, the Drigg disposal facility has no containment system or low permeability cap, rather it relies on the encapsulation of wastes in cement to limit the mobility of radionuclides over a long period. While the post-closure safety case for Drigg contains radiological dose estimates over certain time periods, it is not possible to extract the dose attributable to particular radionuclides or examine the rationale in order to make a separate estimate for oil industry NORM.

A possible way of comparing risks from landfills using the above methodology would be to assume that a proportion of the radionuclides are discharged to surface water in treated leachate, which would be expected. The profile of radionuclides released over time would be extremely difficult to predict given the uncertainties expressed above, but from a few simple calculations, it can be seen that the overall comparison is extremely sensitive to the quantity of radionuclides that might be released from landfills (including disposal facilities such as Drigg). The reason for this is that the release is most likely to be to a small watercourse and the relevant dose coefficient is 3-5 orders of magnitude greater than either the small marine or large marine compartments that are relevant to most of the other options. For example, if it is assumed that 10% of the radionuclides in landfill are released over 100 years, the annual 6 GBq of activity in terminal wastes would have approximately the same dose as the 9840 GBq in all the produced water in the UKCS.

Although incineration is not currently practised, it can be examined using this methodology. If the estimated annual 500 tonnes of oily terminal wastes was incinerated in a 50m stack, the predicted dose would be around 2µSv. Although this is still less than 'trivial' levels, it is of the same order of magnitude, and it is much higher than the marine disposal options. A more detailed site-specific assessment would be prudent if this was proposed in practice.

Other figures for doses from nearshore disposal of oil industry NORM that are in the public domain shown in **Table 11**. The method of calculation is not known and the data is not endorsed by the authors of this report; nevertheless it supports an extant authorisation.

Table 10. Dose calculations for disposal pathways

Description of NORM	Annual mass tonnes	Annual activity GBq	Compartment	Annual Dose nSv
Produced water to sea (offshore)	282,000,000	9840	Large marine box	40
Reinjection	7,500,000	278	Reinjection	0
Produced water to sea (terminals)	220,000	6	Small marine box	2
Offshore decontamination	1,300	23	Large marine box	0.1
Workovers	35	4	Large marine box	0.02
Onshore decontamination	36	9.5	Small marine box	4
Terminal decontamination	500	6	Landfill (Other)	unknown
	Mass per facility tonnes		**Compartment**	**Annual Dose nSv**
Platform decommissioning (offshore)	15	1.5	Large marine box	0.01
Platform decommissioning (onshore)	1.8	0.2	Small marine box	0.1
Pipeline decommissioning (onshore)	4	unknown	Landfill (Drigg)	unknown

Figure 4. Dose comparison for disposal pathways

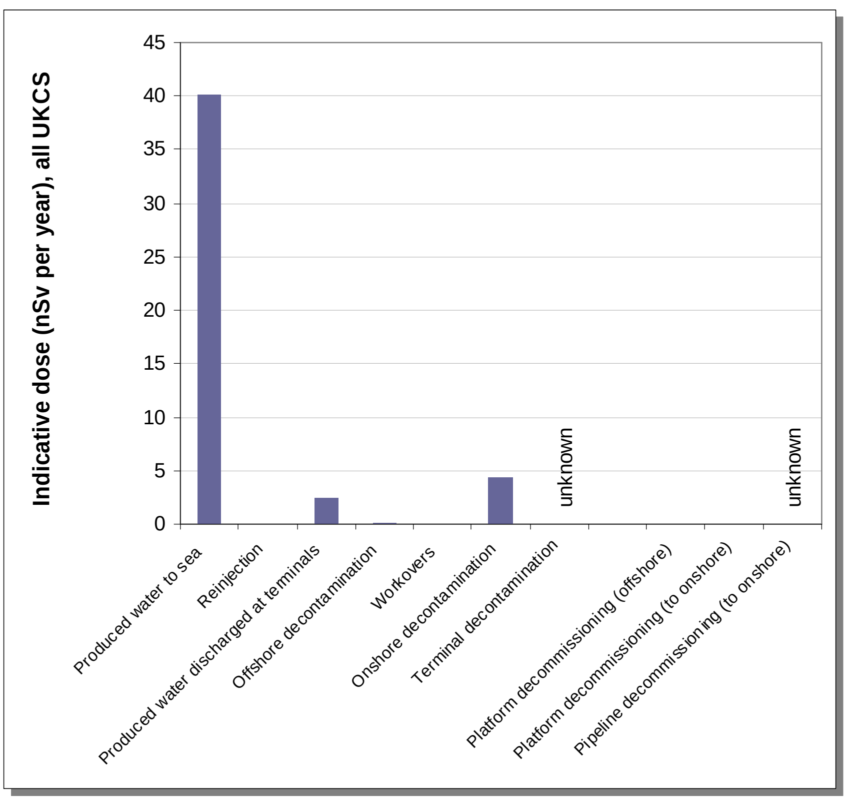


Table 11. Dose calculations for a nearshore discharge

Exposure route	Dose
Exposure to individuals using the pier from the presence of the pipeline.	Committed external dose equivalent (CEDE) 0.002 mSv (Ra 226) and 0.001 mSv (Pb 210)
Exposure through external contact with liquid effluent.	2.38 x 10^{-7} mSv/h for total immersion in undiluted effluent.
Exposure through ingestion of liquid effluent.	From drinking 2 litres of undiluted effluent (highly improbable worst case) CEDE Ra 226 0.05 mSv and for Pb 210 0.2 mSv
Exposure though inhalation of spray.	0.0006 mSv/yr Ra 226 0.0005 mSv/yr Pb 210
Ingestion of contaminated seafood	From annual consumption of 10 kg seafood from the discharge area. 0.05 mSv/yr

Of these, only drinking the effluent takes the dose above the IAEA ‘trivial’ level of 10 μSv per year.

Some dose figures have been found in the literature but these relate to practices in the US and may not be directly comparable to the situation in the UK. There are reported below. Smith *et al* (1996) at the Argonne laboratory in the US carried out preliminary dose risk assessments of the main US NORM disposal routes namely:

- Subsurface re-injection
- Down hole encapsulation
- Smelting
- Shallow burial

Dose estimates were based on average total radium activity for US scales and sludges and used proprietary approved models to calculate the doses.

Landspreading: this was the worst option and lead to highest worst case exposure of public of 30 mSv/yr. The average case was 3.4-0.6 mSv/yr. This is no longer a permitted as a disposal method in US.
Smelting: the dose to the public from smelting 50,000 tonnes of contaminated scrap metal was calculated as 0.004 μSv/yr. The dose to a slag worker was calculated to be 1.4 mSv/yr.
Shallow Burial: the disposal of NORM contaminated scrap metal was calculated on the basis of a volume of 5,700 m^3, mixed with an equal volume of clean soil and covered by a 0.5m thick soil layer. Access to the site was assumed to be restricted for 30 years. The dose calculated for subsequent residential use (worst case) was 0.8mSv/yr.
Underground injection: based on public exposure from contaminated groundwater at different distances from the disposal well, 0.1 μSv/yr a year was calculated and was considered insignificant. This is not comparable to subsurface injection offshore in the UKCS where drinking water aquifer contamination would be almost impossible.

It is concluded that landspreading and shallow burial represent doses to the public that would require considerable further assessment and justification from a radiological viewpoint if proposed in the UK.

The remaining dose values, although indicative, are nevertheless well 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.

To put these dose levels into context, the annual average exposure per person in the UK is 2.62mSv (NRPB, 2002) of which 50% is due to ^{222}Rn in the home.

9.3 Conclusions

The following main conclusions are drawn:

- Doses from offshore reinjection, salt cavern and marine disposal options are trivial and the doses do not provide a strong argument for differentiating between these options. Onshore salt cavern disposal may require a site-specific assessment to demonstrate risks to groundwater are negligible.
- Doses from landfilling are unknown, and although they may well be trivial, a site-specific assessment would be recommended.
- Doses from incineration may be small but significant and a site-specific assessment would be recommended.
- Doses from smelting are not well known, but involve a combination of landfill and atmospheric discharge, and it is reasonable to conclude that while may well be trivial, a site-specific assessment would be recommended.
- Doses from landspreading are unacceptable unless there is no other option available.

Additionally,

- It is not clear that maceration of scale offshore has any benefit in terms of dose.
- Virtually all radium in NORM discharged to sea will exist in the form of a highly insoluble sulphate that does not readily pass up the food chain.
- A significant proportion of the whole dose from radium sulphate scale is from polonium and lead, which are much more soluble and bioavailable than radium.

10 RANKING OF NORM MINIMISATION AND DISPOSAL OPTIONS

10.1 Introduction

The disposal options for oil and gas NORM waste disposal as practiced in different areas of the world have been described in the foregoing sections. In this section of the report the options are compared using a common set of risk criteria for their suitability for UKCS oil and gas NORM disposal.

The disposal options considered below are:

- Sea disposal
    - Offshore discharge
    - Nearshore discharge
- Re-injection
- In situ downhole disposal
- Encapsulation and disposal downhole in disused wells
- Onshore built repository
- Onshore landfill
- Landspreading
- Smelting
- Incineration
- Disused mine disposal
- Disposal in salt caverns
- Sewer
- Export

Some of these are more obviously unsuitable than others but for the sake of comparison all have been ranked in the tables. Where there are unknowns associated with some disposal routes these have been indicated.

Risk Criteria
In order to rank the potential options a set of criteria has been developed which allows options to be scored in terms of the following criteria. These will incorporate health, safety, environment, sustainability, public and reputation issues.
These are summarised below:

- 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 ranking is based on ALARA principles (as low as reasonably achievable). In order to do this tolerable and intolerable HSE risks are identified, initially, using the UKOOA risk assessment matrix. None of the options present an intolerable HSE risk and this matrix is not sufficiently discriminatory to rank the risks of the listed disposal options. 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 what is BPM in best professional judgement. The ranking criteria for each aspect are listed in the relevant sections below.

Sustainability covers a wider range of issues dealing with the long-term future of the option these are dealt with in the long tern viability ranking but the following points can be made.

- 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 the following sections 11.2.1 to 11.2.7 and a summary of the overall ranking for each disposal option with respect each aspect is shown in a table at the end of each section. A final summary table of overall ranking of disposal options is shown in the summary **Table 21**.

As agreed in the Scoping Report for this project 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 disposal options are scored for each of the aspects and assigned a colour to give a generic picture of the ranking for that particular aspect. These are qualitative best judgements. Qualifying comments are included in the aspect tables. The decision not to apply numeric ranking values is deliberate. The use of colours is considered a more appropriate ranking indicator for this level of exercise as the use of numeric values can imply equivalence of ranking between different and not directly comparable aspects. In addition, totalling of numerical values from each aspect ranking might not reflect the overall, final ranking as there are qualitative issues to be considered.

Finally although a number of waste reduction methods, NORM prevention methods are described in this report they are not included in this disposal option ranking. Those already practiced 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 below.

10.2 Risk ranking

10.2.1 Health and Safety Risks: Radiological aspects

The main health and safety risk specific to NORM disposal will be the degree of radiological exposure and this has advised the ranking, for this section. Potential; exposures are discussed in detail in section 10 and are divided into:

- Occupational exposure
- Public/ Involuntary exposure

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 but not NIL. The occupational exposure risks are identified as:

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

All are indicated as low/acceptable, except for landspreading.

The disposal routes can be differentiated by the potential for involuntary exposure to other critical groups such as the public e.g. through ground water contamination from leachate or to fishermen e.g. from sea discharge.

Table 12. Option ranking by health and safety risks

Ranking

minimum-acceptable
low -acceptable
not ALARA , some degree of exposure though below tolerability limit.

Option	occupational	public	Comment
Sea disposal offshore discharge			• Critical groups identified as offshore workers (occupational exposure) and fishermen catching potentially contaminated fish, Public exposure potential through fish/seafood consumption.
Sea disposal nearshore discharge			• Low but present risk of public exposure due to discharge to nearshore environment
Re-injection			• Low risk of public exposure when carried out in deep subsurface offshore.
In situ downhole abandonment			• Low risk of public and occupational exposure (never brought to the surface) • Isolation in subsurface
Encapsulation and downhole disposal			• Low risk of public exposure • Isolation in subsurface
Onshore built disposal facility			• Potential public exposure though transport, potential leachate
Onshore landfill			• External radiation (offshore handling/ transport/landfill site workers) • inhalation (offshore handling/transport/ landfill site workers, public from site leachate) • ingestion (offshore handling/transport/ landfill site workers, public from site leachate)
Landspreading			• Handling exposure (off and onshore workers) • External radiation (off and onshore workers) • Inhalation (off and onshore workers) • Ingestion (off and onshore workers) • groundwater contamination (ingestion risk) public
Smelting			• Handling exposure • External radiation (on/ offshore workers handling the NORM , steel workers) • Ingestion of particles (on/ offshore workers handling the NORM , steel workers)

			• Inhalation of gaseous and fine particulates (on/ offshore workers handling the NORM, steelworkers, public-stack emissions)
Incineration			• External radiation (off and onshore workers) • Inhalation (off and onshore workers) • Ingestion (off and onshore workers • Inhalation of gaseous and fine particulates (plant workers, public -stack emissions) • Contaminated land, deposition of particulates
Disused mine workings			• Groundwater contamination (ingestion risk) public
Disposal in salt caverns			• External radiation (off and onshore workers) • Inhalation (off and onshore workers) • Ingestion (off and onshore workers) • Low public exposure
Sewer			• Handling exposure (off and onshore workers) • External radiation (off and onshore workers) • Inhalation (off and onshore workers) • Ingestion (off and onshore workers) • Groundwater contamination (ingestion risk) public • Risk from contaminated land (sludge spreading) worker and public
Export			• External radiation (off and onshore workers) • Inhalation (off and onshore workers) • Ingestion (off and onshore workers

10.2.2 Environmental impacts

There is some potential for local dose to benthos if there is settling of NORM particles under the sea discharge and there is some evidence from the Gulf of Mexico that this does occur over a very limited area. There is a lack of baseline data on NORM nuclides in bottom sediments and in the water column surrounding offshore facilities, without which this effect cannot be eliminated for offshore sea disposals.

All disposal options will show up as limited local effects on the UKOOA risk assessment matrix therefore they have to be differentiated within that category. Greater or lesser local effects depending on longevity of effect and which part of the environment is affected for this reason this aspect has been ranked using the matrix below.

Table 13. Environmental impacts

Ranking

- No significant effects (lightest fill)
- Some effect possible /likely (medium fill)
- Potential noticeable effects (darkest fill)
- Box not filled = no anticipated effects

Area of environmental impact							
Climate	**Air quality**	**Water quality**	**Seabed**	**Benthos**	**Marine life(general)**	**Wildlife (land)**	**Drinking water (Onshore)**
Sea disposal offshore discharge							
		No significant effects	Some effect possible /likely	Some effect possible /likely	No significant effects		
Sea disposal nearshore discharge							
		Some effect possible /likely	Some effect possible /likely	Some effect possible /likely	No significant effects		
Re-injection							
	No significant effects						
In situ downhole abandonment							
Encapsulation and downhole disposal							
	No significant effects						
Onshore built disposal facility							
	No significant effects	No significant effects				Some effect possible /likely	Some effect possible /likely
Onshore landfill							
	No significant effects	No significant effects				Some effect possible /likely	Some effect possible /likely
Landspreading							
	Some effect possible /likely					Potential noticeable effects	Potential noticeable effects
Smelting							
	Some effect possible /likely					No significant effects	
Incineration							
	Some effect possible /likely					No significant effects	
Disused mine disposal							
	No significant effects					Some effect possible /likely	Potential noticeable effects
Disposal in salt caverns							
	No significant effects					No significant effects	No significant effects
Sewer							
	No significant effects	No significant effects			No significant effects	Some effect possible /likely	Some effect possible /likely
Export							
	No significant effects					No significant effects	

The table above is intended to give an indication of which areas of the environment are likely to be impacted and an indication of degree of impact. A detailed assessment is not appropriate at this stage as it would need to be site specific. Table 14 shows that, with the exception of landspreading and mine disposal, impacts are minor. Re-injection offshore is environmentally the optimum disposal method.

If radioactive environmental contamination (seabed or land) is one of the environmental impacts it will be a long term effect due to long half lives of the NORM radionuclides.

Incorporating the results of **Table 13**, **Table 14** shows the combined rating for environmental impact.

Table 14. Option ranking by overall environmental impact

Option	Overall environmental ranking	Comment
Sea disposal offshore discharge		Potential local effects on seabed and benthic organisms near the discharges. Water column quality when discharging. Runs counter to OSPAR and UK regulatory stated aspirations to reduce radioactive discharges to sea.
Sea disposal nearshore discharge		Potential local effects on seabed and benthic organisms near the discharges. Water quality when discharging. Proximity to public amenity areas (75m) Runs counter to OSPAR and UK regulatory stated aspirations to reduce radioactive discharges to sea.
Re-injection		Removes NORM from surface environment at source minimum impacts. Minor injection pump fuel combustion emissions
In situ down hole abandonment		Minimal, cementing discharges
Encapsulation and downhole disposal		Onsite disposal and isolation of NORM, in situ abandonment best option
Onshore built disposal facility		Transport of NORM, leachate,
Onshore landfill		Transport of NORM, leachate,
Landspreading		Contaminated land, groundwater contamination, airbourne contamination
Smelting		Radioactive releases to atmosphere,
Incineration		Atmospheric emissions
Disused mine disposal		Potential for groundwater contamination
Disposal in salt caverns		Small potential for loss of containment
Sewer		Land contamination from sludges, water contamination : runoff and nearshore contamination from sea outfalls.
Export		Dependent on final disposal route in host country

10.2.3 Generation of secondary wastes

Table 15. Option ranking by secondary waste production

Ranking

Limited secondary waste which can be readily disposed of

Additional secondary waste or waste unknown needing additional handling and disposal

Secondary waste requiring new systems and facilities and permits

Option	Ranking	Comment
Sea disposal offshore discharge		
Sea disposal nearshore discharge		Contaminated packaging, oily wastes (this route is only from onshore decontamination)
Re-injection		No radioactive wastes
In situ downhole abandonment		No radioactive wastes, cementing wastes.
Encapsulation and downhole disposal		No radioactive wastes, cementing wastes.
Onshore built disposal facility		Leachate
Onshore landfill		Leachate
Landspreading		Contaminated soil
Smelting		LLW slag, radioactive gaseous emissions,
Incineration		Non -combustible residue LLW, radioactive gaseous emissions.
Disused mine disposal		Uncontainerised disposal--leachate
Disposal in salt caverns		Minimal if pre-existing caverns used. For solution mining of new caverns large volumes of dense brine produced.
Sewer		Production of contaminated sludges
Export		Contaminated containers

All transport of oilfield NORM especially, contaminated equipment, will produce contaminated packaging waste. The more handling required for any disposal route the more contaminated PPE will be produced. From table 16 it is clear that the best options as regards production of secondary wastes are offshore re-injection and offshore sea discharge.

10.2.4 Technical availability/ track record

The maturity of the technology required for the different disposal options is an important factor in the overall risk associated with its use and its viability as a realistic option for the UKCS.

Table 16. Option ranking by technical availability/track record

Rankings

	Established and effective disposal routes Immediately available e.g. the current disposal routes.
	Requiring limited short term development and investment; development within 1-2 years with limited uncertainties in terms of HSE and other risks
	Future (2-5 years) with a number of uncertainties and unknown HSE risks major technical or scientific development

Option	Ranking	Comment
Sea disposal offshore discharge		Current NORM disposal method on UKCS oil and gas facilities
Sea disposal nearshore discharge		Current disposal method for NORM the majority of
Re-injection		Produced water already reinjected on UKCS In use for solids on the Norwegian shelf . Will utilize exisiting cuttings injection equipment. OSPAR informed of UK intention to allow re- injection
In situ down hole disposal		Not in current use
Encapsulation and downhole disposal		Not in current use
Onshore built disposal facility		(Non-exempt waste) Drigg
Onshore landfill		(exempt) to landfill . Non-exempt =yellow
Landspreading		
Smelting		
Incineration		
Disused mine disposal		
Disposal in salt caverns		
sewer		
export		

10.2.5 Cost/ Extra infrastructure

Financial feasibility is important for ranking disposal options and there may be insufficient NORM from the UKCS to justify dedicated onshore disposal facilities. The ranking is based on 3 categories.

Table 17. Option ranking on financial feasibility

Ranking

- Low capex low opex, No additional infrastructure
- Low capex/High opex; changes to existing infrastructure with limited new infrastructure
- High capex/low opex or high capex/high opex, fundamental change in infrastructure and consequential financial investment

Option	Ranking	Comment
Sea disposal offshore discharge		Current NORM disposal method on UKCS oil and gas facilities
Sea disposal nearshore discharge		Current disposal method for NORM the majority of NORM from onshore decontamination. Discharge Monitoring costs
Re-injection		Using existing equipment (cost of equipment installation if not present) PW and dissolved NORM many already installed
In situ downhole disposal		Lower cost abandonment option
Encapsulation and downhole disposal		New handling equipment
Onshore built disposal facility		High capital costs, public consultation costs additional monitoring required
Onshore landfill		Additional monitoring required
Landspreading		
Smelting		
Incineration		
Disused mine disposal		no infrastructure exist for emplacement, legislative changed required, additional monitoring requirements.
Disposal in salt caverns		Suitable caverns exist onshore UK and off the N sea coast but no infrastructure exist for emplacement
sewer		
export		

Any form disposal by of emplacement in an onshore overground or underground repository will have a permanent monitoring requirement (cost) for the life of the facility. Reinjection, offshore disposal and export will not.

10.2.6 Legislative issues

It is possible that some options would not be permitted under current legislation, however desirable, therefore the likelihood of exemptions or future regulatory changes will need to be taken into account. Other options may be permissible in principle but would require a significant effort and timescale to obtain approval.

Table 18. Option ranking by legislative issues

Ranking

Already Available short term, in line with trends

Significant new/amended permits and/ or legislation required or against existing legislative trends

Fundamental change in permitting/legislation required at national and/or international level

Option	Ranking	Comment
Sea disposal offshore discharge		Current practice
Sea disposal nearshore discharge		Current practice
Re-injection		DTI has already informed OSPAR of intention to re-inject. Already carried out in Norway.
In situ downhole disposal		Current practice
Encapsulation and downhole disposal		Requires legislative change
Onshore built disposal facility		New authorisation and public consultations
Onshore landfill		Current practice
Landspreading		Significant regulatory obstacle
Smelting		
Incineration		
Disused mine disposal		Lack of containment- liability
Disposal in salt caverns		
sewer		
export		

10.2.7 Long term viability

This is a complex issue and a number of aspects have been combined for assessing the long term viability of the disposal options.

Table 19. Ranking criteria for long term viability aspects

1. Regulatory pressures and trends (Ref . UKOOA ABC categorisation)	
Method covered by Existing regulatory system	
Method requires change in existing system to meet new regulatory requirements and trends	
Methods will require fundamental change in regulations national and international stakeholders	
2. Overall Management (see UKOOA ABC categorization)	
Low risk- established practice with no major stakeholder implications (A -UKOOA)	
Medium risk, minor to considerable impact with lifecycle implications - risk trade offs -best practice with significant economic implications (B- UKOOA)	
high management- -novel and challenging approach with strong stakeholder views-uncertainties involving societal values and perceptions	
3. Long-term Commercial Viability;	
Low risk-known costs and requirements	
Medium risks-additional costs with risks of uncertainty requiring further studies	
High risk -unknown costs in short and long-term requiring cooperation to stabilise market and costs over long-term	
4. Reputation Issues (Ref. RAM matrix and ABC categorisation	
Low risk- zero to slight impact, no major shareholder implications known costs and requirements	
Medium risks-additional costs with risks of uncertainty requiring further studies	
High risk -unknown costs in short and long term requiring co-operation to stabilise market and costs over long-term	
5. Long-term capacity constraints	
Capacity can be accommodated within existing planned system over 1-3 years and planned projections "business as usual	
Capacity will reach limit within I year requiring significant investment immediately over the long-term	
Immediate requirement for major investment and regulatory revisions	
6. Ability to expand and accommodate change	
Expansion capacity available	
Limited expansion and time constraints	
no expansion capacity or extremely expensive and technically or regulatory challenge	
Security and future outlets for secondary waste	
Low risk	

Medium risk requiring study and definition	
High risk - unknowns requiring wide ranging evaluation	

The aspects ranking according to **Table 20** is shown below.

Table 20. Option ranking by long term viability

Option	1	2	3	4	5	6	7
Sea disposal offshore discharge							
Sea disposal nearshore discharge							
Re-injection of dissolved NORM and produced water							
Re-injection of solid NORM slurry							
In situ downhole disposal							
Encapsulation and downhole disposal							
Onshore built disposal							
Onshore landfill							
Landspreading							
Smelting							
Incineration							
Disused mine disposal							
Disposal in salt caverns							
Sewer							
Export							

10.3 Summary of disposal option ranking

Table 21 below shows a summary of the option rankings above. This is qualitative and is a broad judgement, and different conclusions may be reached in particular circumstances. The colour shown indicates the mode colour in all the rankings.

Table 21. Summary disposal option ranking based on all criteria

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

Comments

The best option from radiological risk and environmental aspects is re-injection to the deep subsurface offshore, if the re-injection equipment is already installed. Slurry injection pumps have a high fuel consumption (having to fracture the receiving formation and overcome lithostatic and hydrostatic pressure) and if such pumps are not already in use at a facility there will be financial and combustion emission costs. There is the potential to use existing cuttings reinjection equipment for solid NORM disposal, but for existing facilities with no cuttings reinjection it would be very costly for the likely amount of NORM, and inter-field disposal of NORM would appear more sensible.

In situ abandonment ranks highly due to degree of isolation and no handling, although this is only suitable for in-well NORM.

Sea disposal methods rank highly largely due to the distance (offshore) from the public, dilution and minimal handling.

Onshore disposal routes rank lower largely due to proximity to the public. The lowest ranking options involve significant risk of radionuclides getting into groundwater or the food chain.

The influence of public perception cannot be avoided in radioactive waste disposal, however out of proportion it may be to the real risks involved. Public concern derives from historic concerns over the activities of the nuclear industry and MOD (Kelly and Finch 2002). Public perception also feeds operator reputational concerns.

11 CONCLUSIONS

11.1 The *status quo*

Although 'business as usual' presents no immediate problems, there are several pressures on the *status quo* regarding oilfield NORM disposal.

The most significant could be OSPAR and EU targets to reduce radioactive discharges to sea to background levels by 2020, despite oilfield discharges presenting a trivial dose risk. In the interim, the dearth of land-based disposal outlets and the virtual reliance on a single onshore decontamination outlet are seen as risks.

If nothing is done to provide alternative disposal options there is the potential for stockpiling and consequent problems with public relations, licensing and ultimate disposal. In the worst case, the closure or non-availability of certain outlets could have direct consequences on UK oil and gas production.

11.2 General

By far the most prevalent form of oilfield NORM is mineral scale, and this is primarily related to water production from oil wells. If ignored, mineral scales can cause operational problems and loss of production and for these reason significant steps are already taken to prevent the deposition of scale, largely through use of chemical scale inhibitors. NORM prevention, i.e. preventing NORM exiting the reservoir, is virtually impossible. Metallic NORM deposits from radon daughters in natural gas are also impossible to prevent.

Many treatment and removal methods exist that are either established (principally mechanical removal methods and some chemical treatments) or in development or not currently used in the UKCS (e.g. novel chemical treatments, radium concentration, acoustic and percussive removal).

Of the disposal routes, with the exception of landspreading, and possibly landfill, incineration and smelting under very pessimistic assumptions, none of the routes discussed should present a significant public dose risk. The risk ranking is therefore relative and factors other than dose may be deemed equally important determinants.

It is apparent that some disposal routes are suited to some types of waste and not others. The overall solution must be a combination of minimisation, treatment and disposal options. There is no one size fits all. Some disposal routes are more suited to decommissioning and some for operational wastes.

Developing new outlets or processes requires significant capital, and the quantities currently encountered onshore make it difficult to justify a business case for a facility that is solely for oil industry NORM. This may change if larger quantities are brought onshore due to regulatory changes related to discharge reduction, but this is not necessarily a desirable scenario. The free market cannot be relied on to offer alternative solutions without support from industry and/or regulators. New solutions may also take some years to be fully available.

Several factors militate against having single outlets for certain wastes (e.g. Drigg and Scotoil). These wastes are of strategic importance, because although they are small in volume, the absence of a disposal route could have consequences for oil and gas operations. The proximity principle, minimising radioactive waste transportation, and differences in regulation between Scotland and England and Wales (and potentially Northern

Ireland) suggest that more than one outlet should be provided in principle, but the free market will not necessarily offer this. There is currently no known onshore disposal facility for non-exempt NORM waste in Scotland and this is a significant shortcoming.

For some options, particularly marine disposal, given that doses to the public appear to be well below trivial, a case could be argued to bring in an exemption from regulation.

11.3 NORM prevention, minimisation and treatment options

These are summarised in **Table 22**.

Table 22. Summary of NORM prevention, minimisation and treatment options

	Status of techniques	Effectiveness
Prevention		
Downhole removal of NORM nuclides in the reservoir	Commercial	Very limited
Downhole water separation (DOWS)	Development	Not proven
Preventing and minimising norm solids		
Scale inhibitors	Commercial	Good
Sulphate removal	Commercial	Good
Electrochemical	Development - Commercial	Selectively good
Engineering solutions	Commercial	Fair
Removing NORM from produced water	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
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

11.4 Disposal options

Sea disposal offshore discharge

- With the exception of reinjection, this option has the lowest dose to the public.
- Nevertheless, reputational issues have been raised regarding the discharges of alpha-emitters to the North Sea by the oil and gas industry.

- 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.
- Effects on marine biota not well understood.

Sea disposal nearshore discharge

- Higher dose than offshore discharge but probably still 'trivial'.
- Currently only one onshore decontamination facility (security of supply risk).
- No viable alternative at present except Drigg, who could accommodate current volumes in their limits. Drigg, however, is reluctant to accept radium-containing LLW as it diminishes capacity for higher activity wastes. The costs for Drigg and for analysis and conditioning would be high.

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 already present.
- Increased emissions from power generation.
- Centralised reinjection has attractions but legal basis would need affirmation.

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.

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.

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 cannot be relied upon as it has radium and thorium limits that might be fully taken by MOD and other industrial radium-containing wastes.
- Public resistance to new radioactive waste disposal sites although NORM has the perceptual advantage of being "natural"
- Economics militate against construction of a oilfield NORM-only facility
- Currently no disposal site in Scotland for non-exempt NORM waste, and a very small number in England and Wales. 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.
- Several contractors have interest or plans but are reluctant to invest without some guarantee of revenue.
- Shared facility may bring unwanted associations (MOD, nuclear industry) - reputational issue.

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.
- Non-exempt NORM waste is not WFD waste and in the absence of special precautions burial requires a RSA authorised disposal facility, discussed above.
- Doses from landfill disposals are uncertain.

Landspreading

- Landspreading is dismissed primarily due to significant dose issues and it would also be very difficult to license under either RSA or the Landfill Regulations.

Smelting

- Smelting is a potential outlet for used tubulars, but not suited to loose NORM.
- Relatively higher public doses (although probably still trivial) due to atmospheric emissions.
- Very few companies in EU undertaking this.
- Potential increase interest in future due to increased steel prices

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.

Disused mine disposal

- Used in some other NORM industries.
- Containment cannot be guaranteed and some existing mine discharges are very polluting, i.e. there are real and reputational pollution risks.

Disposal in salt caverns

- Possible to demonstrate good containment
- Isolated from public
- Some technical (and potentially licensing) challenges so long lead-in time
- Potential sites on and offshore UK identified

Sewer

- Still promoted under extant Government guidance, but anachronistic.
- Much of the radioactivity may well exit as a nearshore discharge.
- This option has been discounted by other commentators and would not be acceptable in terms of perceived (or real) doses to the public from sewage sludge recycling or incineration and doses to sewage workers.

Export

- Transboundary disposal is legally permitted but against Government policy.
- Other countries are receptive but only under certain conditions, e.g. waste accompanying a decommissioning project.

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APPENDIX 1 - BACKGROUND INFORMATION ON RADIATION DOSES, FATE OF NORM DISCHARGES TO SEA AND DOSE ESTIMATES.

12.1 Potential Impacts and Exposure Pathways

Radiation (from whatever source) interacts and disrupts biochemical processes in the cells of living tissue, with the following possible responses:

- Misrepair of damaged cells may generate a mutation that is expressed as in the cell as cancer or in case of germ cells mutation in their progeny. The severity of these effects is independent of the dose but the risk of such effects increases with dose. These are referred to as **stochastic effects**.
- Death of the cell, leading to reduced tissue function and effects on individual morbidity, fertility and reproductive rate. The severity of the effect increases with dose above some effective threshold dose. These are referred to as **deterministic effects.**
- Chronic exposure to radiation may result in mortality, sterility and decreased fertility of organisms all of which are important to the reproductive success of a species (Simmonds et al 1995).
- For human protection it is the risk of stochastic effects (principally, cancer) at low adsorbed doses and dose rate that is of concern rather than the deterministic effects caused by relatively high doses and dose rate. For organisms other than man, deterministic effects may be of more concern especially with respect to self sustaining populations.

The magnitude of the incremental radiation exposure will depend on the interactions between a wide range of factors:

- The release rates and quantities of the individual radionuclides in the wastes and their radiation characteristics
- Their physicochemical form
- Transport pathways and mechanisms of uptake and or accumulation
- The nature of the receiving environment.

12.2 Accumulation and Food Chains

Discharge of NORM into the environment carries with it the possibility that some components may enter the food chain, and of those, some may accumulate.

Most NORM discharged at sea will ultimately be deposited in the seabed sediments, and will be subject to bioturbation by the benthos or sediment living species. Crustacea, molluscs and worms feed on the sediments and absorb nutrients as well as pollutants. Bottom feeding predators including fish will in turn feed on the benthos.

If an accumulation of radionuclides occurs in the food chain, the consequences are two fold:

- Accumulation and concentration of radionuclides may be carcinogenic and can have effects on reproduction, and subsequent generations – fecundity, longevity of overall viability of different life cycle stages.
- If humans feed on fish or shellfish which contains radionuclides they may suffer health effects from such doses, usually through chronic exposure

EA and SEPA guidelines suggest that generic approaches and limits can be used as an indication of the likelihood of an adverse effect, but may need to be reconsidered in a site specific context, as there is considerable variation in radiosensitivity between species and life stages. There is currently no internationally accepted methodology for environmental impact assessment with respect to ionising radiation and therefore no means of demonstrating environmental protection (Strand et al. 2001, EA 1998).

This is inconsistent with legislation for 'hazardous' materials and is currently being addressed. A procedure to combine the exposures of plants and animals from low linear energy transfer (LET or ionisation intensity) beta and gamma radiation and high LET alpha radiation is required. The main radionuclides of concern in NORM disposals are predominantly alpha emitters which have a high LET.

According to the ICRP the standards for radiological protection should be such that they do not place other species at risk.

Work is in progress (FASSET 2003) on the assessment of radiation impacts on ecosystems and on defining the effects of chronic long term exposure from different types of radiation on different species. They have produced a radiation effects database.

The OSPAR Threatened and Declining Species Justification Report (2004b) states radioactivity to be one of the main current threats to both the Northern Right Whale and bowhead whale presumably due their longevity, late maturation and low fecundity.

12.3 Radiation Dose and Human Health Risk

It is assumed for radiological protection purposes that any radiation dose, however small, carries risks to human health, the risks of most concern being the induction of cancer in the individual who receives the dose, and the induction of genetic defects in the individual's descendents.

To assess radiological impact on humans it is therefore necessary to estimate potential doses, however small, rather than simply to show that doses will be below some "safe" level.

Radionuclides released into the sea offshore disperse over long time scales and are diluted by large volumes of water and taken into sediments before reaching humans via direct exposure or the food chain. Dose estimates can be made using mathematical models e.g. Simmonds *et al* (2002).

Where releases are close to shore, more direct calculations can be made and the potential radiation effects on marine species and habitats and their long term sustainability assessed.

The most obvious way in which radionuclides released into the marine environment can cause radiation doses to humans is through consumption of seafood, particularly fish, molluscs, crustacea, and to a lesser extent seaweed.

Other possible human exposure pathways include inhalation of sea spray and suspended materials.

12.4 Comparisons with dose limit and exemption level

The significance of the doses estimated above needs to be judged in two ways: first to determine whether they are below the level which is regarded as intolerable, and second to determine whether they are potentially acceptable.

The dose limit recommended by ICRP for members of the public is 1 mSv per year (10^{-3} Sv per year) (ICRP, 1991). This limit is for all practices which can lead to radiation exposure of the public, except for medical procedures.

To judge the potential acceptability of the doses, the most relevant level is that given in an IAEA document on principles for exemption of radiation sources and practices from regulatory control (IAEA, 1988b). This document states that a radiation dose to an individual is likely to be regarded as trivial if it is of the order of 10 µSv per year and it is understood that the IAEA will be using this dose level in their work to define wastes which can be regarded as non-radioactive for the purposes of the London Dumping Convention.

For further perspective, the estimated doses can be compared to those which could be received from radionuclides naturally present in sea water. The annual dose from such radionuclides to a person who consumes above average amounts of seafood could be 2-5 mSv per year (Pentreath 1988).

12.5 Doses to human populations

Within the framework of radiological protection, estimates of doses to human populations ("collective doses") are used in determining compliance with the requirements that practices causing radiation exposure should be justified, and that all exposures should be as low as reasonably achievable, economic and social factors being taken into account (the ALARA or optimisation requirement) (ICRP, 1991). There are no limits on collective doses as there are for individual doses. However, the IAEA has suggested a level of collective dose to be used in determining whether practices might be exempted from regulatory control. This level is in terms of the collective dose which would be received by the whole exposed population, integrated over all time, from one year of carrying out the practice, and is 1man Sv (IAEA, 1988b).

In the case of radionuclide releases into the oceans the population to be considered in collective dose calculations is that of the world. Clearly it is not possible to calculate the dose to every person in the world, for every year after the release, and sum them to obtain the collective dose. The procedure used calculates radionuclide concentrations in seafoods in each part of the ocean, as a function of time, using mathematical models. Seafood catch data for each part of the ocean are then used to estimate the total amounts of radio nuclides in seafoods potentially available for human consumption, and it is assumed that all the edible parts of the seafoods are consumed. This procedure has been used in studies with the NEA model, and in the European Community MARINA project.

12.6 NORM discharges to sea

12.6.1 Introduction

12.6.2 Fate of radium

Radium in oil industry NORM accounts for the majority of the radioactivity. Barium and radium behave similarly (both group II metals) in the environment (Legeleux and Reyss 1996, Carroll et al. 1995). Radium in scale is present as radium sulphate and while there is little data on the effects of radium sulphate there has been considerable research in the oil and gas industry on the effects of barium sulphate (barite) due to its widespread use as a weighting agent in drilling muds. The solubility of barium sulphate is very low and for sulphates, successive Group II elements are approximately 100 times less soluble as the periodic table is descended, with radium sulphate having the lowest solubility. The high concentrations of sulphate in marine environments also push the equilibrium between metal sulphates and their respective ions towards the insoluble state.

Many studies on barite have concluded that its uptake in the food chain is very limited. For example, Neff et al (1988) found that barium was not accumulated by lobsters or flounder. Barium was found in sandworms in the ingested sediments in the gut, and Schaaning *et al* (2002) found that barium uptake can be explained by indiscriminate uptake of sediment by the organisms, rather than selective uptake of ions or fine particles.

Radium concentrations in marine organisms decrease with trophic level (Neff, 2002). Radium, once bio-accumulated, although retained for a long time in the tissues of marine animals, does not biomagnify up the food chain due to very inefficient trophic transfer of radium.

12.6.3 Radiological impacts on marine organisms

Exposure

Marine organisms living in the vicinity of NORM discharge sites will be exposed to different levels of radiation, emitted from NORM or diffused into the water column. The dose received by an organism depends upon its location and behaviour, i.e. mobility, life cycle and feeding strategy. According to Neff (2002) marine invertebrates and fish are extremely tolerant to radiation toxicity and in general there is an inverse relationship between taxonomic position and sensitivity to radiation.

Life cycle

Generally, early life stages are more sensitive than their adult stages, but also there are large differences between species (IAEA 1988, FASSET 2003). Consequently, the acute dose or dose rate necessary to have measurable effect on fertility or even to cause mortality are both species and life stage specific.

Sustainability of Populations

The fate of individual members of a population is important, but so also is the performance of a population as a whole, i.e. its ability to maintain itself through reproduction.

Acute radiation exposure is not likely to be caused by any of the listed NORM disposal routes. Longer term chronic exposure is possible from some and could result in tissue damage and eventual death although the accumulated doses to marine species due to NORM disposal are not likely to reach lethal levels.

The most severe effect would be an increase in mortality/defects closest to the source. The reduction in reproduction success of a population, on the other hand, is the most critical parameter as it may effect the ecosystem as a whole.

A more subtle result of chronic radiation exposure, which may be noticeable over several generations, is an increase in mutation rate in the gene pool (Simmonds *et. al*.1995).

12.6.4 Data on activities and doses

There is no published data for levels of NORM nuclides in receiving waters or surface sediments around NORM discharges for the UKCS. It is understood (pers comm.) that some work was carried out in Norway around produced water discharges which showed no measurable increase in ^{226}Ra in the water column beyond the 500m zone. There is no published baseline data for ^{226}Ra in bottom for the UKCS. However on reported figures for activity from barium sulphate in marine sediments in the vicinity of oil and gas developments was found to contain activity of 22 Bq/g "for radium" assumed to be total radium (Snavely 1989).

Studies in Louisiana (Hart *et. al.* 1995) have shown elevated levels of ^{226}Ra beneath produced water discharges, with sediment values of 0.1-19.7 Bq/g compared to background values of 0.1-0.18 Bq/g. These are not directly comparable, however, to the North Sea discharges into deep saltwater as ^{226}Ra is more soluble at the lower ionic concentration found in brackish water and there will be less dilution in shallow water. It is reported by the same authors that further offshore in the Gulf of Mexico there was no significant ^{226}Ra increase in surface sediments: 20m from the offshore discharge ^{226}Ra was 0.018-0.068 Bq/g and at 200-2000m from the discharge ^{226}Ra activity was 0.011-0.018 Bq/g. There was no data for discharges of solid NORM.

To date there is relatively little known about the effects of radiation on benthic organisms. The available data do, however, indicate that dose rates below 10 mSv h^{-1} will not result in death for individual organism. A reduction of reproductive success may be observed at dose rates >1 mSv h^{-1}. At rates <1 mSv h^{-1}, but still exceeding the background radiation level, changes in the gene pool and somatic effects, that do not effect the fitness of the population, may occur (IAEA 1988).

No dose rate measurements were available for the NORM discharges to sea, but measurements of scaled vessels and pipes on offshore installations indicate that dose rates outside closed vessels and pipes are usually less than 7.5 µSv h^{-1} (0.75 millrem h^{-1}) (Smith 1985).

The natural background dose rate for marine organisms is shown in table xx below

Table. Background dose rates for marine organisms

Type of organism (location)	Range of dose rate in mSv/hr		Range of annual exposures in mSv	
Zooplankton (small pelagic crustacean)	2.60×10^{-4}	5.9×10^{-3}	2.3	52
Mollusc (small, on seabed)	8.1×10^{-4}	3.4×10^{-3}	7.1	30
Crustacean (seabed)	5.7×10^{-4}	1.4×10^{-2}	5	123
Fish (pelagic)	3.3×10^{-5}	5.7×10^{-4}	0.3	5
Fish (demersal)	4.5×10^{-5}	5.2×10^{-4}	0.4	4.6

(Pentreath and Woodhead 2001)

Table. Relevant radionuclide dose coefficients (Chen et al. 2003)

	Compartment receiving discharge Dose $Sv.y^{-1}$ for a discharge of $1GBq.y^{-1}$					
	50m stack	Small river	Medium river	Large river	Small marine box	Large marine box
^{228}Ra+	2.0E-07	7.2E-06	1.8E-07	3.6E-08	3.0E-09	2.7E-11
^{226}Ra+	4.1E-07	4.0E-06	1.0E-07	2.0E-08	1.3E-09	2.9E-11
^{210}Pb+	1.9E-07	9.5E-06	2.4E-07	4.7E-08	9.0E-10	1.3E-11
^{210}Po	3.8E-07	8.1E-06	2.0E-07	4.0E-08	2.2E-10	4.1E-12

Notes:

1. ^{228}Ra+ = dose from ^{228}Ra and ^{228}Ac
2. ^{226}Ra+ = dose from ^{226}Ra, ^{222}Rn, ^{218}Po, ^{218}At(0.04%), ^{214}Pb(99.96%), ^{214}Bi and ^{214}Po
3. ^{210}Pb+ = dose from ^{210}Pb, ^{210}Bi

APPENDIX 2 - PATENTS REFERRED TO IN THIS REPORT

Note: this is not an exhaustive list of patents relevant to oilfield NORM.

Patent number	Title	By	Description
US6382423	Selective reduction of naturally occurring radioactive material to be treated, and its treatment	Inventor(s): BUSH JOHN G (US); GAUR SIDDHARTHA (US) Applicant(s): BPF INC (US)	A method for processing a mass of solid fine particles including Naturally Occurring Radioactive Material ("NORM") is disclosed. In one embodiment, the material is sampled and classified into fractions based upon one or more selected criteria such as particle size or particle density. The level of radioactivity associated with each fraction is determined, leading to separation of the mass of fines into selected fractions based upon one or more selected criteria and the activity levels of the fractions. Selected fractions are chosen for chemical treatment, thereby reducing the volume of material to be treated. By reducing the volume of solid material to be treated, the amount of chemicals used for treatment is reduced, along with the size and capacity of the processing equipment required to treat the material. Radionuclides are extracted from the selected fractions into an aqueous solution which may be subsequently injected into a subterranean formation, such as the formation from which the materials originated. In one embodiment, the aqueous solution consists of water, a chelant comprising an alkali metal salt of a polyamine polycarboxylic acid, and sufficient alkali metal hydroxide to result in a pH of the aqueous solution of about 5 to about 14
US6137028	Method for the disposal of oil field wastes contaminated with naturally occurring radioactive materials (NORM)	Inventor(s): SNOW DANIEL WAYNE (US)	A method for the disposal of oil field wastes contaminated with naturally occurring radioactive materials (NORM). The method includes the steps of: drilling a pair of wells which intersect in a salt formation, providing a slurry containing NORM wastes and a carrier liquid, injecting the slurry through one of the wells into the salt formation wherein the NORM wastes settle, and removing the carrier liquid from the other one of the wells. One carrier liquid, fresh water, dissolves the salt formation to form and enlarge a cavern for receiving the NORM wastes. The quantities of carrier liquid removed from the salt formation are disposed of by injection into permeable formation remote from the salt formation.
US5678239 GB2310530	Treatment of radioactive material	Inventor(s): DAVIDSON IAN DAVID FARQUHAR (GB) Applicant(s): SCOTOIL GROUP PLC (GB)	A process for treating naturally occurring radioactive material (NORM) comprises use of NORM as a mud constituent in a drilling mud manufacturing process and particle size reduction of the NORM particles during or before that process to attain a selected particle size corresponding to that of a particulate drilling mud component, said particle size reduction being optionally accompanied by additional mixing, if necessary, of the NORM and mud component particles, the aim of said use being the achievement of irreversible dilution of the NORM particles in said component to nullify the radioactive nature thereof.
US5336843	Process for compacting normally occurring radioactive material (NORM) in sealed tubular members	Inventor(s): ZIMMER JOHN (US) Applicant(s): ZIMMER JOHN (US)	A process for compacting normally occurring radioactive material (NORM) into a cylinder, such as a pipe, by providing a cylinder having a continuous sidewall, a first open end and a second closed in, and a cavity formed by the side wall defining a NORM storage space therein; providing a hopper for holding a quantity of the NORM; positioning the open end of the cylinder

			against the hopper, so that there is communication between the hopper space containing the NORM and the cylinder space; moving a ram member through the hopper toward the open end of the cylinder for forcing a quantity of the NORM contained within the hopper into the cylinder; repeating the compaction step until the cylinder is substantially filled with the NORM; and closing off the open end of the cylinder so that the NORM cannot move from the cylinder. The process also includes the step of removing the moisture from the NORM before the NORM is compacted in the cylinder.
GB2283852	Process for conditioning material for disposal	Inventor(s): MASON JOHN YOUNG; BLOCK RANDALL JOSEPH; TYLER RANDALL KEITH; MILLIKEN JOHN DUNCAN Applicant(s): EXXON CHEMICAL PATENTS INC (US); RIO LINDA CHEM CO INC (US)	Disposable deposits and sediments which contain naturally occurring radioactive material (NORM) from petroleum production, refining and mining are treated with particle separation to reduce the mass of disposable materials. The sediments are slurried in a liquid and then smaller particles of less than 80 microns are separated. The smaller particles contain the radioactive matter.
WO0213202 2002-02-14	Oil scale volume reduction	Inventor(s): BRADBURY DAVID (GB); ELDER GEORGE RICHARD (GB); LINDBERG MARIA (SE) Applicant(s): BRADBURY DAVID (GB); ELDER GEORGE RICHARD (GB); LINDBERG MARIA (SE); STUDSVIK RADWASTE AB (SE)	A process for the volume reduction of radioactive oil scale, comprising: providing a de-oiled solid scale material, dissolving barium and strontium sulphates and associated radioactivity thereof, removing sulphate ion from the solution obtained by means of an anion exchange operation and separating radioactive and non-radioactive constituents, by means of cation ion exchange operation. Apparatus for such volume reduction, comprising a dissolver vessel at least one anion exchange column, at least one cation exchange column, and recovery vessels.
WO03065381 2003-08-07	Process and apparatus for volume reduction of oil scale waste	Inventor(s): BRADBURY DAVID (GB); ELDER GEORGE (GB); LINDBERG MARIA (SE) Applicant(s): BRADBURY DAVID (GB); ELDER GEORGE (GB); LINDBERG MARIA (SE); STUDSVIK RADWASTE AB (SE)	A process for the volume reduction of radioactive oil scale, comprising: providing a de-oiled scale material, dissolving barium and strontium sulphates and associated radioactivity therefrom by means of a combination of cation and anion exchange resins, separating said resins from each other, subjecting the cation resin to a separation operation to separate radioactive and non-radioactive constituents from each other; and recovering separate radioactivate and non-radioactive fractions in solid form. An apparatus for such volume reduction.
US5764717 1998-06-09 WO9708107	Chemical cleaning method for the removal of scale	Inventor(s): ROOTHAM MICHAEL W (US)	An improved method for removing scale, sludge, corrosion and other debris and deposits from the interior of a heat exchanger vessel such as a nuclear

	sludge and other deposits from nuclear steam generators	Applicant(s): WESTINGHOUSE ELECTRIC CORP (US)	steam generator, includes generating pressure pulses in a non-corrosive, strongly basic, amine-containing chemical cleaning agent in aqueous solution after the agent has been introduced into the interior of the vessel to create shock waves in the liquid for dislodging, dissolving and fluidizing sludge and corrosion products. The chemical cleaning agent is an aqueous solution containing at least one of the group of lower alkyl amines, lower alkanol amines, lower alkoxy alkyl amines and cyclic diimines or combinations thereof. The method further includes simultaneously recirculating the chemical cleaning agent through a filter assembly during the pressure pulsing operation in order to remove fluidized sludge and corrosion products dislodged by the pressure pulsing and chemical action, thereby affording them no opportunity to resettle back onto the surfaces of the heat exchanger vessel and interfere with the chemical cleaning of the vessel. The method reduces not only the time required for a particular chemical cleaning agent to effectively clean the vessel, but further reduces the number of times such chemicals need to be introduced into the vessel, which in turn results in the production of less radioactive liquid waste products, and minimizes new corrosion through use of relatively non-corrosive cleaning agents.
US5386077 1995-01-31 CA2085154	Method for removing radioactive scale from fluid carrying equipment	Inventor(s): DECOOK JOHN G (CA); CUTHILL TREVOR F (CA)	A method for removing radioactive barium sulphate from fluid carrying equipment includes immersing the equipment and scale in liquid nitrogen or other cyogenic liquid, followed by immersing the equipment and scale in water or other aqueous solution, and subsequent impacting of the equipment and scale to remove the scale.
US5322121 1994-06-21	Hydraulic fracturing technique employing in situ precipitation	Inventor(s): HRACHOVY MARTY J (US) Applicant(s): UNION OIL CO (US)	A fracturing fluid comprises (a) a carrier, (b) a nucleating agent capable of reducing the concentration of scale-forming ingredients and/or natural occurring radioactive materials (NORMs) present in an aqueous subterranean fluid, and optionally (c) an ingredient selected from the group consisting of proppants, friction-reducing additives, fluid-loss-control additives, gelling agents, bactericides, and scale stabilizers. The fracturing fluid is employed in hydraulic fracturing procedures to, among other things, reduce the concentration of the scale-forming ingredients and/or NORMs present in produced aqueous subterranean fluids.
US5111887 1992-05-12	Method for reducing radioactivity of oilfield tubular goods contaminated with radioactive scale	Inventor(s): PAUL JAMES M (US); MORRIS RICHARD L (US) Applicant(s): MOBIL OIL CORP (US)	Alkaline earth metal scales, especially barium sulfate scale deposits are removed from oilfield pipe and other tubular goods with a scale-removing composition comprising an aqueous alkaline solution having a pH of about 8 to about 14, a polyaminopolycarboxylic acid, preferably EDTA or DTPA and a catalyst or synergist comprising oxalate anion. When the scale-removing solution is contacted with a surface containing a scale deposit, substantially more scale is dissolved at a faster rate than previously possible.
US5085709 1992-02-04 US4973201	Method for treating natural gas equipment	Inventor(s): PAUL JAMES M (US); MORRIS RICHARD L (US) Applicant(s): MOBIL OIL CORP (US)	Natural gas processing equipment and sorption media such as charcoal, silica or alumina, contaminated with adherent scale deposits of alkaline earth metal sulfates may include radioactive components, especially radium sulfate and thorium sulfate, which render the equipment radioactive. The scale is removed from the processing equipment by washing with an aqueous chemical

			composition including a polyaminopolycarboxylic acid such as EDTA or DEPA as a chelant in combination with a synergist, preferably oxalate or monocarboxylate acid anion such as salicylate. The washing may be carried out with the equipment in place or by immersion of the equipment in a body of the solution in a suitable treatment tank.
US3873362 1975-03-25	Process for cleaning radioactively contaminated metal surfaces	Inventor(s): SNYDER GERALD A; MIHRAM RUSSELL G Applicant(s): HALLIBURTON CO	A process for removing radioactive scale from a ferrous metal surface, including the steps of initially pre-conditioning the surface by contacting it with an oxidizing solution (such as an aqueous solution of an alkali metal permanganate or hydrogen peroxide), then, after removal or decomposition of the oxidizing solution, the metallic surface is contacted with a cleaning solution which is a mixture of a mineral acid and a complexing agent (such as sulfuric acid and oxalic acid), and which preferably contains a corrosion inhibitor. A final step in the process is the treatment of the spent cleaning solution containing radioactive waste materials in solution by adding a reagent selected from the group consisting of calcium hydroxide or potassium permanganate and an alkali metal hydroxide to thereby form easily recovered metallic compounds containing substantially all of the dissolved metals and radioactivity.
GB2266002 1993-10-13	A method of removing radioactive material from metallic objects	Inventor(s): KINSEY JOHN STUART Applicant(s): ALTRA CONSULTANTS LIMITED (GB)	The method comprises placing the metallic objects into a furnace (1) and melting the metallic content of the object to produce a melt. The radioactive impurities are permitted to settle out of the melt in the form of a slag and the melt is then removed from-the furnace (1). Typically, non-radioactive metal material is added to the contaminated metallic objects prior to introduction into the furnace to dilute the level of radioactive contaminant to an environmentally acceptable value. The method is particularly useful in removing low specific activity scale from metallic objects recovered from oil-field operations.
GB2314865 1998-01-14	Removal of sulphate scale from surfaces	Inventor(s): KEATCH RICHARD WILLIAM Applicant(s): KEATCH RICHARD WILLIAM (GB)	A method for dissolving sulphate scale comprises contacting the sulphate scale with a solution containing a scale convertor, e.g. potassium carbonate; a catalyst, e.g. potassium formate; and a chelating agent.
EP0869201 1998-10-07	Method for preventing metal deposition and an oil or gas well with electrically contacting means	Inventor(s): KEATCH RICHARD (GB) Applicant(s): KEATCH RICHARD (GB)	A method for inhibiting or preventing the deposition of metals onto metallic surfaces, particularly the metal surfaces in an oil or gas well.
EP0869201 1998-10-07	Method for preventing metal deposition and an oil or gas well with electrically contacting means	Inventor(s): KEATCH RICHARD (GB) Applicant(s): KEATCH RICHARD (GB)	A method for inhibiting or preventing the deposition of metals onto metallic surfaces, particularly the metal surfaces in an oil or gas well.