Phase I Technical Report **Project UKRSR07**

Identification and assessment of alternative disposal options for radioactive oilfield wastes

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EXECUTIVE SUMMARY

This report is the first part (Phase 1) of the SNIFFER project UKRSR 07: Identification and Assessment of Alternative Disposal Options for Radioactive Oilfield Wastes. The contents of Phases 1 and 2 are as laid out in the project Scoping Report.

This report covers the origins and occurrence of naturally occurring radioactive material (NORM) from oil and gas fields. Amounts of NORM waste produced on the UKCS are quantified and predictions made of potential arisings from future production and during decommissioning. NORM waste in this context refers to liquid and solid radioactive disposals. The assessment of current and future disposal routes is the subject of the Phase 2 report.

There is a perceived lack of information on the part of the UK government and regulators on current and future low level radioactive waste arisings from oil and gas production on the UK continental shelf. With changes in landfill regulations, increasing low level waste arisings in other industries and an increasing demand for reduction of radioactive discharges to sea there is a need to investigate disposal capacity against likely requirements. In order to do this a quantification of the NORM arisings is necessary.

The low level radioactivity present in oilfield wastes (and subject to regulation) is due to the presence of naturally occurring radionuclides. These are derived from decay of Uranium and Thorium isotopes (^{238}U and ^{232}Th) present throughout the earths crust. These have long half-lives and have been present since the formation of the earth (primordial nuclides). Although the ^{238}U and ^{232}Th are relatively immobile and remain in the subsurface their daughter nuclides are more mobile and are unavoidably extracted from the reservoir with produced hydrocarbons and water. They are subsequently deposited in oil and gas production and processing facilities from where they have to be removed either by onshore decontamination or discharge to sea as scale, sludge and in produced water.

This report deals primarily with the origins and quantification of radioactive oilfield wastes onshore and offshore. Likely arisings of Naturally Occurring Radioactive Material (NORM) from production and processing facilities are discussed. Data obtained from operators, decontamination contractors, literature review, disposal outlets and the regulators has been included in the estimates.

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

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

The estimates of the current arisings have been prepared and are summarised in the table below (taken from Table 12).

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

Table - Estimated current annual arisings of NORM from the UK 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 (4.1)	9840	282 Mm^3	E&NE	Medium
Reinjection (4.1)	278	7.5 Mm^3	E&NE	Medium
Offshore decontamination (4.4)	23	1,300 t	E&NE	Medium
Workovers (4.6)	4	35 t	E&NE	Low
Platform decommissioning (offshore) (4.9)	1.5	15 t	NE, some E	Low
Platform decommissioning (to onshore) (4.9)	0.2	1.8 t	NE, some E	Low
Pipeline decommissioning (to onshore) (4.10)	<14.8 Bq/g Ra >14.8 Bq/g Ra	0.2 t 3.8 t	E NE	Medium
Onshore decontamination (4.3)	9.5	36 t (in suspension)	E&NE	High
In water to terminals (4.1)	12	220,000 m^3	E&NE	Medium
Terminal decontamination (4.7)	6	500 t	E&NE	Low
Produced water discharged at terminal (by deduction) (4.1)	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)

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

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

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

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

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

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GLOSSARY AND ABBREVIATIONS

Alpha radiation	Radioactive decay by ejection of a high energy charged particle consisting of 2 protons and 2 neutrons (equivalent to a Helium nucleus)
becquerel Bq	SI unit of activity equivalent to 1 nuclear transformation per second.
Beta radiation	Radioactive decay by ejection of a high energy negatively charged particle from the nucleus of an unstable atom (a beta particle has the same mass and charge as an electron)
CNS	Central North Sea
COVRA	Centrale Organisatie Voor Radioacteif Avfal (radioactive waste disposal facility in the Netherlands).
Decay series	A succession of radionuclides each of which is transformed by radioactive decay into the next member until a stable nuclide is reached. The first member of the series is the parent, the succeeding nuclides are the progeny or daughters.
DTI	Department of Trade and Industry
EA	Environment Agency
EEMS	Environmental Emissions monitoring System
EU	European Union
FPSO	Floating Production Storage Offloading system
Gamma radiation	High energy electromagnetic gamma photons emitted from an unstable nucleus. Very penetrating
GBq	$1x10^9$ Bq
Half life	The time required for half of the activity of the radioactive material to decay
IAEA	International Atomic Energy Authority
ICRP	International Committee on Radiological Protection
IRR 99	Ionising Radiations regulations
keV	kilo electron volts (1 keV= $1.6X10^{-19}$ Joules)
LPG	Liquefied petroleum Gas
LSA	Low specific activity
MBq	$1x10^6$ Bq
MOL	Main Oil Line
NGEO	Natural Gas Exemption Order
NGL	Natural Gas Liquids
NNS	Northern North Sea
NORM	Naturally Occurring Radioactive Material

OLF	Olje Industriens Landsforening. (Norwegian UKOOA equivalent)
OSPAR	Oslo and Paris Commission for the protection of the marine environment of the North East Atlantic
PSEO	The Radioactive Substances (Phosphatic Substances, Rare Earths etc.) Exemption Order
PWRI	Produced water re-injection
RPA	Radiation Protection advisor
RPS	Radiation protection supervisor
RSA 93	Radioactive Substances Act 1993
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
Secular equilibrium	Where all daughters in a decay series are present at the same activity (the rate of decay of each is matched by the rate of ingrowth)
SEPA	Scottish Environment Protection Agency
SNS	Southern North Sea
TBq	$1x10^{12}$ Bq
TENORM	Technologically enhanced naturally occurring radioactive material
Total Activity	In this report: 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.
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association

1 INTRODUCTION

This study has been undertaken in response to a perceived lack of quantification of current and future NORM arisings from the UKCS oil and gas industry. With changes in landfill regulations and an increasing focus on reduction of radioactive discharges to sea there is a need to investigate disposal capacity against likely requirements. This report deals primarily with the quantification of radioactive oilfield wastes onshore and offshore. Likely NORM arisings from different types of production and processing facilities are discussed. Data obtained from operators and the regulators has been included in the estimates. The current scope of the study includes offshore production facilities, onshore terminals, major pipelines and onshore production facilities and covers the issues of current arisings, future lifetime of facility arisings and potential arisings on decommissioning.

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

In this Phase 1 report the origins of oilfield NORM are discussed. The occurrence of NORM in oil and gas production facilities and waste streams are investigated and the practical experience of operators on the UKCS and abroad in monitoring, removing and characterisation of NORM wastes is discussed. Information for this study comes from published information, the results of consultations with operators based on interviews and discussions and the results of an operator questionnaire.

The disposal routes, their capacity and associated risks will be discussed in the Phase II report.

The structure of this report is as follows:

Section 2	Discussion of NORM origins
Section 3	Review of the data acquisition stage and results
Section 4	Discussion of the main oil and gas NORM streams and data on quantities and activities
Section 5	Collation of data on current NORM arisings
Section 6	Forecasting NORM arisings into the future
Section 7	Conclusions
Section 8	References

<u>Terminology</u>
In this report the naturally occurring nuclides from the decay of ^{238}U and ^{232}Th found in radioactive oil and gas field wastes are referred to as NORM (Naturally Occurring Radioactive Material). Other terms appear in the literature, TENORM (technically enhanced naturally occurring radioactive material) and LSA scale (which refers only to hard mineral scales) being the most common.

Where the term 'Total Activity' is used in this report it refers to a calculated[1] activity for ^{226}Ra and ^{228}Ra and their daughter isotopes. This is different to the calculation to determine the applicability of RSA (Schedule 1 element limits) and exemption orders. In other EU countries levels are set for individual isotopes and this can lead to confusion in comparison of authorised limits or reported activities between countries. The total activity calculation assumes no loss of gaseous radon (radon emanation)

Where solid NORM arisings are described as exempt and non-exempt in this report this refers to elemental activities of radium and polonium isotopes in relation to the 1962 Radioactive Substances (Phosphatic Substances, Rare Earths etc.) Exemption Order (PSEO). Activities below 14.8 Bq/g are classed as exempt[2].

For liquid wastes there is no exemption order and the Schedule 1 element limits of the Radioactive Substances Act are applied. Radium is the most restrictive element; the limit at which it becomes regulated is 0.00037 Bq/g.

[1] SEPA 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 either it is not present or it is recorded as below limit of detection and only the Ra terms are used.

[2] if either $1x\ ^{226}Ra+2x\ ^{228}Ra$ or $2x^{226}\ Ra+1.7\ x\ ^{228}\ Ra$ = > 14.8 Bq/g the material is not exempt from RSA.

2 NORM ORIGINS

2.1 General origins

This section explains the presence of natural radioactivity in oil and gas NORM wastes.

Uranium and Thorium are ubiquitous in the earths crust (average concentrations of 4.2 ppm and 12.5 ppm corresponding to 0.05 Bq/g ^{238}U and 0.05 Bq/g ^{232}Th (Eisenbud and Gessell, 1997)). These are two of the primordial radionuclides present since the earth was formed and extraction of their decay products during oil and gas production is unavoidable and is the source of the radioactivity in oil and gas field scales and deposits.

U and Th concentration in the subsurface varies; in reservoir rocks it is usually <20ppm whereas igneous, metamorphic, volcanic rock and black shales can show U and Th contents from 1000-10,000ppm. The natural radioactivity of reservoir and source rock formations has been used for the past 40 years in down hole logging tools and the natural, spectral gamma ray tool can distinguish between ^{40}K , ^{232}Th and ^{238}U to identify source rock and reservoir horizons. Gamma anomalies can be used to identify downhole buildup of NORM scales.

The radioactivity in oilfield scale is due to the presence of decay products of ^{232}Th and ^{238}U. The original depositional environment, geological setting of parent rock will influence the amount ^{238}U and ^{232}Th. ^{238}U and ^{232}Th both decay to produce a series of daughter products of which the most relevant to this report are ^{226}Ra, ^{228}Ra, ^{222}Rn, ^{210}Pb and ^{210}Po. **Figure 1** illustrates the decay series.

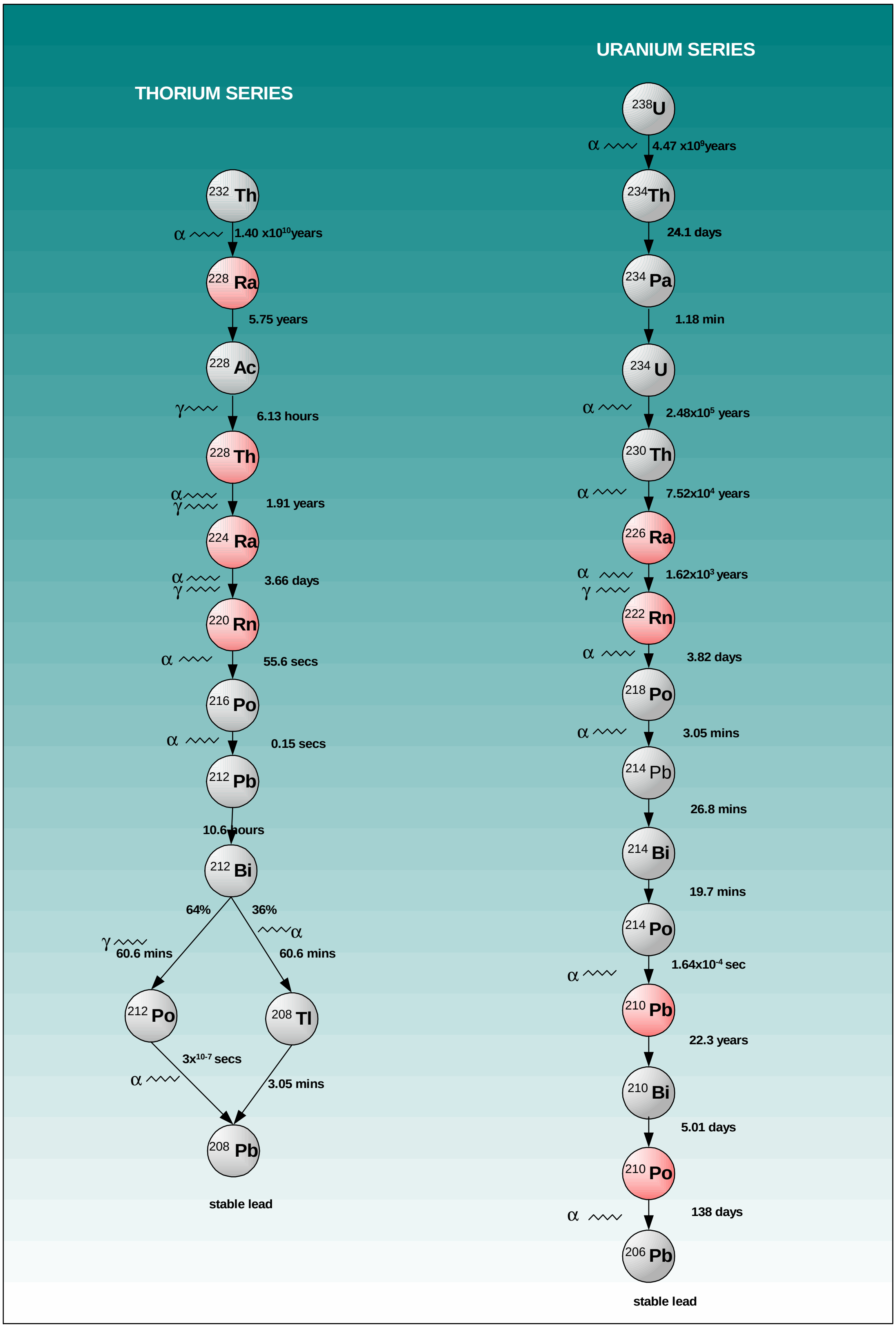
Within a closed system, over geological time, the decay series will be in secular equilibrium *i.e.* all daughters present at the same specific activity (Bq/g). This equilibrium is disturbed over the relatively short, 15-30 year, timescale of oil and gas production by the removal of soluble and or gaseous daughter nuclides. Once removed these nuclides are unsupported *i.e.* they are cut off from their parent and ingrowth of daughters is no longer supported by radioactive decay of the parent.

Uranium in sediments

Uranium tends to be concentrated in organic rich sediments such as oil and gas source rocks. At the time of deposition uranium forms very stable complexes with carbonates and with humic and fulvic acids. Sediments rich in humic compounds absorb uranium from groundwaters. Under reducing conditions organometallic complexes are formed and can lead to enhanced uranium concentrations *e.g.* concentrations up to 6000ppm U, equivalent to 70 Bq/g are seen in peat, lignite and in the kerogen fraction of source rocks.

The ^{238}U and ^{232}Th tend to remain trapped in the source rock and do not migrate to the reservoir with the hydrocarbons. The daughter nuclides that are mobile or soluble under subsurface pressure and temperature conditions and enhanced salinity and absence of sulphate can be transported with the produced fluids and gases. Radon can be transported in gas, hydrocarbons and brines (Hartog 2002) but radium and lead are present in ionic form and require water for transport.

Figure 1. ^{238}U and ^{232}Th Decay series



In nature radium only occurs as the decay product of ^{238}U[3] (*i.e.* ^{226}Ra which has a half life of 1620 years) and ^{232}Th (*i.e.* ^{224}Ra which has a half life of 3.7 days and ^{228}Ra which has a half life of 5.6 years). ^{226}Ra is present at about 10^{-12} g/g in crustal rock corresponding to approximately 0.004Bq/g (Eisenbud and Gessell, 1997).

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

Radium migration

Primary migration of radium into formation water occurs in three stages (Hartog 2002):

1. Expelled from the mineral lattice into capillary surface water by alpha recoil from decay of its parent nuclide.
2. An equilibrium is set up between the mineral phase and bound water on the capillary surfaces.
3. A second equilibrium is established between the capillary surface bound water and the mobile formation water. This equilibrium will be disturbed by the production of the formation water as produced water with hydrocarbons.

Leaching and migration of radium is enhanced by low electrochemical potential (<0), acidic conditions pH <7 and the presence of other cations. Hartog (2002) reports that the relative influence on radium mobility decreases in the following order for common cations in formation water.

$$H^{+} > Ba^{2+} > Pb^{2+} > Sr^{2+} > ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$$

Radium is relatively immobile in an oxidising zone but shows much greater mobility in a reducing zone.

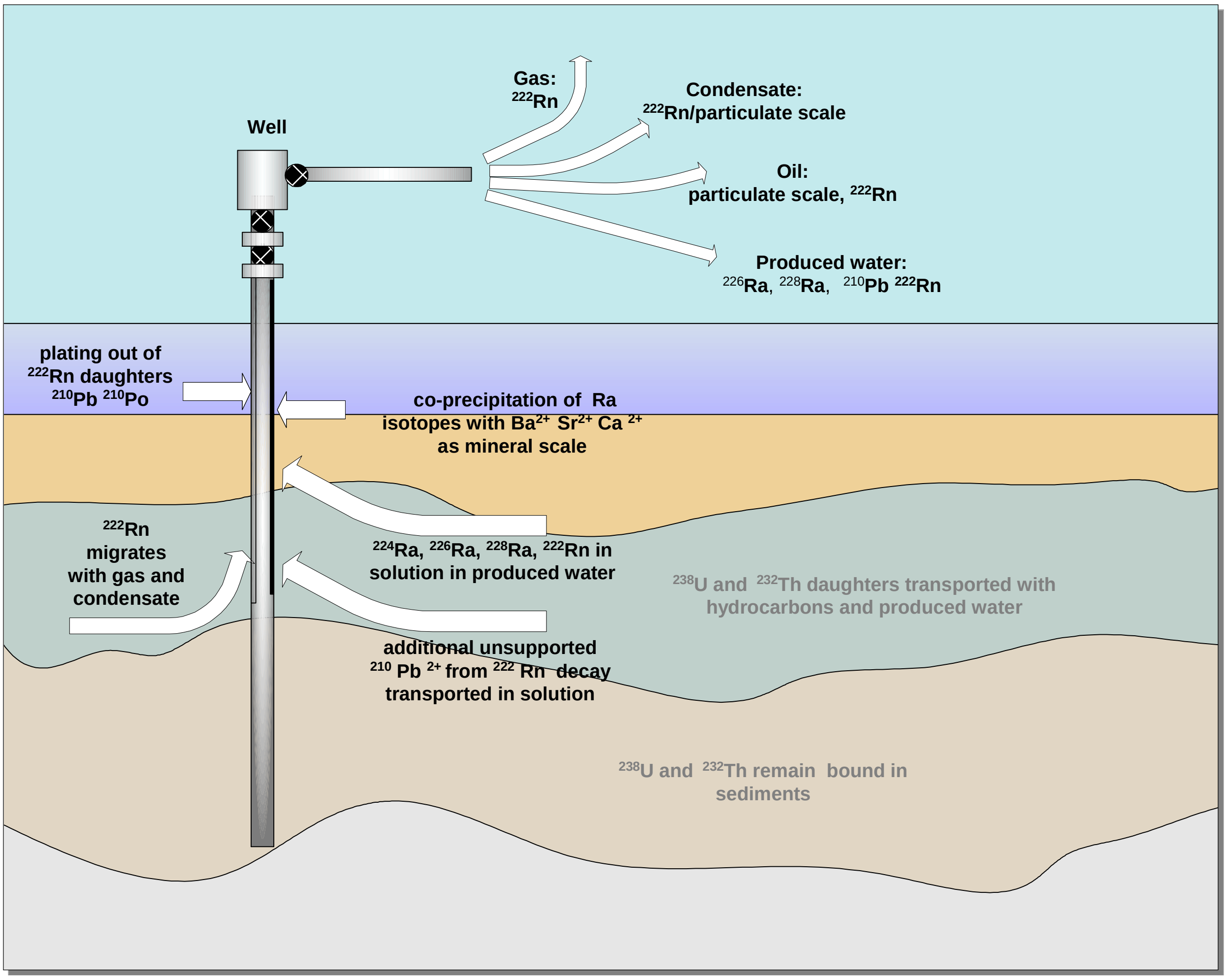
Secondary radium migration includes transport, adsorption and precipitation. Radium may be present as Ra^{2+} ions or be transported adsorbed onto dispersed colloids. Radium can become locally concentrated due to the relative mobility of the Ra^{2+}, its ability to form stable $RaSO_4$ complexes and its tendency to be stabilised by high ionic strength solutions *e.g.* saline formation water where activities from ^{226}Ra of 100 Bq/l have been recorded.

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

Figure 2 summarises the processes at work in the transmission of reservoir NORM into oil and gas production equipment.

Figure 2. Summary diagram of NORM origins

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



2.2 Norm types

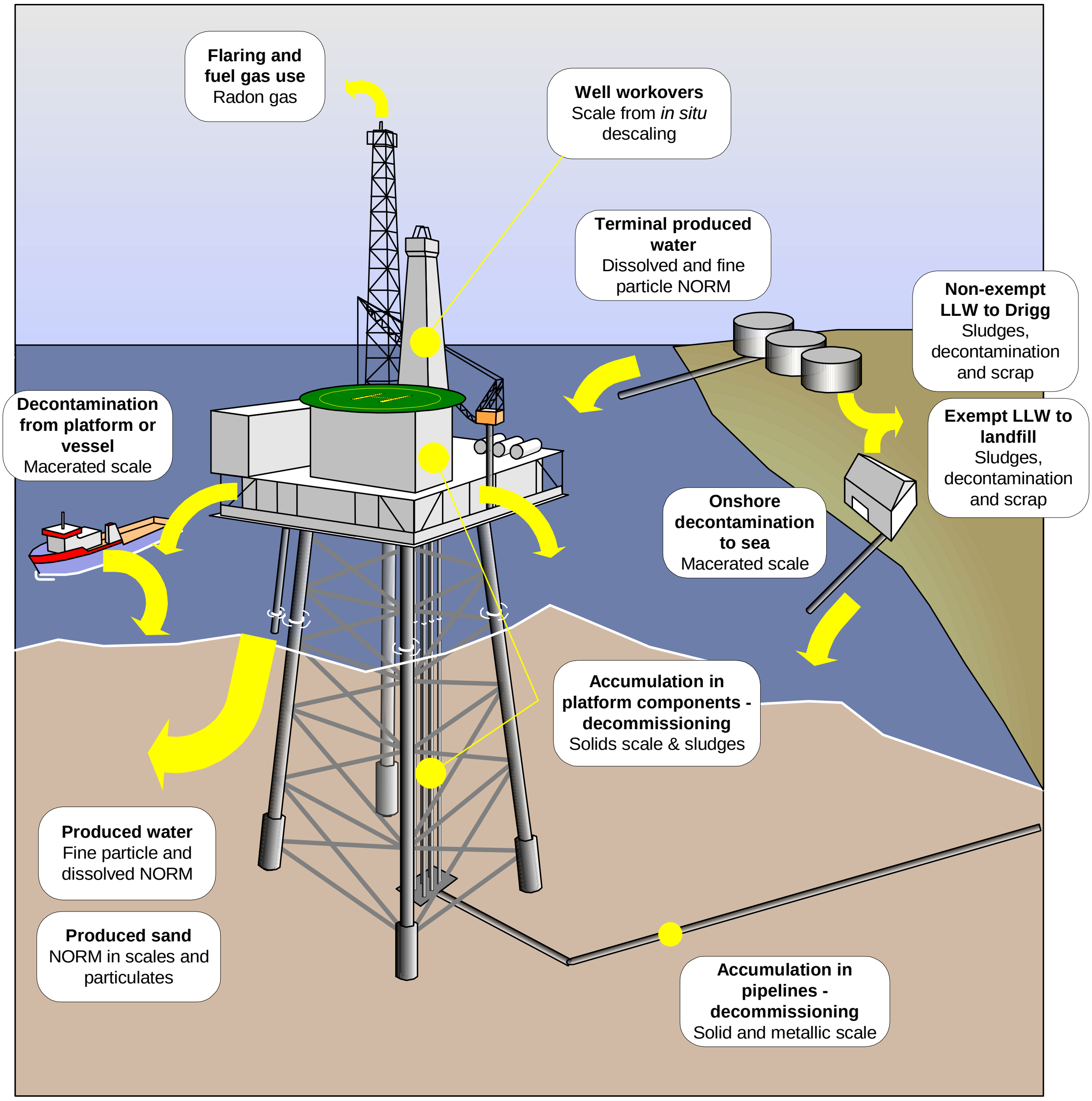
NORM is deposited in components of both oil and gas production and processing facilities and is associated with the production of oil, natural gas and produced water. Petroleum industry NORM most commonly consists of scale in pipes and vessels that carry oil or produced water, and thin coatings lining gas processing components. All Waste streams from oil and gas processing operations can contain NORM (Veil and Smith 1999, Chamber *et al* 1994). The main types of oil industry NORM are summarised in **Table 1**.

Table 1. Summary of the main types of oil and gas industry NORM (adapted from IAEA 2003)

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

Figure 3 illustrates the main NORM waste streams from oil and gas facilities.

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



NORM nuclides are deposited in oil and gas production and processing facilities. NORM deposits fall into 2 broad groups:

- **mineral scales**, mainly containing ^{226}Ra and ^{228}Ra and daughters, either coating equipment or as mineral scale particulates or fragments in sludges and sands. Mineral scale is normally associated with oil and water processing equipment
- **thin metallic coatings** and deposits usually on gas production and processing equipment containing the longer lived ^{222}Rn daughters ^{210}Pb and ^{210}Po. Metallic NORM is particularly associated with LPG and NGL processing.

The general ranges of activity for different types of oilfield NORM are shown in Error! Reference source not found.. **Range of NORM activities from oil and gas industry sources**

Source	**Activity, Bq/g (unless stated otherwise)**						**Location**	**Reference**
	^{226}Ra	^{228}Ra	^{224}Ra	^{210}Pb	^{210}Po	^{222}Rn		
Produced water	0.059						Oklahoma	Strålberg 2002
	0.017	0.023					Australia	Amdel 1992
	0.0089-0.250	0.0096-0.3					Australia offshore	APPEA 2002
	0.004	0.002					Norway	Lysebø et al. 1998
	<0.001-0.04	<0.0004 – 0.17					UKCS	UKOOA 2003
	0.00002 -1.2	0.0003-0.18	0.0005 -0.04				Netherlands	Hartog *et al* 2002
	Below LOD-1.2						Netherlands	confidential
LSA scale	0.1-15,000	0.5-2,800		0.02-75			Netherlands (production tubulars)	confidential
	Up to 3,700						Northern North Sea	E&P Forum 1988
	Up to 15,200						Mid North Sea	E&P Forum 1988
	Up to 3,400						Northern Europe	E&P Forum 1988
	21-250	48-300					Australia	APPEA 2002
	Below LOD to 1050	below LOD to 860					UKCS	Scotoil, 2001-2003
						0.98-18.5 Bq/g	Algeria	Hamlat *et al* 2003
NORM sludges	0.05-800			0.1-1300	0.004-160		Netherlands	confidential
		Below LOD to30					UKCS	confidential
	25	30					Austalia	APPEA 2002
Gas deposits				0.5-7,80Bq /cm^2	0.2-7,80 Bq/cm^2		Netherlands	confidential
				5			Brazil	Vegueria *et al* 2002

Source	Activity, Bq/g (unless stated otherwise)						Location	Reference
Natural gas						40-1000 Bq/m^3	Algeria	Hamlat *et al* 2003
						5-200,000 Bq/m^3	Netherlands	confidential
NGL/LPG						300-2500 Bq/m^3	Algeria	Hamlat *et al* 2003
						0.1-900 Bq/L	Netherlands	confidential
Oil						0.02-0.03 Bq/g	Algeria	Hamlat *et al* 2003
	0.001-0.04						Netherlands	confidential

Note: this list is intended to be illustrative and is not exhaustive. LOD = Limit Of Detection

2.3 NORM associated with mineral scales

Scale consists of minerals precipitated from reservoir fluids. The commonest scales are sulphates ($BaSO_4$, $SrSO_4$) and carbonates (predominantly $CaCO_3$). Naturally occurring isotopes of radium (^{226}Ra and ^{228}Ra) have similar chemical properties to Ca, Mg, Sr, Ba (Group IIa metals) and become incorporated by substitution into the scale minerals. The proportion in which Ra co-precipitates with Sr and Ba is very small (10ppb) but distribution of Ra is irregular and "hotspots" can occur. $RaSO_4$ is reported to be less soluble in water than $BaSO_4$ by two orders of magnitude (Satjajit and Heaton 2002). Routine monitoring with hand held monitors will indicate if there is any activity above background in the scale and the amounts and identity of NORM nuclides present can be established by radiological analysis.

Not all scales contain NORM nuclides but where the produced water contains measurable NORM it is likely that scale deposited will be radioactive. The commonest radioactive LSA scales on the UKCS are sulphate scales although carbonate scales may also contain small amounts of NORM (usually below regulatory limits).

The occurrence of NORM scale can be summarised as follows:

- Hard scale precipitated on equipment - Downhole in tubulars and blocking perforations, in the well head, production manifold, around flanges, valves and in pumps. In topsides, it can occur in produced water re-injection pumps, seawater injection equipment, water treatment plant and flotation cells, (Hartog *et al* 2002, operator questionnaires, proprietary reports). It is normal practice to monitor all equipment for NORM when it is removed for maintenance.

- NORM contaminated sludges and sands:
    - Scale is brittle and fragments frequently become detached and are removed in the process stream. This loose scale is trapped in separators and sand traps.

The fines collect in the slops tanks and storage vessels as sludges and sands containing ^{226}Ra and ^{228}Ra.

- Fine sludges precipitated in process equipment from produced water. These are dominated by silicates and carbonates with trace quantities of radium salts as co-precipitates. They tend to accumulate in process system where produced water collects allowing fall out of solids, such as storage vessels, separators, degassers, desalters and water treatment plant. (Baird *et al* 1990).

The activity measured in NORM mineral scales from petroleum production facilities comes mainly from ^{226}Ra (which has a half life of 1,620 years) and ^{228}Ra (which has a half life of 5.75 years). There is some contribution from the rest of the decay series, but as these have much shorter half lives, with exception of ^{210}Pb, they are unlikely to accumulate. They will contribute to some of the scale activity but up to 90% of scale activity is attributable to ^{228}Ra and ^{226}Ra (White 1992). In general the activity of carbonate scales is lower than that of sulphate scales (APPEA 2002).

Scale build-up in production tubulars and processing equipment can lead to serious losses in production and steps are taken to prevent it through use of scale inhibitors. Although these steps do not remove NORM nuclides, they reduce the amount of NORM-contaminated solids that are produced by keeping NORM in the produced water, which is discharged to sea or re-injected.

The cross section of a typical heavily scaled pipe is shown in **Figure 4**. Scale deposits on the surfaces of tubulars reduce fluid flow by reducing cross sectional area and increasing surface drag.

Figure 4. A heavily scaled 30 cm pipe with capacity reduced by 90%

Scale formation

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

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

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

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

For scale to develop the following are needed:

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

Scale forms when the solubility limit for the scaling ions in solution is exceeded. Mineral solubilities have a complex dependence on temperature and pressure but in general more ions can be held in solution at higher temperatures and fewer at lower pressures; as a rule of thumb, solubility decreases by a factor of 2 for every 48 MPa drop in pressure. The solubility of scaling ions is also affected by the presence of CO_2 and H_2S, being higher in the more acid fluids. It has also been shown that barite scale formation can be increased by the presence of gas hydrate inhibitors especially methanol. The nucleation rate of barite is increased by even by the addition of 5% methanol (Tomson *et al*. 2003)

Scale forms from solution by either:

- Homogenous nucleation: in supersaturated solution small clusters of atoms form seed crystals, once these reach a critical radius they will not re-dissolve and serve as nuclei for scale mineral growth.
- Heterogeneous nucleation: where scale crystals grow on surface irregularities in equipment joints and seams *e.g.* the characteristic scale “doughnuts” which form around joints in tubulars. A high degree of turbulence also can also catalyze scale formation, which explains why scale accumulation can occur at the position of bubble point pressure in a flowing system. Hence the rapid build up of scale deposits on downhole completion equipment (Crabtree *et al* 1999).

The likelihood of scale formation and chemistry of the scale can be predicted from the composition of the formation water, reservoir and well tubing temperature and pressure.

There are a number of proprietary models for estimating scaling potential and scale composition. If any major change in ionic composition of the produced water is predicted *e.g.* new reservoir being co- produced, produced water re-injection, startup of seawater injection, predicted seawater breakthrough, extensive predictive modelling of scale formation will be carried out to avoid loss of production, although this will not provide an estimate of how much NORM will be present.

The deposition of mineral scale in production and process pipework leads to reduced flow and eventual blocking. Regular inspection and changing out of scaled tubulars and valves is necessary where scaling occurs. Scale inhibitors, either downhole and/ or in the topsides, are widely used in the UKCS to control production problems associated with scale build up. NORM in the scale is secondary problem compared to loss of production.

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

The highest activities from NORM nuclides are usually found in downhole equipment: pumps, valves and tubulars. This is corroborated in the data from the major onshore cleaning company based on a breakdown of the activity by equipment type.

Location in the production system is not the only factor affecting NORM scale. The amount of time that NORM has had to build up is also reflected in the levels of activity recorded. This is especially true of process vessels such as separators. From the operator questionnaire replies: operators have varying cleanout policies- some clean out every year when they have their have annual shutdown but the average is 3-5 years between vessel openings with some not opened for 9-10 years.

2.4 NORM associated with gas production and processing

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

The gas deposits are found on inner surfaces of gas/condensate transport lines and vessels and contain ^{210}Pb, ^{210} Bi and ^{210}Po. These typically exist with stable Pb and Fe oxides, carbonates, sulphides as thin coatings or sometimes nodules. NORM contamination is usually measured as activity per unit area rather than by mass or thickness.

A well known exception to this is the NORM found at the Wytch Farm onshore oil field where the predominant NORM type is thin coatings of metallic ^{210}Pb and ^{210}Po. Very little radium isotope containing scale is found although there is plenty of produced water. Worden *et al*

(2000) reports that the formation water from the reservoir has a high ^{238}U content, up to 70ppm, and is therefore rich in ^{238}U daughters. It also has high sulphate levels and very low barium content so that any ^{226}Ra will precipitate out with barite as radium sulphate and not remain in the produced water. However the waters are undersaturated with respect to PbS therefore ^{210}Pb will remain in solution in the produced water and be deposited in downhole and processing equipment. Some high activity values (1000s Bq/g) are recorded from these tubulars.

Gas deposits can accumulate downstream in low energy regions in process equipment in the form of black sludges. These sludges may show activities up to 1000 Bq/g. The radon in the gas and NGL is unsupported once removed from the reservoir (*i.e.* no parent nuclide present to replenish it) and decays away over a short period.

There is also evidence of another type of unsupported lead NORM where ^{210}Pb appears to be transported in ionic form direct from the reservoir (Hartog *et al* 2002) unsupported by its parent nuclide, this ^{210}Pb is always associated with stable lead which acts as a carrier. These deposits are distributed throughout gas processing and range from a few mm thick to large lumps blocking tubing and water injection pumps.

As ^{210}Pb is a weak gamma emitter and ^{210}Po is an alpha emitter these deposits would not be reliably detected through a steel vessel wall from outside by standard NORM monitoring methods.

In view of difficulties with detecting activity from ^{210}Pb and ^{210}Po externally, one operator has tried a mass balance approach. From the residence time of gas and NGL in the lines between offshore facilities and the processing site and taking into account the length of operation of the facilities, it was suspected that a significant build up of longer lived ^{222}Rn progeny would be present in the onshore facilities. An empirical calculation based on half life, gas and NGL volumes and ^{222}Rn activity concentration was carried out (no details supplied). The calculation took no account of changes in gas composition or operating parameters (*i.e.* is a general worst case) and did not include transport of any unsupported ^{210}Pb and ^{210}Po in the gas/NGL. Results indicated that there might be 600 MBq of activity from ^{210}Pb within the facilities and, if in equilibrium, the same activity of ^{210}Po. However the Operator's RPA has reported that the monitoring at this particular facility is very thorough and that they have only ever found one pump that was radioactive but exempt. The facility regularly measures the ^{222}Rn content of the gas arriving, but no figures were supplied.

The levels of activity in this type of NORM vary from just over background to high 0.5-7,200 Bq/cm^2 for ^{210}Pb and ^{210}Po (confidential, and EPA, 1997) and can reach several thousand Bq/cm^2 on downhole equipment.

No data was supplied in the operator questionnaires on ^{222}Rn daughter activity encountered. One operator, however, has supplied survey reports from gas facilities, the results of which are included in

Table 2. Others have reported activities from ^{210}Pb and ^{210} Po but have not supplied values except to say that they are non-exempt.

To what extent NORM deposits are present in gas transmission systems is beyond the current scope but relatively low levels have been reported in gas pipelines in Brazil around 5 Bq/g activity for ^{210}Pb. No figures for the UK could be sourced.

It is possible that significant activity from ^{222}Rn daughters will be encountered on decommissioning gas and condensate facilities and unmanned gas facilities where no monitoring has taken place. However, it is unlikely that these deposits will produce a large volume of waste. They are also unlikely to contain radium and therefore should not present a problem if onshore disposal to Drigg is required.

There may be an exposure risk to personnel from ^{210}Po during the dismantling and reprocessing of components.

Radon in natural gas

The presence of radon in natural gas has been known since 1904. Average concentrations at the wellhead are around 1500 Bq/m^3 but can be substantially higher; 37,000 Bq/m^3 (Gessell 1995). There is considerable variation in the amount of ^{222}Rn present in gases and condensates from the UKCS. Published figures are scarce although UK operators are obliged to sample their gas to demonstrate compliance with the Natural Gas Exemption Order limit of 5 Bg/g so data obviously exists but has not been available for this study..

In general, higher ^{222}Rn values are found in gases in SNS and less in the gas from the CNS and NNS (pers. comm.). The role of the geology in this is not clear although the SNS gas is derived from the carboniferous coal measures and these contain intervals which contain uranium enriched phosphatic nodules, up to 1000 ppm ^{238}U (Smith 1987). The structural relationship of the gas source rocks to the overlying reservoir formations allows contact. in the CNS and NNS of reservoir brines with the U enriched sediments and it is suggested by Smith (1987) and Hartog *et al* (2002) that this is the mechanism of ^{222}Rn enrichment of SNS gases.

There is considerable variation in the amount of ^{222}Rn present in gases and condensates from the UKCS. Published figures are scarce although UK operators are obliged to sample their gas to demonstrate compliance with the Natural Gas Exemption Order limit of 5 Bg/g. It is reported (various operators and their RPAs), that there is more ^{222}Rn in the carboniferous sourced gases in the SNS area than in those associated with oil from Jurassic source.

^{222}Rn activities of up to 200,000 Bq/m^3 have been reported in natural gas. During gas processing Rn tends to become concentrated in the NGL fraction. A concentration factor of 1000 has been seen in the propane fraction. This is due to the boiling point of Radon being between those of ethane and propane (ethane:-88.6^{0}C, Radon: -61.8^{0}C, propane: -42.1^{0}C)

^{220}Rn (“Thoron”), a ^{224}Ra daughter, is also present but as this has a short half life (55.6 seconds) and no long lived daughters, as such it is not usually reported.

Table 2. Examples of activity levels of surface contamination in NGL processing equipment.

System (equipment)	Activity levels recorded Bq/g (^{210}Pb and ^{210}Po)
De-ethaniser	
Reflux drum	29.3
Tower	8.2-8.6
Reboilers	8.9-31.3
C3 recycle exchanger	18.3
De- propaniser	
Tower	184.7
Reflux drum	76.4
reboiler	106-174
De –butaniser	
Tower	0.3-234
Reboilers	9.7-52.9
Bottom cooler	24.6
Bottom filters	4.8

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3 DATA AQUISITION

3.1 Summary

A large number of general texts on NORM were reviewed but there was relatively little firm data for the UK offshore oil and gas industry.

Detailed questionnaires on NORM arisings and occurrence were distributed by e-mail to all UK operators. These were returned for 82 facilities and further detailed information was supplied by several operators. This covered a wide range of facility types and locations and was followed up with selected telephone interviews and an Operator Workshop.

NORM analyses of produced water were obtained for 96% of produced water discharges, supplemented by further analyses from some Operators.

Offshore decontamination records (EEMS and RSA returns) appeared to be incomplete and did not accurately quantify exempt disposals, although offshore disposal records held by operators contained more detail. One Operator's detailed records for 14 facilities (of varying types) were used, combined with other data, as the basis for estimating current offshore decontamination disposals.

Detailed records of onshore decontamination were received and as they are from the only functioning, onshore NORM decontamination facility in the UK for 2002/2003 these are believed to be comprehensive record of decontamination arisings (with the possible exception of the onshore Wytch Farm field).

A reasonable level of detail on decommissioning wastes was obtained from decommissioning reports cross-referenced with waste contractors although firm historic records were difficult to source. Predicted decommissioning arisings have consistently been far higher than actual disposals.

Data obtained on terminal arisings was patchy and seen to be a sensitive issue in some circumstances.

A list of oil and gas disposals to Drigg was obtained, although one operator reported a historic disposal that was not on the list.

3.2 Literature review

An extensive literature search was carried out. There is an abundance of general information on NORM but relatively little published data on amounts or activity of NORM arisings for the UKCS oil and gas industry. In addition to the references in this report, a full bibliography will be contained in the combined Phase I and Phase 2 report (the Final Technical Report).

3.3 NORM reporting to regulators

3.3.1 Overview

Statutory reporting of all non-exempt NORM disposals, regulated by SEPA/EA under RSA 93, is submitted annually. Non-statutory reporting of NORM solid disposals to the DTI is undertaken via the Environmental Emissions Monitoring System (EEMS).

For this study records of NORM disposals reported to SEPA and to the EEMS were obtained for 2002 and, where available, for 2003.

The EA has not had a mandatory reporting system until 2004. The EA has also issued a smaller proportion of RSA disposal authorisations to oil and gas offshore and onshore facilities. Therefore the data for these facilities is sparse. Some further information was obtained by contacting regional EA staff and RSA authorisations were collected as an indication of which facilities on and offshore had NORM present.

3.3.2 RSA Reporting

Under their RSA 93 discharge authorisation operators are legally required to report non-exempt offshore and onshore disposals. However, some operators have also voluntarily reported exempt offshore disposals and this complicates interpretation of the overall totals.

SEPA supplied their 2002 offshore returns for the study and these totalled 390 tonnes with an activity of 25.8 GBq. This data was reported from 72 facilities and includes nil returns. This is more than the EEMS offshore disposals for the same period, when it would be expected to be less, as it should only include non-exempt disposals, which casts doubt on the reliability of the EEMS data. No 2003 disposal data was available from SEPA however 33 questionnaire replies included the 2003 SEPA returns.

SEPA's 'onshore' returns for 2002, covering data from 25 facilities, showed 30.4 tonnes with an activity of 15.7 GBq. This would be expected to be less than the Scotoil returns as, in most cases, it does not include exempt material. The mass of material reported by Scotoil is indeed higher (44 tonnes) but Scotoil's reported activity disposed of is lower (13.1 GBq). It is possible that this discrepancy is due to differences in sampling and estimation.

3.3.3 EEMS Reporting

The EEMS onshore disposals are subdivided into exempt and non-exempt categories. This refers to the calculated activity for radium and polonium. If this is below 14.8 Bq/g the material is exempt from RSA under the PSEO.

Table 3 shows the total activity and weight discharged to sea from offshore installations in 2002 and 2003. Including the "onshore disposals", which is equipment sent from offshore facilities to Scotoil Services who dispose of the removed NORM to nearshore via a pipeline, the totals are:

- for 2003: 624 tonnes of material with an activity of 34 GBq and
- for 2002: 354 tonnes with an activity of 31 GBq.

Table 3. EEMS disposal records

Year	Offshore tonnes	Offshore MBq	Onshore exempt tonnes	Onshore exempt MBq	Onshore Non exempt tonnes	Onshore non exempt MBq
2003	598.9	29,192.9	4.76	192.2	20.47	4690.2
2002	316.7	16,902.3	15.8	610.9	22.1	14,140.7

Note: the number of significant figures reflects the numbers reported, not necessarily their accuracy.

These totals do not include activity discharged in produced water.

The total weight and activity for Scotoil services for the same period (which should approximately equate to the total EEMS onshore disposals) were

- for 2003: 36 tonnes with an activity of 28.6 GBq and
- for 2002: 44 tonnes with an activity of 13.1 GBq

In both cases the EEMS onshore return is lower than that for Scotoil. As there is currently no other onshore cleaning facility[4] this implies that data is missing from EEMS. The EEMS data should be the same or higher, as they might include onshore disposal to a waste contractor or to Drigg.

3.4 General observations on the data received

The number of facilities with returns reported to the EEMS database in 2003 was 55, but as nil returns are not recorded, it cannot be determined whether there are omissions. The current number of RSA authorisations for NORM disposal is 93.

It appears that neither the EEMS nor the SEPA returns data set is complete. Checks were carried on complete data sets supplied for some facilities and for these the EEMS and SEPA record were correct. There was insufficient data available from most operators to attempt this exercise.

In theory, with a full set of SEPA/EA and EEMS returns, a reliable annual quantification could be made. To date, however, the data reported under EEMS and RSA are incomplete. The two reporting schemes are not comparable and do not necessarily provide a meaningful comparison between facilities, or between years. The EA has not had a mandatory reporting system until 2004 and the EA has also issued a smaller proportion of RSA disposal authorisations and the data for these facilities is sparse. Some further information was obtained by contacting regional EA staff and RSA authorisations were collected as an indication of which facilities on and offshore had NORM present.

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

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

[4] there is a small onshore facility in S. England but this is currently for a single field

From the questionnaire results there is a considerable variation in operator maintenance and shut down programmes ranging from annual to 10 year plus for vessel entries and cleanout.

On an individual facility basis the best estimates can be obtained by looking at the NORM disposal history. Facilities keep a detailed record offshore of all disposals although this may or may not be reported in full in onshore databases. From interviews and data sent from operators there is trend towards more comprehensive record keeping to aid rapid reporting to the regulator, especially in the last two to three years.

Complete data sets have been obtained for a number of facilities covering several years and these have been used with all other available data as guides to the likely amounts of exempt and non-exempt material.

3.5 UKOOA Produced Water Data

At the end of 2002 to early 2003 UKOOA reported a study on the potential dose risks from NORM nuclides in produced water (Smith and Watson, 2003). Samples were obtained from 82 offshore facilities. The activity data gave a useful indication of facilities that may have NORM to be disposed of. Although not all of the facilities with RSA authorisations and registered NORM disposals were covered by the UKOOA study, the facilities where an analysis was undertaken represented 96% of all produced water discharges. NORM activity in produced water is discussed in more detail in Section 4.2.

3.6 Operator Questionnaire

3.6.1 Approach

Questionnaires were prepared and sent out to all operators. These were in electronic format in Microsoft Excel for ease of completion and circulation within recipient organisations.

The questionnaire was divided into sections covering the following issues:

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

The questionnaire was followed up by an Operator workshop held on 19 May 2004 and attended by representatives from 10 Operators.

3.6.2 Responsiveness

A copy of the questionnaire sent to operators is shown in Appendix 1. Replies were received from 82 facilities from 22 different operators. The level of response to different sections was variable. Not all operators filled in all sections as more than one area of expertise was required to complete the questionnaire and, as it later emerged, some of the data may only be held in sufficient detail offshore. It was agreed with the SNIFFER Steering Group that the results would not be attributable. The results below are summaries of the findings for each set of questions as much of the information obtained was very repetitive and there is a large volume of data.

Returned questionnaires accounted for 71% of the UKCS facilities.

3.6.3 General NORM occurrence

There is a preponderance of data from the Central and Northern North Sea. The geographic distribution of replies is as follows:

Central North Sea	32%
Northern North Sea	37%
Southern North Sea	13%
West of Shetland	1%
Irish Sea	5%
Inner/outer Moray Firth	11%
Onshore	1 %

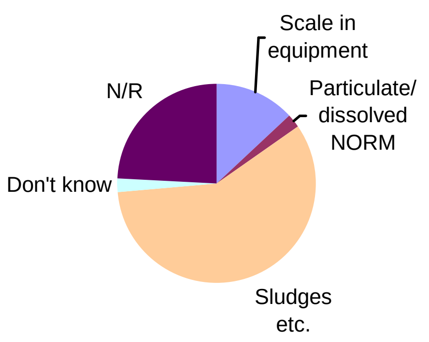
Of the facilities that replied 23% are gas or gas condensate producers, 67% are primarily oil producers and 10% oil and gas.

50% had NORM associated with liquid handling only, 2% reported associated with gas equipment only and 24% with liquid and gas equipment (23% did not indicate a distinction). 13 facilities reported that they have no NORM occurrence. All of these, bar one, show activity in their produced water below limit of detection for ^{226}Ra and ^{228}Ra.

The gas and gas condensate facilities which replied all reported the presence of $Pb^{210/}$ Po^{210} deposits and some also have mineral scale associated with produced water. The oil producing facilities which reported having NORM present all have mineral scale and several of the older facilities are now finding activity from ^{210}Pb in scale and vessel sludges due to ingrowth of ^{210}Pb from ^{226}Ra present in the scale. Some also have also reported ^{210}Pb and ^{210}Po coatings on gas equipment.

Figure 5 shows the response relating to the physical type of NORM present.

Figure 5. Physical type of NORM present



Operators were asked if there were radiological analyses of the NORM and if so what the main nuclides present were: most reported mineral scale containing ^{226}Ra and ^{228}Ra, a few reported only ^{210}Pb and ^{210}Po (20% no response).

Operators were also asked whether there were standard chemical analyses of the scale. There were 17 responses, noting the following constituents present in the scale.

- Barium sulphate 10
- Barium and strontium sulphate 6
- Calcium carbonate 8
- Iron oxides 2
- Metal sulphides 1

No detailed information on the chemical composition of the scale was supplied by any operator.

Finally in this section operators were asked whether they had any particularly persistent problems with NORM at their facilities. Most reported continuous occurrences in the produced water treatment and injection systems. Also high on the list were choke valves, separators, degassers, hydrocyclones, seawater lift pump, pigging wax, process vessels and pipework in general, ballast tanks.

One operator reported severe scaling with LSA in a separator due to incompatible waters from different wells entering the vessel. After a scaling study a new scale inhibition program was put in place which prevented further build up of scale, the NORM now remains in the produced water.

3.6.4 Scale inhibition

Operators were asked whether they had a scale inhibition programme in place. Most did (62%) but a significant number did not (more than the number who had reported no NORM). They were also asked whether their scale inhibitor use had increased over time. Only half replied to this but of those that did most reported static (58%) or increasing (37%) use. Only one reported decreasing use. Many operators with significant scaling problems use inhibitor squeezes (periodic forced injection to the formation) to prevent scale build-up downhole and in the formation near the wellbore.

It has been assumed in previous predictions of future NORM arisings that the amount to be disposed of will rise with increasing water cut towards the end of field life. With improved scale inhibition, however, this may not be the case. The total amount of NORM nuclides produced may well increase as the rate of water production increases but NORM is likely to remain in the produced water. The results also suggest that there is no relationship between NORM concentrations and field age (see Section 6.1).

3.6.5 NORM Data

RSA and EEMS returns for 2002 were requested from the operators. RSA returns were received for 2003 (36) and 2002 (33). The returns sent were compared with the EEMS returns. The problem being that operators are only legally required to report non-exempt radioactive disposals to SEPA but in fact some are reporting all disposals. In some cases it has been possible to see all disposals off and onshore and calculate what weight and percentage is exempt but there is insufficient information to do this for most. This is of relevance in the event of a ban on offshore disposal requiring return of all NORM waste to land for storage as there are very restricted options for non -exempt waste disposal

Relatively few operators supplied analytical details of their NORM.

Operators were asked if they ever had to dispose of NORM containing waste to shore apart from contaminated equipment bound for Scotoil. All except 3 plus 1 onshore facility said no. The question sought to establish amounts of NORM containing oily wastes that cannot be put through the macerator. Some reported de-oiling pigging wastes offshore and then disposing of the NORM to sea however not all facilities have this capacity. One operator provided a comprehensive data set including solid NORM wastes.

The set of questions about amounts and sources of NORM received a limited response. Some operators, however, forwarded detailed NORM disposal databases which provided a useful historical insight.

It is clear that amounts of NORM from vessel clean outs will vary from year to year depending on frequency of shut downs and clear outs number and size of vessels. Available figures for 2002 showed between 1.7 and 45 tonnes from vessel clean out.

The question about amounts of radioactive pigging wax and relation to type of pipeline was not completed. Although in the disposal records from one operator at least there was a disposal to shore of exempt pigging wax. Pigging wax has the additional problem of being oily and therefore a hazardous waste as well as being radioactive. The monitoring of pigging wax should be covered in the facility local rules.

Some operators commented that due to improvement in scale management, reaming and milling are now much less common, if needed at all, and therefore there was less scale from down hole to be disposed of. The largest source of NORM for offshore disposals is from vessel cleanouts. Valves, pumps, tubulars are usually removed onshore for cleaning and nearshore disposal.

In general anything which could be decontaminated offshore would be, to avoid disposal to onshore.

3.6.6 Produced water

Operators were asked whether they had and could supply any other produced water analyses apart from those taken for the UKOOA study. Only two sent extra analyses to add to the UKOOA data. From interviews many operators have or are about to instate a quarterly sampling programme.

Produced water discharge data is obtainable from EEMS but in the questionnaire the amount (if any) re-injected was also requested. Plus, if known, the amount discharged to shore in export lines.

Eight facilities replied that they had produced water re-injection and two were currently conducting trials. Operators were also asked about the amount of water exported to shore in oil/gas/condensate lines.

Five gave a volume, others gave the average water cut in oil lines. It is difficult to get a useful overall figure from this. This is also a mechanism by which NORM can be inadvertantly moved onshore to terminals.

One operator commented on the possible removal of fine particulate NORM from produced water by filtering but was concerned that the filter media would then become a radioactive waste for which they had no disposal route. They were also concerned that as some of the NORM is present in solution that filtering would not remove all of the activity.

3.6.7 NORM equipment decontamination

Operators were asked a set of questions about onshore and offshore cleaning and what was removed and what equipment was cleaned and by whom.

Decontamination companies do not have their own RSA authorisations and dispose of removed NORM to sea under their client's facility RSA authorisation. They do not bring waste onshore themselves.

NORM decontamination is carried out by physical/mechanical methods involving vessel entry cleanouts and high pressure water/abrasive jetting. Estimates of volume and/or weight are made by the cleaning contractor by methods agreed with the operator prior to disposal to sea. Disposal is managed by the contractor's RPS and representative samples of the material taken for radiological analysis, overseen by the operator RPS. The platform has to keep records of this because the activity of the material is not known at the time of disposal *i.e.* whether it is exempt or not therefore all monitor readings and volumes are recorded until sample analyses are returned and the correct entries can be made (Platform LSA disposal records).

One operator provided a copy of contractor vessel entry procedures and reporting interface with operator RPS procedures for recording of disposals. These are used to compile the reports for the EEMS and SEPA returns.

Operators were asked which items they routinely cleaned on and offshore the results are shown in **Figure 6**.

Figure 6. Onshore and offshore cleaning

Cleaned offshore Cleaned onshore

Scotoil supplied an inventory of their oil and gas decontamination jobs for the last three years. Tubulars produce the greatest volume of NORM waste compared to pumps, spools and valves.

None of the operators who replied reported using chemical NORM removal methods offshore. Many operators commented that they would clean as much as possible offshore but that more complex items which require dismantling had to be sent onshore. One pump manufacturer, Score Europe, has an authorisation to receive contaminated equipment but this has to be sent to Scotoil for decontamination and NORM disposal.

3.6.8 NORM monitoring

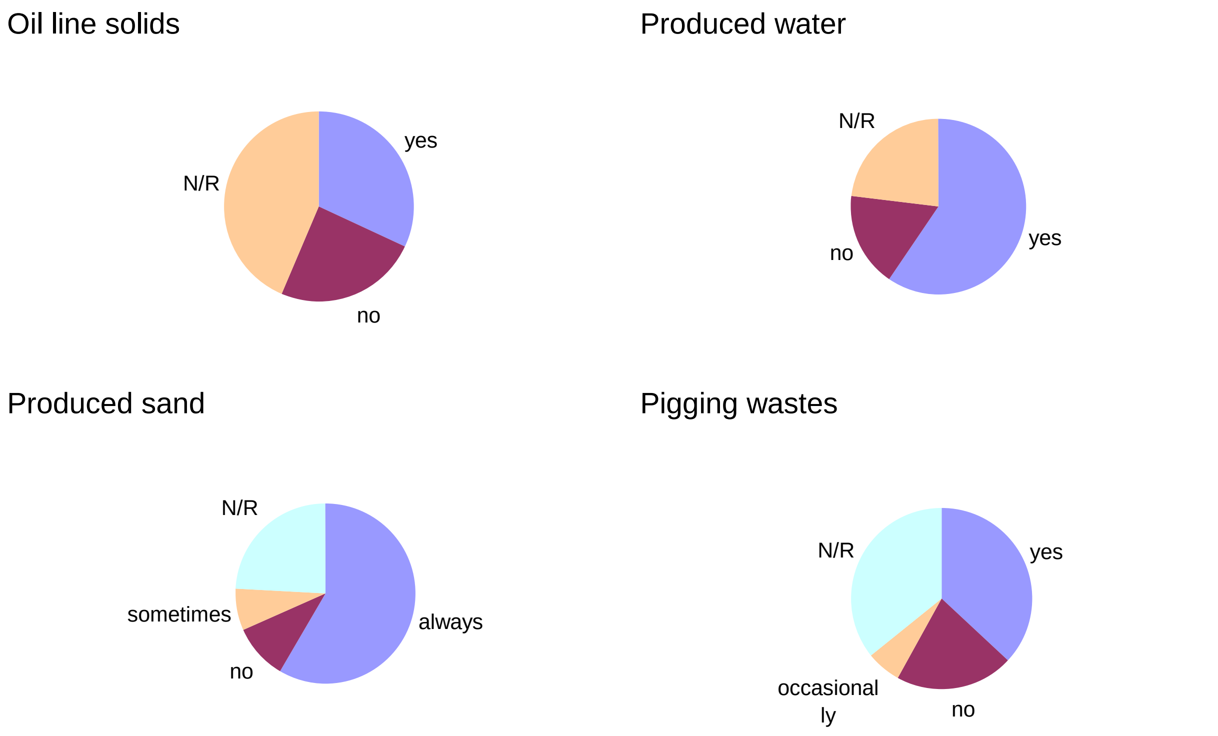
The operators were asked where NORM was monitored and the results are summarised in **Figure 7**. The aim of this was to identify whether any potential NORM waste stream was not being monitored.

Most operators do not routinely monitor particulate NORM in the export lines, and are not expected to do so, although when any export system equipment is changed out it will all be monitored for radioactivity under the facility local rules. Oil line solids are analysed on a weekly basis but not routinely for the presence of NORM. Oil line solids are periodically monitored for NORM (usually when pumps or other equipment are dismantled) but operators are less likely to pick up suspended NORM particles in the flow. This is relevant as it is reported that some onshore oil and gas/condensate terminals have experienced a NORM disposal problem due to suspended fines in product streams. This can have legal/financial implications if terminals are receiving from more than one operator and passing product on to third parties downstream.

Most operators monitor produced sand for NORM although some only occasionally.

Operators were also asked whether they monitored produced water for NORM. Most respondents did but some reported no. Many operators have started quarterly sampling while awaiting SEPA approval of the produced water sampling protocol.

Figure 7. Operator responses on NORM monitoring



Note: N/R=non-response

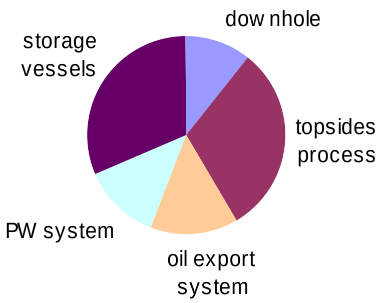
Some of the “no” replies were from facilities which had been shown to have “radioactive” *i.e.* regulated produced water in the UKOOA study.

Operators were asked, for each of their facilities, whether they receive pigging waste from other facilities; 59% of the respondents did, 29% did not and 12% did not respond. They were also asked whether the pigging wastes were monitored for NORM; 35% reported that they had sent pigging wastes for radiological analysis 33 % have not (31% did not respond).

A further question was asked about NORM occurrence in different product lines. Most reported NORM associated with water in oil lines. None reported any NORM in gas and gas condensate lines, although it is known from other sources that NORM is are present in gas and condensate lines and disposals have been made. There was a low overall response to this question and gas and condensate facilities were under-represented in the replies.

Operators were asked if they had ever carried out a detailed NORM survey on part or all of the facility separate to routine monitoring (**Figure 8**). Most had not for a variety of reasons: not deemed necessary, not required for legislative compliance, no significant NORM issues. Where surveys had been carried out these were usually in response to a specific issue or problem. Two operators supplied supplementary reports on NORM surveys and investigations.

Figure 8. Areas where NORM surveys have been carried out



Of the storage vessels surveyed 50% were oil and 40 % water and 5% each for gas and condensate.

Separate to surveying for NORM, *in situ* NORM monitoring can be carried out downhole using modified gamma logging tools or from new anomalies in gamma tool response in the well due to build up of LSA scale. Some operators reported the use of in situ techniques and it is common practice in the USA.

All facilities must have Local Rules (Under IRR 99) that include what, where and when monitoring should take place. From interviews with operators there is increasing awareness that if a facility has NORM then all areas are candidates for contamination and any equipment opened up or removed will be monitored. There was generally less recognition of potential for contamination in gas /condensate equipment. It was perceived as largely a Southern North Sea issue.

In external monitoring, using the standard equipment on platforms, only γ radiation with energy over 50 keV will be detected. Steel vessel walls will stop α and ß radiation and attenuate γ radiation by approximately 50% for 1cm of steel. It is reported that this would limit external detection of γ radiation from anything under 200 Bq/g ^{228}Ra, ^{228}Ra and ^{224}Ra combined (Hartog *et al* 1998).

Routine external monitoring will therefore not reliably show activity from ^{210}Pb (approximately 30-40 keV) or ^{210}Po which is an α emitter. The shorter lived radon daughters (above ^{210}Pb) might be detectable externally if present at enhanced concentration but these all have very short half lives and activity would decay away rapidly after plant shutdown. An example of this type of rapid activity loss was reported in a questionnaire and subsequently explained by the operator's RPA. In that case filters from a gas facility had non-exempt levels of activity when removed but this was observed to disappear to near background after a couple of days. This was activity was due to the decay of ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po. The next nuclide in the series (see Figure 1) is ^{210}Pb with a much longer half life so much lower activity levels are seen.

From the responses to this section, follow-up interviews and other research it appears that current monitoring is not fully capturing suspended or solid NORM in produced sand although this is unlikely to account for a significant proportion of NORM discharged. A small number of operators sample the product stream for NORM but activities were not ascertained.

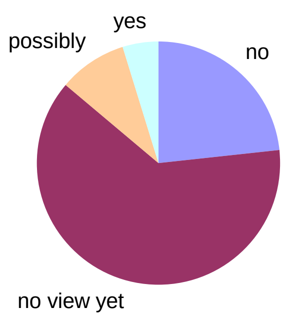
3.6.9 NORM disposal

The aim of this group of questions was to obtain additional numbers or at least corroborating data for EEMS and SEPA disposal figures and to seek opinions about NORM disposal. Some operators were able to provide SEPA returns other years in addition to the year requested. The questions were also aimed at establishing how many facilities already had slurry (cuttings re-injection) *i.e.* for how many would NORM re-injection be feasible in future. Five operators responded that they had maceration equipment installed. Most do not and rely on mobile units brought on board by decontamination contractors.

Operators were asked whether they had cuttings re-injection equipment, *i.e.* which might be used in future for NORM re-injection without a lot of extra investment. 18% of respondents did, 58% did not (26% no reply).

They were further asked if they had cuttings re-injection whether they would consider using it for NORM disposal. The response is shown in **Figure 9**.

Figure 9. Whether cuttings re-injection equipment would be considered for NORM solids

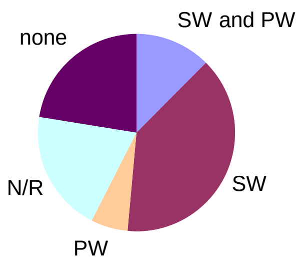


The DTI has informed OSPAR of the UK's intention to permit re-injection of solid NORM but to date there is no record that this has been carried out on the UKCS.

Operators were then asked if they were intending to install equipment to re-inject NORM solids. In follow up interviews it was commented that the expense, financial and in emissions, of installing re-injection equipment for relatively small amounts of NORM would not be justified. It was pointed out in replies that the re-injection pumps have a high power consumption.

Operators were also asked about water re-injection equipment at their facilities. The response is shown in **Figure 10**.

Figure 10. Types of re-injection carried out



SW = seawater
PW = produced water
N/R = no response

Some facilities that re-inject do not use produced water, but drill water extraction wells to ensure a constant supply of injection water. Frequently the supply of produced water is insufficient or unreliable for reservoir pressure maintenance, and mixing produced water and sea water for re-injection would almost certainly result in a massive scaling problem.

Relatively few operators reported re-injection of produced water, although, from the questionnaire and interviews, many more are considering it as a method of meeting the OSPAR oil in water targets, which would incidentally reduce NORM discharges to sea.

Operators were also asked about current, installed re-injection capacity. Replies ranged from 100,000 barrels per day to a few thousand barrels per day.

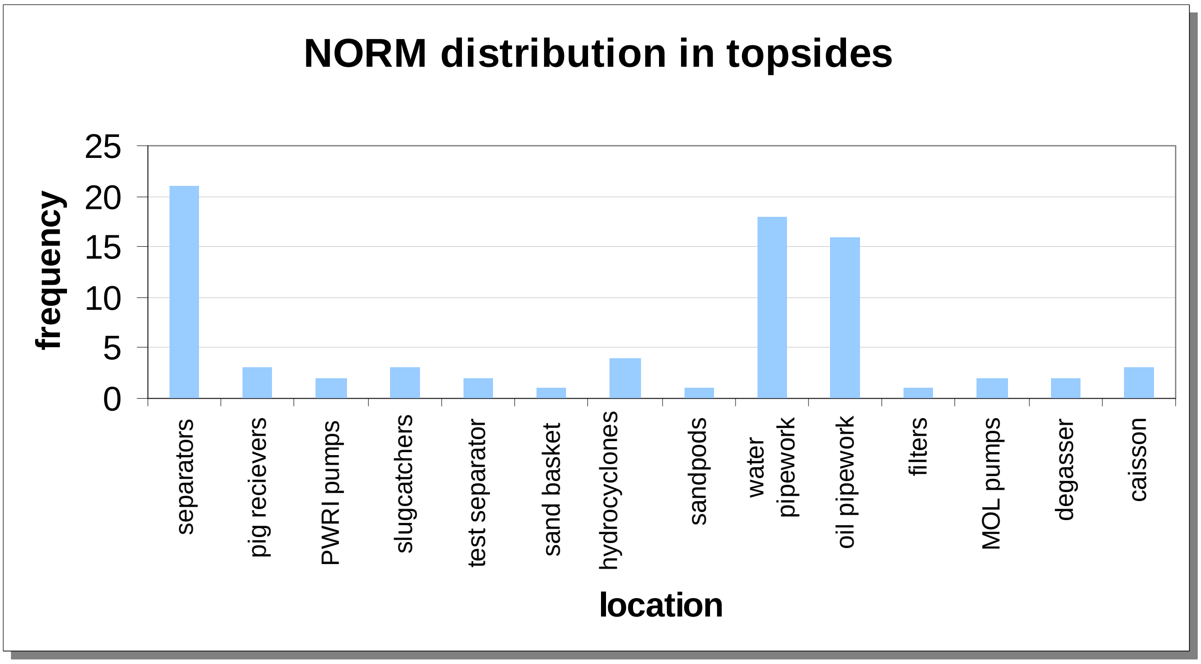
They were also asked about disposal of pigging waxes and vessel sludges. Of those who replied, most disposed of removed NORM to sea via a macerator. None reported any non-exempt pigging waxes.

Operators were asked for a breakdown showing what percentage of solid waste was exempt although this will obviously vary year on year according to what activities are being carried out. There was little response to this even though this information must be captured in the platform LSA disposal records.

Operators were asked about the general occurrence of NORM at their facilities. They were asked to list the main areas where NORM had been found.

Figure 11 show the reported distribution in topsides equipment.

Figure 11. NORM distribution in topsides equipment



The replies were as predicted with most occurrences in the separators and water treatment system. The distribution may also reflect monitoring programmes.

Whether the NORM in the oil system reported is due to water present or to particulate NORM in suspension would have to be established on a case by case basis as both occur.

No data was submitted on activity of the NORM in the questionnaires. From analysis of the activity of Scotoil jobs for the last 3 years the distribution of activity in tubulars and other components has been analysed.

In general, downhole equipment exhibits higher specific activity than equipment at the surface, but no clear relationship is observed and hot spots can be observed in many locations. Variation is due to specific local conditions of pressure and temperature, turbulence and throughput.

This study has not included every subsea tie back in the facilities list however there was space for replies in general NORM occurrence section. Obviously these are not frequently opened up for inspection and therefore there is rather sparse data. However several operators reported NORM where interventions have been carried out and equipment valves etc. changed out.

3.6.10 General points

The occurrence of solid NORM at any facility depends on the subsurface geochemistry, level of scale control, the activity of the produced water, the throughput and type of processing carried out. Where there is gas and condensate there will, in time, be ^{210}Po and ^{210}Pb deposits in gas handling facilities to a greater or lesser extent.

Careful monitoring of NORM and recording of results will allow a reasonable prediction to be made for individual facilities for estimation of future disposal requirements and planning for NORM disposal on decommissioning.

The study did not have access (in most cases) to the minutiae of each facility's Local Rules (IRR 99) or detailed monitoring programmes for RSA 93 and not all questionnaire responses gave sufficient monitoring details. In general, from follow up interviews it is clear that while there is there is fairly thorough recording of NORM occurrence at the facility this is not always held in as much detail onshore and equally only that which is legally required is reported to SEPA (*i.e.* non-exempt disposals on and offshore).

4 NORM OCCURRENCE

4.1 Produced water

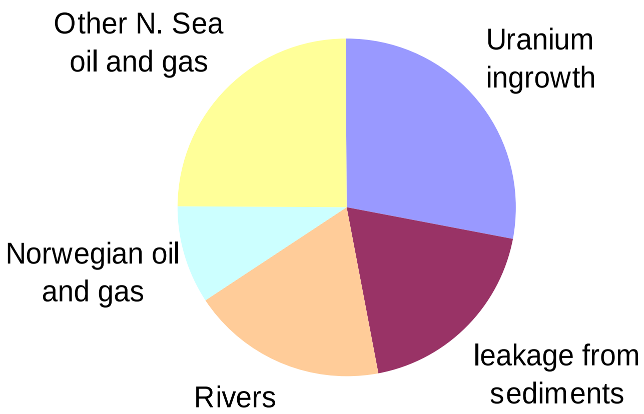
4.1.1 General

NORM from oil and gas reservoirs is released to the environment in produced water discharges. Seawater naturally contains some NORM radionuclides and concentrations may be increased by the addition of industrial emissions to sea, rivers and the atmosphere. Data for NORM nuclides in seawater are scarce.

Dutton *et al.* (2002) suggests that the greatest contribution to the total collective alpha radiation dose in the OSPAR area comes from the phosphogypsum and oil extraction industries. The reason for this is the high relative radiotoxicity of the common NORM radionuclides discharged ^{226}Ra, ^{210}Pb and ^{210}Po. In the past there have been significant contributions to collective alpha dose from man made radionuclides discharged to sea from nuclear installations. These have dropped considerably in recent years and the overall reported discharge of alpha emitters into the OSPAR II region, which has remained relatively constant since 1986, is now due mainly to discharges from the NORM industries. Due to the decline in input from the phosphate industry the relative contribution from oil and gas extraction has increased although the total input overall has declined.

Varskog (2003) quotes 1.1 TBq/year from ^{226}Ra from the North Sea countries' oil and gas industries, compared with a total from other sources to the North Sea of 2.1 TBq, illustrated in **Figure 12**.

Figure 12. Relative contribution of different sources of ^{226}Ra to the North Sea



Source: Varskog (2003)

In the 2002 Radioactivity in Food and the Environment (RIFE) report (CEFAS, 2003), the total activity of discharges of alpha-emitting liquid radioactive waste in the UK is reported as 193 TBq, almost all from leachate from historic disposals at Drigg which drain into a tidal estuary.

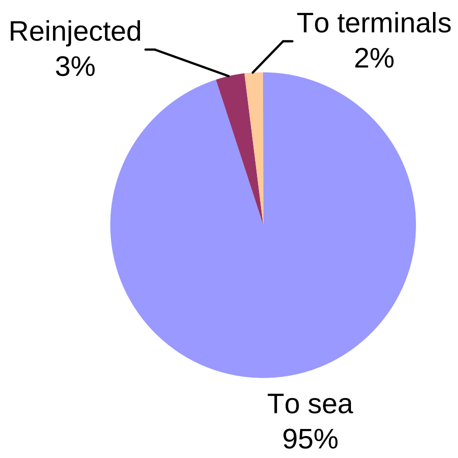
4.1.2 UKCS Produced Water

The amount of NORM in produced water was not routinely monitored on the UKCS production facilities until recently. Partly in response to statements in the EU 'Marina II' study, UKOOA undertook a sampling and analysis programme.

Even though unit activities are very low, the volumes of produced water discharged mean that the sum of activity discharged appears relatively high. Most produced water discharges exceed the RSA Schedule 1 liquid limit for radium and are therefore 'radioactive', requiring regulation under an RSA 93 authorisation. Historically, many production facilities have had RSA 93 authorisations to cover the disposal of solid NORM arisings, with annual limits of 5-10GBq, but not a produced water discharge. For example, a North Sea platform with an annual produced water discharge of 4,600,000 m^3 with ^{226}Ra activity of 0.0093 Bq/g and ^{228}Ra activity of 0.012 Bq/g gives a total activity for the annual discharge of 700 GBq. Operators are in consultation with the regulators to resolve this issue and it is understood that revised authorisations have been sought by a number of operators to cover the discharge of produced water.

99.8% of produced water in the UKCS originates from oil production facilities, with 0.2% from condensate production facilities and a negligible amount from gas-only facilities. The current fate of the produced water is shown in **Figure 13**.

Figure 13. Current fate of produced water



Source: DTI (2004) and Operator questionnaires

The study of produced water from 82 UKCS production facilities by UKOOA in 2003 covered approximately 96% of the UKCS produced water discharges by volume.

The results show ^{226}Ra ranges from below the limit of detection (0.001 Bq/g), to 0.04 Bq/g and ^{228}Ra from below the limit of detection (0.0004 Bq/g) to 0.17 Bq/g. The analyses did not include ^{210}Pb and ^{210}Po as these were below the limit of detection for most of the samples (0.00003 Bq/g).

Some samples were filtered to 4µm and the results are shown in
Table 4.

Table 4. Activity (Bq/g) Filtered versus unfiltered produced water samples.

Unfiltered activity Bq/g		Filtered activity Bq/g		% activity removed in solids	
^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra
0.013	0.0073	0.0063	0.0021	48.4	34.7
0.013	0.008	0.0069	0.0012	53.1	15
0.01	0.024	0.0068	0.002	68	8.3
0.017	0.011	0.0087	0.0039	51.1	35.4
0.013	0.0094	0.0058	0.0025	44.6	26.6

Source: UKOOA (2003). Filtered to 4 µm

It can be seen from **Table 5** that less than half of the total activity was in particles >4µm, the remainder either being in solution or as particles <4µm. It might be expected that there would be a significant variation in size of suspended material from different process conditions might contribute to the variation in amount of NORM in solution versus in particulates.

4.1.3 Current total activity discharged to sea in produced water

To estimate current total activity in produced water, the most recent analysis of produced water is used for each facility, or where no analysis was available, the mass-weighted UKCS average figure is used. Where activities were below LOD, the LOD value has been adopted (0.001 Bq/g for ^{226}Ra and 0.0004 Bq/g for ^{228}Ra), which will result in a slight overestimate of total activity. Produced water figures were obtained from the questionnaires for a further seven facilities provided by Operators in the questionnaires.

According to the UKOOA data, the total annual activity discharged from produced water for 2002 for 82 UKCS installations (not including onshore facilities) to the OSPAR area is estimated as 9800 GBq (9.8 TBq). The figure calculated for the UKCS for 1999 in the Marina II report was 4.5 Tbq specific activity for each of ^{226} Ra and ^{228}Ra. This would indicate a total activity of 63 TBq discharged. For this report the values from the UKOOA study have been used as they are based on reported volumes of produced water discharged and measured produced water activities.

Addendum: the Norwegian Radiation Protection Authority has recently issued a report (NRPA 2005) on the natural radioactivity in produced water from the Norwegian oil and gas industry in 2003. This uses repeat analyses, at monthly intervals, of produced water from 41 offshore installations on the Norwegian shelf and reported discharge volumes. On this basis it was calculated that 0.44 TBq ^{226}Ra and 0.38 TBq ^{228}Ra were discharged to sea. The Marina II (Dutton *et al*, 2002) discharge figures for ^{226} Ra and ^{228}Ra for the Norwegian sector were calculated as 5.2 TBq for each nuclide.

4.1.4 Produced water re-injection (PWRI)

Reporting volumes of PWRI is not currently a regulatory requirement and relatively few operators replied to this section of the questionnaire. Many operators are currently investigating re-injection as a potential solution for oil in water reduction targets. It is widely expected that re-injection will increase in the near future although it is impossible to estimate quantities with any accuracy.

The DTI surveys operators annually to determine PWRI figures, which are provided on a voluntary basis. The data for 2002, supplemented with data from the questionnaires, identify 9 facilities currently carry out re-injection, with total volume of 7,500,000 m^3 and an activity of 278 GBq. This is approximately 2.5% of all UKCS produced water. This excludes seawater, which is re-injected for reservoir pressure maintenance.

Of the nine facilities that are reported as re-injecting, the UKOOA (2003) analyses identify six that have water that is above the RSA 93 Schedule 1 limit, *i.e.* is radioactive, a further two that were below the limit of detection and may or may not be radioactive, and one that had no analysis.

4.2 Arisings from process vessels

4.2.1 Vessel sludges

NORM sludges may consist of detached scale fragments, or mixtures of scale, sand corrosion products. They are generally of lower total activity than attached scale as the scale in sludges is mixed with other non-radioactive solids. The sludges usually occur in pipeline bottoms, particle traps in oil and water lines, in and near filters. The largest quantities are recovered from storage vessels for oil, NGL, gas or water. Significant volumes are also found in process equipment: slugcatchers, separators, desalters, degassers, hydrocyclones. The activity of the sludges is highly variable depending on the source of the NORM and the source of the sludge. Most of the offshore disposals reported are removed vessel sludges. Samples will have been sent for analysis in order to establish whether the sludges are exempt or not and therefore whether they have to be reported to SEPA. This data is held offshore as part of the platform disposal records.

Until recently most operators did not analyse for ^{210}Po unless they has a special reason to do so as a separate analysis is required. So there is relatively little ^{210}Po data available for any types of sludge.

A significant gap in the current data set is the amounts of sludge from gas treatment facilities, there are some published figures for activities but none for volumes/weights for disposal.

Hartog *et al* (2002) recorded some activities in sludge from gas processing facilities, *i.e.* ^{226}Ra 0.05-800 Bq/g, ^{228}Ra 0.5-10 Bq/g, ^{210}Pb 0.1-1,300 Bq/g and ^{210}Po 0.004-160 Bq/g. Radium activities in sludges from oil and water treatment and storage vessels generally range from under one to a few tens of Bq/g.

4.2.2 Produced sand

Operators were asked in the questionnaires about monitoring of produced sand. Most, though not all, routinely monitor produced sand for radioactivity. Some carry out sandwashing of vessels prior to entry and vessel sediments may pass into the PW system, where they may be trapped and later removed or from where they may be discharged to sea. The fate of such sand will depend on the topsides layout in each facility.

Some operator studies have shown that under some process upset conditions, sand and particulate NORM can pass into the oil export system. Product streams are not routinely monitored for NORM.

Amongst data received from Operators there were 32 analyses of produced sand. Two of these were above the solids exemption level and the remaining 30 were less than 9 Bq/g.

4.3 Onshore decontamination of equipment

4.3.1 Overview

Equipment that cannot be cleaned offshore is sent ashore to a decontamination facility for cleaning and the removed NORM is disposed of by that facility. Virtually all onshore decontamination is currently undertaken by Scotoil in Aberdeen. Until December 2001, AEA Technology at Dounreay received equipment for decontamination and the removed NORM was cemented and stored on site, where it remains awaiting final disposal. Scotoil's data for 2002 and 2003 represents all onshore decontamination from UKCS facilities with the exception of one onshore field. For this field, RWE Nukem carries out decontamination of tubulars at Winfrith, Dorset, but the mass of NORM is relatively insignificant. Since Scotoil is routinely audited, their datasets for 2002 and 2003 should represent a comprehensive record of onshore decontamination arisings for those years.

After cleaning, the weight and activity for ^{226}Ra, ^{228}Ra, ^{210}Pb (if present) and ^{210}Po is recorded in removal certificates provided by the decontamination contractor to the operator. Operators report this via EEMS and RSA as 'onshore disposal' although Scotoil report their discharges to SEPA as to the nearshore marine environment.

4.3.2 Information from decontamination contractors

Scotoil have provided a comprehensive set of data for all jobs in 2001, 2002 and 2003. The data was supplied in a form that is not attributable to any particular Operator or facility. This includes the type of equipment decontaminated and the average activity for each job of ^{226}Ra, ^{228}Ra, and ^{210}Pb and ^{210}Po. All of the equipment decontaminated (approximately 1500 jobs) is from the oil and gas industry.

The data is divided into tubulars and other components, *i.e.* pumps, valve trees, spool pieces etc. A summary is given in **Table 5**.

Table 5. Total activity and weight of NORM disposed of by Scotoil in 2001-2003

	Tubulars		Other Components		Total wt (Kg)	Total Activity (GBq)
Year	wt (Kg)	total activity	wt (kg)	total activity		
		MBq		MBq		
2001	5260	6900	2880	1830	8140	8.74
2002	8960	8060	35,000	5070	44,000	13.1
2003	20,200	6890	15,500	2620	35,800	9.51

There is a considerable range in the average activities recorded:

Tubulars:
- ^{226}Ra: 0.17-1020 Bq/g
- ^{228}Ra: 0.06 - 842 Bq/g
- ^{210}Pb: 0 - 3456 Bq/g
- ^{210}Po: 0 - 3628 Bq/g

Other Components:
- ^{226}Ra: 0.4 - 573 Bq/g
- ^{228}Ra: 0.1 - 465 Bq/g

^{210}Pb: 0 - 7551 Bq/g
^{210}Po: 0 - 6935 Bq/g

Figure 14 and **Figure 15** below show the distribution of activities for ^{226}Ra and ^{210}Pb for the tubulars and other components.

Figure 14. ^{226}Ra activity in Tubulars (85 jobs)

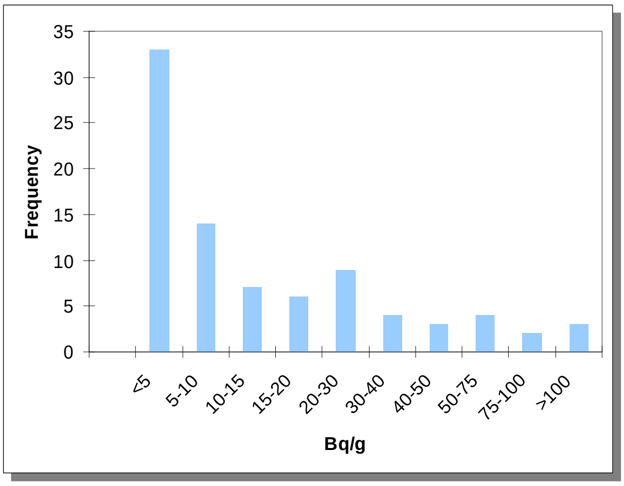
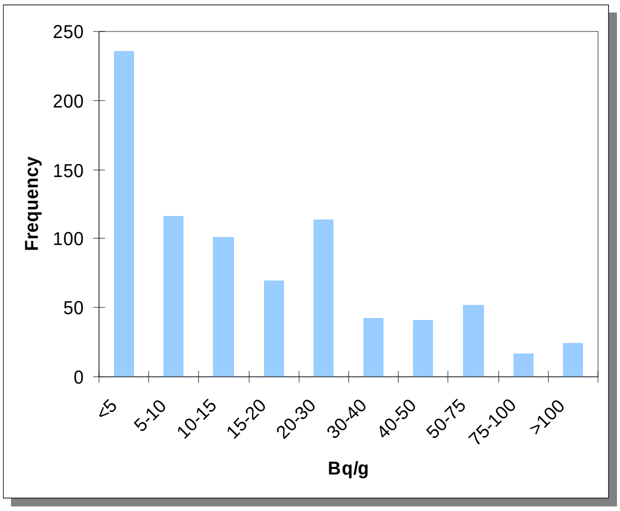


Figure 15. ^{226}Ra activity in components (813 jobs)



The maximum recorded activity for ^{226}Ra is 1020 Bq/g and 842 Bq/g ^{228}Ra. This was for a 5" tubular. The total activity for this material was 12,856 Bq/g. 44kg of this material was disposed was and this high activity is exceptional for North Sea NORM as demonstrated in the above graphs.

The ^{210}Po and ^{210}Pb activities are predominantly below the LOD (these jobs are not included. Some higher activity was observed in tubulars and downhole pumps from an onshore field, which has predominantly ^{210}Pb- and ^{210}Po-containing NORM.

Figure 16 and **Figure 17** show the distribution of activity from ^{210}Pb in tubulars and components where these nuclides were present in detectable amounts.

Figure 16. ^{210}Pb distribution in tubulars (32 analyses)

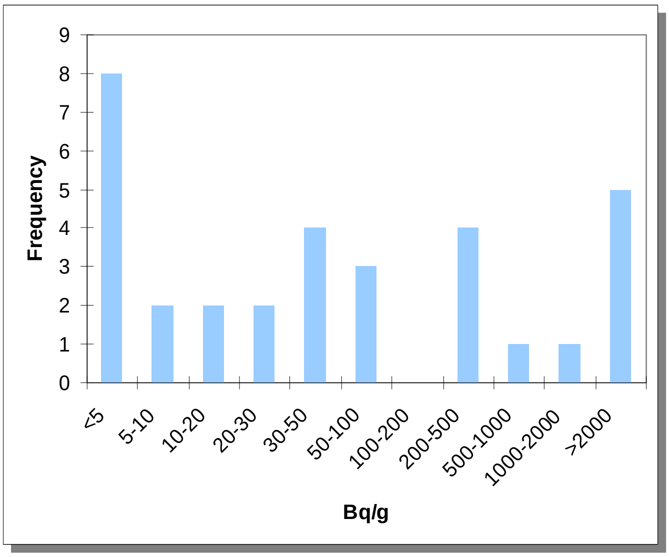
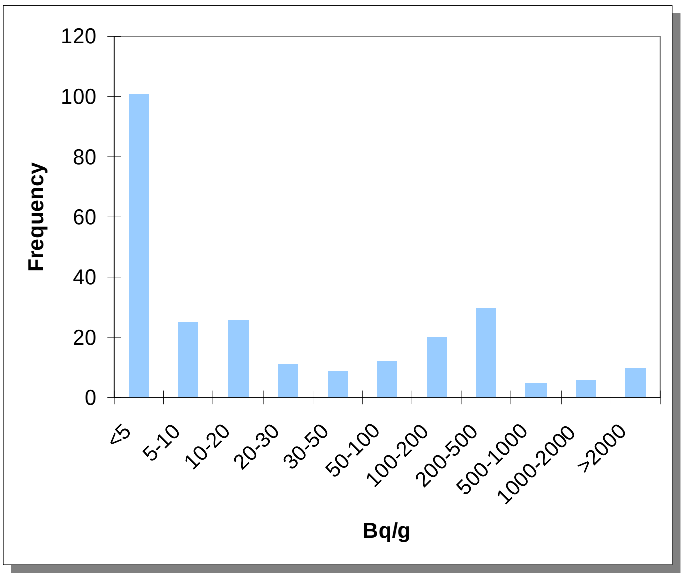


Figure 17. ^{210}Pb distribution in components (255 analyses)



Sufficient records are taken to allow each job to be identified as exempt or non-exempt, although this is not strictly necessary under the current discharge arrangements. The removed NORM waste is collected in a common vessel, macerated, mixed with seawater and discharged to sea. The relative amounts of exempt and non-exempt NORM removed have, however, been calculated and are shown in **Table 7**.

The higher exempt figure for components in 2002 was due to one large, low activity job; without this job there is about 26 % exempt material.

Table 6. Proportions of exempt and non-exempt decontaminated materials

Date	Total weight kg	Exempt weight kg	Non exempt weight kg	% exempt
Tubulars				
2001	19788.3	4288.6	15499.7	22
2002	8959.1	1357.2	7601.9	15
2003	20228.0	1390.2	18837.8	7
Other components				
Date	Total weight kg	Exempt weight kg	Non exempt weight kg	% exempt
2001	9475.59	2749.5	6726.1	29
2002	35026.02	16706.8	18319.2	47
2003	15445.73	3637.8	11088.0	23

4.4 Offshore decontamination

NORM removed from vessels and equipment offshore is disposed of to sea under the RSA authorisation for the host facility. The offshore cleaning contractors do not have their own RSA authorisations.

Mobile macerators are taken to facilities which do not have their own maceration facilities to grind the removed NORM waste to 1mm prior to discharge to sea.

Vessel entry procedures obtained from an offshore decontamination contractor detail the typical process of NORM removal. Formal waste transfer notes are retained by the operators showing amounts and activities of NORM and NORM containing sludges removed. The presence of radioactivity is established at the time of removal by hand held monitor and representative samples are taken for analysis. Estimates are made of the weight and volume of material removed and kept in the platform disposal records. The material is macerated to 1 mm and discharged to sea. The results of the radiochemical analysis take several weeks to be returned so the activity and therefore whether material is exempt or not is only known after disposal to sea. So although only the non-exempt disposals are required to be reported to SEPA a record of all disposals has to be kept. From the data returned from operators for the project it is clear that there is some variation in what is reported to SEPA as some returns have included exempt offshore disposals.

All records of these disposals are kept at the facility. The method of estimating volume and weight is not discussed here but is estimated mainly by eye for larger volumes.

4.5 Pigging waxes

Pigging wastes are often heavily contaminated with waxes, asphaltenes or oil and present a different waste disposal problem as they may well be categorised as a hazardous waste on account of their oil content. They cannot be discharged to sea unless there is a de-oiling capability on the platform and such wastes are usually drummed up and shipped to shore. Onshore disposal is normally to landfill by a waste contractor. Records are available from the platform waste manifests and NORM disposal figures should be reported under EEMS as exempt onshore disposal. This appeared to be the case for the Operators who supplied detailed data for this study. From the figures available to this study from Operators, these wastes, if radioactive, are almost always exempt although there have been exceptions, noted in section 4.8.

On the basis of limited data (30 analyses from one Operator over two years), the total activity of pigging wax ranges from <1 Bq/g to around 25 Bq/g, with all but two of the waxes below the exemption level of 14.8 Bq/g.

4.6 NORM wastes from well workovers

Some wells become scaled to an extent that affects production and a workover is required. This may involve removal of scaled production tubulars in which case the removed NORM will be reported under the platform disposal records.

Mechanical milling/reaming inside the tubulars may be required. From discussions with contractors who carry out this work it is usual practice for the well fluids would pass into the test separators. Therefore arisings will be accounted for in the disposal records when the vessel is subsequently cleaned out. However there are instances where there has been such severe scaling that a separate macerator unit has been deployed with solid separation and weighing of scale removed before maceration and discharge to sea via the host platform. It was reported that 12 tonnes of scale per well was removed from very heavily scaled wells by this method. According to the contractor a more usual amount from down hole scale removal would be under half a tonne per well. These disposals should be captured in the host facility disposal records.

Workovers are also undertaken to improve performance for other reasons and scale may incidentally be removed.

Any NORM removed during through tubing drilling activities may contaminate the drilling fluids which could potentially a produce larger volume of NORM contaminated waste. When the drilling mud is passed over the shakers the solids will contain the removed scale. The solids may be returned to the waste fluids after drilling has finished, and drilling fluids are discharged to sea under a Chemicals Regulations permit or returned to shore for treatment.

The data submitted by Operators included analyses of arisings from workovers of two wells undertaken consecutively on one facility. This produced 850 kg of non-exempt waste (scale and shaker solids) with a total activity 300 MBq and 139 tonnes of exempt material (contaminated mud) with an activity of 1164 MBq both of which were discharged to sea under the host facility authorisation (taking up 20% of the annual authorisation).

On another facility where two drilling residues were analysed, the results were:

- a mixed residue of oil-based mud, drill cuttings, swarf and cement just under the exemption level of 14.8 Bq/g;
- cement slurry from the bleed nipple of a well casing with an activity of around 74 Bq/g. Although cement contains naturally occurring radium at levels up to 100 Bq/kg, the activity is more likely due to the cement flow pushing NORM ahead of it to the surface.

4.7 Arisings from onshore terminals

4.7.1 Summary

Onshore terminals are likely be a significant source of NORM waste requiring onshore disposal. Terminal operators were also sent a modified copy of the general operator questionnaire. 20 operators were contacted, covering 14 terminals and responses were received from 7 terminals. All of the facilities were contacted by phone to ask about NORM issues the level of response form this was variable. Some terminals did not wish to discuss their NORM issues although they hold RSA authorisations for NORM waste disposal. Being onshore, therefore highly visible, and having to maintain good relations with local communities makes them vulnerable on potentially emotive issues such as radioactive waste disposal. For this reason no names or locations are given below.

The type and amount of NORM arisings will depend on the type of product, product throughput and the type of processing carried out at the terminal. Non-exempt ^{226}Ra containing vessel sludges and pigging wastes are likely to be of most concern as the only disposal route is to Drigg, which has a ^{226}Ra limit. The ^{210}Po and ^{210}Pb NORM arisings from gas and condensate terminals are likely to present less of a disposal problem as their disposal will not be affected by the radium limit at Drigg and because, from the limited data available they appear to be fairly low volume.

The amount and origins of produced water being imported via pipelines is a factor in amounts of NORM accumulating at terminals. Some terminals also receive significant amounts of ballast water from tankers, which, for local environmental reasons, they cannot discharge to sea. If this seawater is mixed with produced water in water storage vessels it is likely that scaling will occur unless scale inhibitors are used and a significant amount of NORM containing sludge may form in the vessels. There may be an increase in ballast water unloaded at some terminals if discharge to sea is further restricted for environmental reasons (e.g. introduction of alien species).

Not all of the main onshore terminals have RSA authorisations. From the questionnaire responses and from informal conversations with regulators, some terminals were in the process of assessing the situation with their RPA and/or with the regulator to ascertain if an authorisation would be necessary and were understandably reluctant to disclose data. Consequently the data on the likely arisings from onshore terminals is inconclusive.

Table 8 below lists the amounts, activities and sources of disposals from UK onshore terminals. It was hoped that at least all returns from terminals with RSA authorisations would be supplied but not all operators were willing to discuss this.

This report includes terminals that receive hydrocarbons from offshore via pipeline. NORM arisings are also reported anecdotally in tanker terminals and in tanker sludges however this is beyond the current scope of the project.

Table 7. NORM arising from onshore terminals

Terminal	RSA Authorised	NORM waste disposals Weight/volume	Activity (Ra)	Type/source if reported
1. Oil	Yes	117m^3 2500te	> 14.8 Bg/g >0.37 and <14.8 Bq/g	Various offshore facilities - mineral scale/solids
2. Oil	Yes	Negligible, approx 0.2m^3	<14.8 Bq/g	Effluent treatment unit sand filter media
3. Oil	Yes	nil		Historical problem in a water treatment unit
4. Oil	In progress	Nil to date		Setting up a monitoring program possible sources oil storage vessels, desalters sludges, desanders
5. 5.1 Gas 5.2 Gas 5.3 Gas		Nil Nil Nil		Gas ^{222}Rn
6. Oil	Revoked	Nil		
7. Gas		ND	ND	
8. Gas condensate		ND	ND	
9. Gas/ condensate		negligible		Gas ^{222}Rn
10. Gas		ND	ND	ND
11. Oil		ND	ND	ND
12.1 Gas 12.2 Gas 12.3 Gas	Yes	ND NIL Disposals (volume unknown)	Not known	Pigging wastes
13. Condensate / Gas	Yes	1m^3 120-140 m^3	>14.8 Bq/g <14.8 Bq/g	Sands, sludges and gas deposits
14. Gas		Nil		
15. Gas	Yes	Nil to date	ND	Contaminated valves

Note: RSA = RSA authorisation exists
ND = No data

A more detailed summary of the information gained is given in the following sections. This has been included illustrate why it is not possible to give more conclusive figures for terminal disposals.

4.7.2 Oil terminals

Terminal 1

This terminal disposed of 117m^3 of non-exempt NORM waste to Drigg, consisting of pigging waxes and process vessel sludges. It has also disposed of another 2,500 tonnes of exempt waste sludge from a waste water storage tank to landfill. These arisings may not be typical as this terminal is unusual in having to take in ballast water and in having very large amounts of water in the oil line.

This facility has had a study carried out to investigate the source of the activity in the pigging wastes as at least some of the arisings were due to the presence of NORM contaminated material in the oil line from one or more offshore facilities. No scale inhibitors are used at this terminal.

Terminal 2

Apart from exempt activity levels last year on the sand back wash filters in the water treatment system there have been no disposals under RSA. In the questionnaire returned it was reported that there had not been any non-exempt material and very little exempt waste. It was reported to be two years since the last shipment, which was all exempt waste (to Shanks). Periodic small disposals of exempt pigging wax are anticipated.

This terminal receives significant volumes of water from the oil lines and the tankers and discharges waste water to sea. It is noted that the fields feeding into this terminal do not have particularly active water, which might account for the current lack of NORM. To date they have not found significant activity in their pigging wax but monitor for it.

Terminal 3

This terminal does not have any significant NORM problem. It does have a, now unused, contaminated biotower for water treatment. The contamination derives from a time when the terminal accepted oily water for treatment from other facilities although this has now ceased. The tower will require decontamination. There are no disposals under RSA. The terminal currently only receives directly from a facility with little or no NORM and low activity produced water.

Terminal 4.

This terminal is currently applying for an RSA authorisation and instigating a monitoring programme. NORM has been reported in desalters, water treatment plant and in oil and water storage vessels.

4.7.3 Gas terminals

Terminal 5

None of the operators using this terminal have reported any significant NORM contamination to date although all are aware that it may be an issue in future and monitor for it.

According to one operator report an external survey was carried out in 1990 and did not find any enhanced external radiation levels. Samples from molecular sieves were also taken for analysis for ^{210}Pb and ^{210}Po. Low activities were recorded 0.009-0.015 Bq/g ^{210}Po and 0.009 Bq/g for ^{210}Pb. In Mid 1995 another survey carried out no external radiation and not analysed for ^{210}Pb. They also tried a mass balance calculation, taking ^{222}Rn content of the gas, through flow and residence time, to predict NORM in the facilities. It was suspected that a significant build up of longer lived ^{222}Rn progeny would be present in the onshore facilities. An empirical calculation based on half life, gas and NGL volumes and ^{222}Rn activity concentration (no details supplied) taking no account of changes in gas composition or operating parameters (i.e. a general worst case). It also does not include transport of any unsupported ^{210}Pb and ^{210}Po in the gas/NGL.

It was calculated that there might be around 600 MBq of ^{210}Pb activity in the terminal facilities and, if in equilibrium, the same activity of ^{210}Po.

The operator RPA reports that monitoring at terminal 5 is very thorough and that they have only ever found one pump that was radioactive. The ^{222}Rn content of the gas is monitored regularly.

Terminal 10

This terminal has recently received an RSA authorisation in response to finding a NORM contaminated valve. There has been very little NORM to date but they are aware that it may be an issue in the future.

Terminal 12

This is also a multi operator gas terminal. Questionnaire responses were received from three of the four users.

- One operator in a survey in 1996 reported NORM in sludges in the gas/condensate/glycol separators. Analyses showed: ^{210}Pb and ^{210}Po in separator 1 (10.1 Bg/g ^{210}Pb and 6.49 Bq/g ^{210}Po) and in separator 2 (7.25 Bq/g ^{210}Pb and 8.36 Bq/g ^{210}Po). It was noted that there was a homogeneous distribution of NORM in the solids analysed. The total radium activity was much lower: 0.15 Bq/g and 0.4 Bq/g in separators 1 and 2 indicating the presence of unsupported ^{210}Pb and ^{210}Po from radon transported in the gas and condensate.

- Another operator reported no disposals for 2002 but had monitored for and found ^{222}Rn related NORM.

- A third operator reported that they never had any NORM either in this terminal or in any of the facilities supplying it.

From this terminal's import pipelines, pigging wastes were analysed, showing
- Pigging debris 0.63 Bq/g ^{210}Pb and 0.382 ^{210}Po. Ra (total) 0.11 Bq/g
- Pigging debris 1.55-3.47Bq/g ^{210}Po, 1.81-3.3 Bq/g ^{210}Pb, 0.15-0.4 Bq/g total radium

No information was supplied on the volume of waste but the terminal has an authorisation to accumulate up to 30 m^3. The reported activity levels are exempt. No disposal figures were available although informally it is known that the fourth operator has made disposals under RSA.

Terminal 13

This terminal has known NORM occurrence. It is understood that a detailed study of this was carried out but no information has been made available for this study, however as the issues are well known some general information has been assembled.

It is reported that NORM occurs in the pigging waste from a major import line that is pigged daily. There are no details of amounts but NORM activities are reportedly in the low tens of Bq/g. NORM is also reported in a slug catcher and in a condensate boiler.

Problems have also been reported with NORM in product streams contaminating facilities downstream in condensate processing where a catalyst used to pass the condensate through was found to have elevated (no values available but reportedly not very high) activity levels. These were reported to be mainly due to presence of ^{210}Pb. (not surprising as elevated activities from of ^{222}Rn daughters are commonly associated with condensate processing). It is reported that an analytical programme looking at the condensate concluded that most of the activity was due to the presence of fine particulates. It is understood there were issues in disposing of the spent catalyst.

This facility holds an RSA authorisation for accumulation and disposal of both solid and liquid waste. The disposal of solid waste is authorised up to an activity of 0.93 GBq a year, mainly ^{210}Pb and ^{210}Po. Disposals last year were reportedly approximately 1m^3 of non-exempt waste to Drigg and 120-140 m^3 of exempt waste to landfill.

4.8 Onshore oil and gas production

The larger operators of onshore oil and gas fields were also contacted.

4.8.1 Wytch Farm gathering station

Wytch Farm in Dorset, operated by BP, is the only major onshore field in the UK and has well known and documented NORM. It is the only oil field reported to produce the thin metallic ^{210}Pb and ^{210}Po containing deposits that are more normally associated with gas and condensate production. It is the only onshore field with reported NORM disposals. Until recently NORM was disposed of under authorisation by re-injection on site. NORM disposal is now offsite from a cleaning facility at Winfrith. Waste is to be supercompacted and sent to Drigg with a small amount (2%) disposed of to sea via the existing Winfrith sea outfall.

4.8.2 Other onshore fields

Operators of other onshore fields were also contacted. None reported any NORM disposals and none had required an RSA authorisation. Produced water from these fields is all reported to be re-injected. Some relevant data is as follows.

- Welton Gathering station (Star Energy) re-injects approx 3000bbl/day of produced water.
- Humbly Grove (Star Energy) do have monitoring carried out by UKAEA when vessel opening is undertaken but have never found any significant NORM. Produced water is re-injected at a rate of 100-1500 bbl/day.
- Crosby warren and Hatfield Moor Gas Storage (Edinburgh Oil and Gas) were not aware of any NORM occurrence at their facilities.
- Pentex, operators of a number of smaller scattered onshore fields have not reported any NORM.

As far as can be ascertained from the EA none of the smaller onshore facilities hold an RSA 93 authorisation for NORM waste disposal.

4.9 Platform Decommissioning

4.9.1 General

OSPAR Decision 98/3 on the disposal of disused offshore installations is the basis for deciding how decommissioned offshore installations will be disposed of. There is a presumption that platforms will be totally removed, with a derogation for footings in some cases, which in effect means that all platform components that are likely to have a scale accumulation will be removed to shore, with the probable exception of large concrete gravity storage tanks such as at Frigg.

It is common practice to clean platforms as completely as possible before being moved to a dismantling location, which includes scale removal offshore under the platform authorisation. The start of 'decommissioning' is often take to be the time of cessation of production and a large cleaning effort may take place in the months leading up to cessation of production. Consequently it is often difficult to attach a label of 'decommissioning waste' to platform wastes that is distinct from operational cleaning. A more useful quantification is the wastes that must be brought onshore, *e.g.* oily wastes from storage tanks and scales on equipment that cannot be decontaminated offshore.

Most publicly available data on NORM in decommissioning refers to *predictions* about NORM deposits rather than actual amounts disposed of. In the few cases where disposal quantities are known, it appears that pre-decommissioning estimates have been much larger than actual disposals.

Table 8 summarises the arisings of NORM from major fixed platforms identified in this study.

Table 8. Summary of decommissioning arisings from major fixed platforms*

Facility	Non-exempt LLW Mass before conditioning**	Exempt LLW Mass before conditioning**
Conoco Viking	None	<1 tonne
Shell Brent Spar	12 tonnes	unknown
Phillips Maureen	2.8 tonnes	80 tonnes approx.
Kerr McGee Hutton TLP	None	unknown
Platform refurbishment project (confidential)	7 tonnes approx.	unknown
BP North West Hutton	2.5 tonnes	unknown
Odin	None >10 Bq/g	
Tommeliten	None >10 Bq/g	
Ekofisk	None >10 Bq/g	

* Several small gas platforms and fields operated by FPSOs have also been decommissioned for which no NORM wastes have been identified.
** Conditioning is the process by which wastes are stabilised, normally by the addition of cement, which increases the mass by typically a factor of up to two

4.9.2 Occurrence in processes

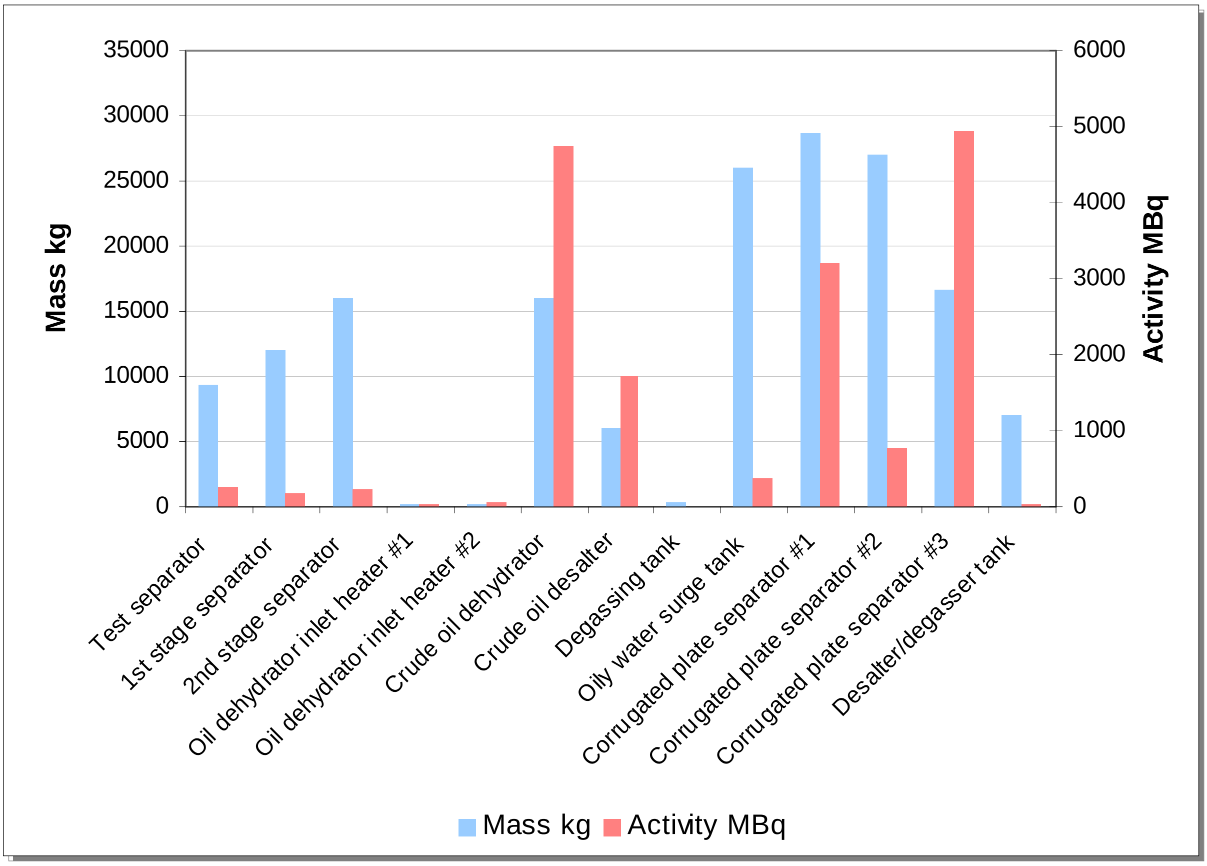
Scale arisings for an oil platform (confidential) were collated prior to decommissioning and the platform was surveyed in some detail for NORM accumulation. **Table 9** summarises the locations where NORM was found and the scale disposals, averaged on an annual basis over the production period (>10 years). The mass-averaged specific activity of the deposits was 99 Bq/g.

Figure 18 illustrates the mass and activity relating to each component. There is a clear indication of NORM accumulation occurring in water separation equipment. Specific activities vary by one or two orders of magnitude.

Table 9. NORM arisings from decommissioned oil platform

	Mass per year kg	Activity Bq/g	Total Activity per year MBq	Exempt/Non-exempt
Main production valve	activity only	408		
Test separator	723	28	20	Exempt
1st stage separator	923	14	13	Exempt
2nd stage separator	1231	14	17	Exempt
Oil dehydrator inlet heater #1	16	86	1	Non-exempt
Oil dehydrator inlet heater #2	13	336	4	Non-exempt
Crude oil dehydrator	1232	296	365	Non-exempt
Crude oil desalter	467	282	132	Non-exempt
Degassing tank	23	0.88	0	Exempt
Oily water surge tank	2004	14	28	Exempt
Corrugated plate separator #1	2207	112	247	Non-exempt
Corrugated plate separator #2	2083	28	58	Exempt
Corrugated plate separator #3	1282	296	380	Non-exempt
Desalter/degasser tank	538	2.3	1	Exempt
Oil loading surge tank	encountered, not analysed			
Oil loading pumps	encountered, not analysed			
Crude oil product pipework	encountered, not analysed			
Oil loading surge tank	encountered, not analysed			
Drains tank oil pumps and caissons	encountered (v low), not analysed			
Produced water injection pumps/pipes	encountered, not analysed			
Flare knockout drum	encountered, not analysed			
1st stage separator off-gas	Radon detected			
Gas compression system	Radon detected			
	Annual Mass kg	**Mass-averaged activity Bq/g**	**Annual activity MBq**	
	12742	**99**	**1267**	

Figure 18. Mass and activity of scale found in a decommissioned oil platform



4.9.3 Shell Brent Spar

Brent Spar and its contents were transported to Norway and radioactive materials were returned to the UK for treatment and disposal. 12 tonnes of waste was authorised to be sent for conditioning at the ex-AEA Technology site at Winfrith, Dorset (ENDS nr 307, 2000), compared to pre-decommissioning estimates of 100-331 tonnes of sludge and 12 GBq activity. The conditioned waste was disposed of at Drigg, where the volume recorded is 26 m^3. This volume and the original tonnage are not directly comparable as additional mass and volume will have been gained during the conditioning process.

Actual activity levels of the material conditioned or disposed of have not been determined, but five samples were taken of the sludge *in situ*. The sludge in the Brent Spar storage tanks was measured as having an average ^{226}Ra concentration of 4.5 Bq/g (1.2-8.0 Bq/g), and an average ^{228}Ac concentration of 3.0 Bq/g (0.8 - 5.2 Bq/g) (Shell website). Estimates of activities in hard scale in the Brent Spar have been made from records of on-shore disposals of scale from Brent Alpha and Brent Bravo. These give an average ^{226}Ra concentration of 17.6 Bq/g (1.7 - 46.6 Bq/g), and an average ^{228}Ac concentration of 15.2 Bq/g (1.3 - 50.8 Bq/g). A later NERC report (NERC, 1988) quotes slightly different figures which include a sixth sample, of average activities 4.4 Bq/g ^{226}Ra and 2.8 Bq/g ^{228}Ra (^{228}Ac).

Assuming 12 tonnes of sludge was conditioned, using the average activity figures for sludge this would amount to 52.8 MBq ^{226}Ra and 33.6 MBq ^{228}Ra(^{228}Ac), with a total activity of 586 MBq.

It has not been determined whether there were any exempt LLW disposals for Brent Spar.

4.9.4 Phillips Maureen Platform

The Maureen Platform, including residues in its storage tanks (after emptying and being filled with ballast water), was transported to Norway and radioactive materials were returned to the UK for treatment and disposal. 2.8 tonnes of LSA scale was cleaned from contaminated equipment with a total calculated activity of 302 MBq. In the pre-decommissioning stages there was considerable debate about radioactive oily deposits in the large storage tanks that were integral with this structure and an upper estimate of 880 tonnes was made. In practice this turned out to be much lower, probably less than 10% of this figure (pers. comm. C. Freeman, ex-Phillips Environmental Manager, 2004), although it has not been possible to source precise data. DNV reported a potential 50-100 tonnes for the whole Maureen structure (DNV 1997). Drigg does not report receiving any wastes from Phillips Maureen.

4.9.5 Kerr McGee Hutton Tensioned Leg Platform

Kerr McGee reports that there was no radioactive waste disposal from the decommissioning of Hutton TLP. The platform has been refurbished and continues to be in use. It has not been determined whether there were any exempt LLW disposals.

4.9.6 BP North West Hutton Platform

The main structure of NW Hutton (jacket and topsides), at time of writing, has yet to be removed to shore for final decommissioning. Various dismantling and cleaning operations have, however, been undertaken, including the main conductors (pipes rising from the wells to the topsides) and this provides some data. 2.5 tonnes of LSA scale was removed from contaminated equipment with a total calculated activity of 133 MBq.

All NORM arisings from NW Hutton to date have been in the form of contaminated equipment, *i.e.* no NORM-contaminated sludges etc. have been encountered.

4.9.7 Experience from Norway

The Norwegian radiological protection board have noted (2002) that NORM estimates in decommissioning projects tend to be major overestimates largely because visual estimates of made of the volume of scales and sludges prior to analysis. These are then revised down ward once analytical results are returned and in many cases facilities do not have any NORM above the Norwegian radioactive threshold of 10 Bq/g.

This was the case for the Odin platform, subsea facilities for Tommeliten, large part of the Ekofisk facilities (more currently under consideration)

4.9.8 Platform refurbishment

Although not a typical decommissioning project, Drigg has received a disposal of 13m^3 of LLW from a platform refurbishment project. It is understood (confidential, 2004) that radioactive material was encountered during the conversion of a production platform into an accommodation platform and had to be disposed of to Drigg. It is also noted that obtaining permission to deposit at Drigg was perceived as a very difficult undertaking with a long lead-in time. It has not been determined whether there were any exempt LLW disposals.

The amounts of NORM likely to be encountered in a facility on decommissioning can best be estimated from the individual facility history from NORM monitoring, decontamination and removal records. The maintenance schedule will show when the major process vessels were last opened and cleaned out and therefore how much NORM might be expected in these.

There will be areas of any facility which are not accessed during normal working and NORM in these should be accounted for. If tubulars are to be removed there is likely to be the most active scale in these. Normally these are left in place and sealed in so disposal id not an issue.

4.10 Pipeline Decommissioning

4.10.1 General

One occurrence of NORM waste from pipeline decommissioning has been identified, relating to the Moira to Maureen oil pipeline and this is discussed below. Several other pipelines have been decommissioned and no reports of NORM waste are reported either at Drigg or at Scotoil, and the records of authorisations are consistent with the Moira pipeline being only pipeline decommissioning with NORM waste since every disposal of non-exempt radioactive waste is subject to authorisation.

OSPAR Decision 98/3 does not require pipelines to be removed and an agreement on the BPEO for disposal is reached between the Operator and the DTI on a case-by-case basis. In general, *in situ* disposal has been the preferred option for larger pipelines.

4.10.2 Moira - Maureen Pipeline

As part of the decommissioning of the Phillips Maureen platform, pipelines from the Moira field to Maureen were also removed. A 24" infield was decommissioned *in situ*. The Moira - Maureen pipeline recovery involved 10km each of a 6" (150mm) oil line and a 2" (50mm) gas lift line. It is understood that LSA scale was detected in the oil line and ultimately 0.5m^3 of waste was deposited at Drigg and 10 tonnes of scale was removed at Scotoil in Aberdeen (pers. comm. C. Freeman, 2004). There is little available documentation, however, to confirm these figures.

4.10.3 Other Pipelines

Based on DTI records and supplemented with data from the North Sea Field Development Guide and other sources, the following pipelines have been decommissioned (**Table 10**).

As part of the Brent redundant facilities project, Shell reports that no NORM has been detected in the Brent gas flare tip, which is planned for decommissioning (Shell website, 2003).

Total reports that no significant NORM has been found following a survey of the Frigg infield pipelines that are planned for decommissioning (pers. comm. 2004).

Several subsea structures and manifolds have been decommissioned, relating to the fields listed in the Table above and also to a small number of decommissioned fields that were operated by FPSOs (*i.e.* with relatively few pipelines).

Table 10. Pipelines decommissioned and onshore NORM arisings

Field	Year of approval of decomm-issioning plan	Pipeline length	Diameter	Type	Fate	Onshore NORM arisings*
Crawford	1991	1.2km	8”	Oil	Recovered	None
Argyll, Duncan and Innes	1992	2.3km 11km 6km 6km 6km	10” 6” 8” 6” 8”	Oil Oil Oil Test Water	Recovered Recovered Recovered Recovered Recovered	None None None None None
Emerald	1996	8km	10”	Oil	*In situ*	None
Staffa	1996	9.5km	8”	Oil	Recovered	None
Fulmar SALM	1998	2.3km	16”	Oil	*In situ*	None
Moira and Maureen	2000	10km 10km 2.3km	6” 2” 24”	Oil Gas Oil	Recovered Recovered *In situ*	0.5m^3 Drigg 10t Scotoil None None
Durward and Dauntless	2002	8km 5.5km 4.9km	6” 8” 10”	Oil Oil Oil	*In situ* *In situ* *In situ*	None None None
Hutton	2002	6km 6km	6” 12.75”	Gas Oil	Recovered *In situ*	None None
Forbes and Gordon	2003	11.5km 35km	10”+2” 10”+2”	Gas+glycol Gas+glycol	*In situ* *In situ*	None None

* ‘None’ means none that has been identified in this study

4.10.4 Pipeline arisings

The Moira-Maureen pipeline is the only pipeline in which NORM has been detected out of eight oil/water pipelines recovered to shore. The status of pipelines *in situ* is not determined. Given this small dataset, the confidence in any predictions is inevitably poor. Nevertheless the following estimate is made.

The Moira-Maureen pipeline represents 16% of the oil/water pipelines recovered on a surface area basis (4 700m^2 out of 29 000m^2). It is assumed that considering oil/water pipelines only and using surface area is a logical basis for forecasting NORM in pipelines given the nature of its deposition. In general, the supply of ions leading to scale are greatly in excess of the deposition rate and the area of nucleation surfaces, reflected in the surface area inside the pipeline, is therefore an important factor in the scaling rate.

Based on the above, to predict future NORM arisings that will be returned onshore for disposal, the following protocol is used:

- Oil/water pipelines give rise to 0.00002 m^3 of non-exempt waste per m^2 (*i.e.* 16% of 0.5m^3 per 4 700m^2 of surface area)

- Oil/water pipelines give rise to 0.0003 t of scale per m^2 for onshore disposal (*i.e.* 16% of 10t per 4 700m^2 of surface area)
- Existing pipelines of 12" diameter or greater will be decommissioned *in situ*;
- Gas pipelines give rise to a negligible mass of NORM waste (although activity may be relatively high).

Applying these criteria to the DTI database of pipelines (DTI, 2004) a total of 954km of pipeline remains to be decommissioned with a total surface area of 674 000m^2. This would therefore be predicted to have 13 tonnes of non-exempt LLW and 200 tonnes of exempt scale.

152km of pipeline has been decommissioned since 1991, 99km of which was in the last 3 years. 26km of the 99km was recovered onshore, *i.e.* approximately 9km per year. This rate would certainly increase as platform decommissioning accelerates. Assuming all existing pipelines will be decommissioned in the next 50 years, this would be a rate of 19km of pipeline per year coming onshore with NORM contamination. Using the above NORM estimates, this would equate to 0.3 tonnes of non-exempt LLW and 4 tonnes of exempt scale per year.

4.11 Uncertainties

Much data is from spot samples and although these are numerous in some areas, it is difficult to state how representative the results are.

Offshore decontamination reports to the regulators (EEMS and RSA returns) do not accurately quantify exempt disposals. One Operator's detailed records were used to estimate offshore decontamination totals.

The level of detail on onshore decontamination is high, nevertheless it should be noted that the mass processed varies considerably from year to year.

A reasonable level of detail on decommissioning wastes was obtained although firm historic records were difficult to source. Predicted decommissioning arisings have consistently been far higher than actual disposals.

Data obtained on terminal arisings was limited. This is due partly to the infrequency of disposals and partly to non response from some terminals and sensitivity about RSA reporting.

Data on NORM from workovers was limited. Normally, workover arisings will be passed through the host facility process and appear in the facility disposals (possibly at a later date). Consequently it is difficult to separate the contribution of workovers from the total.

5 ESTIMATE OF CURRENT NORM ARISINGS

5.1 UKCS estimate

Estimates of UKCS NORM arisings have been made on the basis of the following data sources, much of which is not in the public domain:

- Literature review
- Operator questionnaires
- Detailed Operator data submitted with the questionnaires
- Discussions with, and data from, decontamination contractors and onshore disposal outlets
- Produced water analyses undertaken by UKOOA
- Discussions with, and data from, regulators
- RSA and EEMS reporting
- Public domain decommissioning reports and data
- Published data on UKCS infrastructure

Table 11 summarises the estimated current NORM arisings for the UKCS upstream oil and gas industry and notes the relative confidence in the estimates. This is based on the numbers of platforms existing in 2003, and on 2002 produced water data. For decommissioning and terminal arisings, which are highly variable between years, an averaged value is given.

There are insufficient data, in all cases except onshore decontamination, to attempt to define the accuracy of data received. Even the relatively precise onshore decontamination data varied by 22% in mass between 2002 and 2003 due to variations in the amounts of materials received for decontamination. There are many points at which inaccuracy can occur, such as the estimation of masses of scales discharged offshore, metering of produced water volumes, differences in interpreting exemptions as well as the accuracy and representativeness of sampling and analysis. Various assumptions are made in order to arrive at average annual figures and to forecast arisings and similarly, while based on best judgement, it is impossible to place an accuracy on these assumptions.

NORM in other countries' oil and gas industries is discussed in the following sections to identify similarities. In summary, the findings from other countries are consistent with the estimates for the UKCS, although the comparison is made difficult by the varying definitions of 'radioactive' between countries. For example, the UK EEMS disposal figures for solids include (in principle) exempt and non-exempt material *i.e.* material over 0.37 Bq/g ^{226}Ra, the same data for Norway cover material over 10 Bq/g ^{226}Ra and UK RSA reporting covers material over 14.8 Bq/g.

Differences in regulation are covered more fully in Phase 2 of this project.

Table 11. Summary table of estimated current oil and gas NORM arisings

Description of NORM	Total Activity GBq	Amount of material	Includes exempt/ non-exempt	Relative confidence in source data	Notes
Produced water to sea	9840	282 Mm^3	E&NE	Medium	96% of water sampled. Volume from 2002 data.
Reinjection	278	7.5 Mm^3	E&NE	High	As above
Offshore decontamination	23	1,300 t	E&NE	Medium	Extrapolated from detailed records from 14 platforms
Workovers	4	35 t	E&NE	Low	Limited base data. Usually discharged into process.
Platform decommissioning (offshore)	1.5	15 t	NE, some E	Low	Average for 1 platform, small dataset, highly variable
Platform decommissioning (to onshore)	0.2	1.8 t	NE, some E	Low	Average for 1 platform, small dataset, highly variable
Pipeline decommissioning (to onshore)	<14.8 Bq/g Ra >14.8 Bq/g Ra	0.2 t 3.8 t	E NE	Medium	Annual average, small dataset
Onshore decontamination	9.5	36 t (in suspension)	E&NE	High	Source data very detailed but fluctuates annually
In water to terminals	12	220,000 m^3	E&NE	Medium	Volume estimates are coarse
Terminal decontamination	6	500 t	E&NE	Low	Annual average. Highly variable. Cleanout intervals uncertain. Some data withheld.
Produced water discharged at terminal (by deduction)	6	220,000 m^3	E&NE	Low	No direct data, estimated by deduction
In product	No data				

5.2 Oil and gas related NORM arisings in other countries

5.2.1 Norway

The total arisings in Norway are lower than those from the UKCS, reflecting the smaller numbers of oil and gas production facilities.

In Norway the exemption limit for oil and gas NORM waste is 10 Bq/g ^{226}Ra activity and there is no equivalent of the exempt/non-exempt categories under the UK RSA 93. Anything under this limit is not deemed radioactive and may be accumulated, transported and discharged without authorisation. This limit also applies to produced water, so although published activities show a similar range to those recorded for the UK sector, all produced water in the Norway CS is deemed not radioactive.

According to the Norwegian Radiation Protection Authority (NRPA) the oil and gas industry has a predicted 20 tonnes per year NORM production. The overview of past and present arisings is as follows:

- Approximately 150 tonnes stored at the coastal bases
- 50 tonnes (estimate) contaminated scrap at coastal bases
- Annual production of 20 tonnes from onshore decontamination
- 20 tonnes annually from obsolete platform removal (NRPA 2002)

The NRPA estimate that there are there are approximately 200 tonnes at a repository near Kjeller and spread over 6 temporary storage depots along the west coast of Norway. Annual accumulation is approximately 40 tonnes. (Statens Strålevern pers. comm. 2004)

These are plans for construction of one or two dedicated repositories. One is already authorised and will take in 400 tonnes of NORM waste in the first year and 200 tonnes annually thereafter.

For produced water in Norway, average activity range is given as 3.8-4.8 Bq/l (Strålberg 2002). The total ^{226}Ra discharge from the Norwegian CS has been estimated to be 0.07-2.3 TBq per year (Varskog 2003).

5.2.2 Denmark

Statens Institute for Strålehygiene was contacted as part of this study. It is reported that no solid NORM waste is discharged to sea; it is all brought onshore. Quantities are summarised in **Table 12**.

Table 12. Annual NORM generation for Denmark

Ra 226 activity range (Bq/g)	Weight (tonnes)
0.5-5	1
5-10	10-20
10 +	5-10

A maximum annual arising of 31 tonnes is quoted. No further information could be obtained on other nuclides or total activity. It is understood that the regulator is currently attempting to quantify NORM in the range of 0.5 - 130 Bq/g ^{226}Ra.

The Danish regulator can in theory 'exempt' NORM waste to permit disposal to a conventional landfill but "no landfills have so far been interested". The regulator is now setting up a reporting system for NORM disposals. The regulator reported that one gas company has been generating NORM for some years from the cleaning of gas pipelines but they do not have any records of quantities or activities.

No Danish platforms have yet been decommissioned.

When asked whether Denmark's disposal facilities could accept NORM waste from the UK sector, the answer was that this was not permitted and Denmark would not be willing to do this.

5.2.3 The Netherlands

Regulated under the Nuclear Energy Act and Radiation Protection Ordinance. A license is required for LSA contaminated materials if total specific activity is over 100Bq/g and the total activity over 5kBq. Under Netherlands regulations activities are specified for individual nuclides:

- For ^{226}Ra, ^{228}Ra, ^{227}Ac, ^{228}Th: reporting levels =1 Bq/g authorisation levels= 10 Bq/g

- For ^{210}Po, ^{210}Pb: reporting levels =1 Bq/g authorisation levels= 1000 Bq/g

In Netherlands the only recognised institution for the collection of radioactive waste is the Central Organisation for Radioactive Waste (COVRA), located at Borsele, which must take and store all radioactive waste. COVRA was contacted and data was promised but no data has been received to date.

5.2.4 USA

Several estimates of total NORM arising in the USA have been published. A total of all NORM wastes have been recorded as 500,000-1,000,000 tonnes of which between 15-50,000 tonne a year with activity over 74/Bq/g (Tomson *et al* 2003). An API study estimated 200,000 tonnes. Another US NORM disposal study (Veil *et al.* 1999) reported a total of 250,000 tonnes of oilfield NORM. Reporting of the totals has been complicated by the fact that NORM is regulated differently between states under state rather than federal regulations although this is currently being addressed by the EPA. It is therefore not possible to report any meaningful figures at this point.

6 FORECASTING NORM GENERATION

6.1 General basis

Any attempt to generalise about NORM arisings, and forecast them into the future, is complicated by the wide variability that exists between facilities and the equally wide variability between one year and another for the same facility. NORM arisings are highly dependent on the frequency of cleanouts and operational matters such as the occurrence (and response to) water breakthrough downhole.

Attempts were made to find correlations between (a) volume of produced water or unit activity of produced water and (b) mass of solid scale disposed of, total activity of solid scale disposed or unit activity of scale disposed. This was examined per year and on an aggregated basis.

No meaningful correlation could be obtained for any parameters. This lack of correlation is itself an important conclusion.

A further complication is the difficulty in interpreting what material is represented in RSA and EEMS reporting, which do not describe the source of the NORM. For much of the operational NORM arisings, therefore, the approach taken has been to extrapolate from three years' detailed data received covering 14 oil platforms, which included exempt and non-exempt materials. The data covers a range of circumstances and facility types. This data provides a much better breakdown of arisings than RSA or EEMS returns and although it is only a selection of platforms, it is considered the best basis available from which to forecast operational arisings. A better estimate could only be made by visiting individual platforms and inspecting and processing the relevant documentation held by the platform RPS. This is supplemented with facility-specific data on produced water and with the data researched on decommissioning arisings from facilities and pipelines.

An assumption is made that the database is sufficiently broad to provide a reasonable estimate of NORM arisings for platforms for which no data could be found. There is, however, no way to confirm this assumption.

The overall approach to quantification has been to build up estimates from data from individual facilities. It is simple to identify a major platform as a facility, but more difficult when there are subsea tiebacks and small satellite platforms. The question is important when it comes to forecasting future numbers of facilities and for decommissioning. The approach has been taken to count a 'facility' as an installation with hydrocarbon processing and/or a produced water discharge. In this way, developments such as the Viking field, which contains numerous small satellite platforms, is counted as one facility. This is a logical approach as NORM arisings would be most expected where there is a change in conditions, *e.g.* in processing, and NORM measuring and reporting is done on the basis of where discharges occur.

6.2 Specific assumptions

6.2.1 Offshore disposals

Offshore decontamination is estimated from comprehensive data from 14 platforms, summarised in **Table 13,** and appears concentrated in oil facilities. Arisings are therefore based on the average of the 14 platforms and multiplied pro-rata according to the proportion of oil facilities in the UKCS. This is profiled into the future according to the number of platforms in existence.

The average platform age of the selection is 22 years. This compares with UKCS averages of 15 years for oil and condensate platforms, and 14 years for all platforms.

Table 13. Summary of 3 years' detailed oil platform disposal records

Item	Total
Number of years' records	3
Number of platforms	14
Total mass LSA scale recorded	768 tonnes
Total activity Ra and daughters	14 GBq
Mass-averaged specific activity of scale	18 Bq/g

In addition to the above, a further 103 tonnes of material were discharged for which samples were taken for analysis (*i.e.* surface gamma monitoring showed potentially significant radioactivity) but which later were shown to be below the Schedule 1 limits, *i.e.* not 'radioactive'. These were predominantly sand and drilling mud discharges.

6.2.2 Onshore decontamination

Onshore decontamination is based on the average of detailed records of the last two years activities from Scotoil. This is profiled into the future in proportion to the number of facilities in existence.

It should be noted that given the control measures in place at Scotoil and the level of auditing that takes place, internally and by Operators, these figures can be assumed to be without omissions and reliable from one year to the next. However, the figures show a large variation from one year to the next and this is evidence of the inevitable variability in amounts of equipment sent onshore for decontamination.

6.2.3 Decommissioning

There are always large unknowns in the future of the oil and gas industry, and many investment decisions, including commissioning new fields and decommissioning old facilities, are determined by the oil price. The oil price is notoriously unpredictable and is influenced by many global factors, and it has a pronounced influence in the North Sea where extraction costs are relatively high.

The decommissioning profile used was supplied by the Decommissioning Department at the DTI (correct as of October 2004, having been updated in August 2004). This profile is based on information received directly from Operators on their own decommissioning plans. The profile is adjusted to take account of differences in how facilities are counted in this study.

The forecast decommissioning date for each individual facility is highly confidential. For the purposes of forecasting, therefore, the existing facilities are ranked according to the first month of production, and it is assumed that decommissioning will occur in order of the oldest fields first, and in the numbers per year forecast by DTI.

Decommissioning arisings appear to be concentrated in oil facilities. Arisings are therefore based on the information received for the three most recent oil platform decommissioning projects (Maureen, Hutton TLP and North West Hutton) and multiplied pro-rata according to the proportion of oil facilities in the UKCS. This is profiled into the future according to the number of platforms in existence.

The amounts of NORM waste reported as being disposed of onshore and offshore vary considerably between these three facilities, e.g. offshore totals of 80t, 23t and zero respectively. Given the unique nature of all offshore facilities, it is not possible to estimate future decommissioning arisings with this data other than by using a simple average. The only alternative would be to examine the characteristics and history of every offshore facility in detail.

The 'per facility' decommissioning estimates are therefore:

- Mass of NORM waste disposed of offshore: 34 tonnes
- Mass of NORM waste brought onshore: 1.8 tonnes

6.2.4 New developments

To forecast arisings from new developments, a number of factors come into play. Although there were, for example, 10 new field developments in 2003 and five incremental developments, this included only one major platform (DTI website, 2004). The typical size of new developments has also decreased steadily since the 1970s and the typical NORM arisings per development would be expected to have decreased. Nevertheless it is still deemed meaningful to forecast on a ‘facility’ basis rather than on, say, a barrel of oil equivalent basis as several aspects of NORM such as decommissioning are per facility. Having reviewed development approvals for the last three years, it is assumed that the following profile of future developments is reasonable:

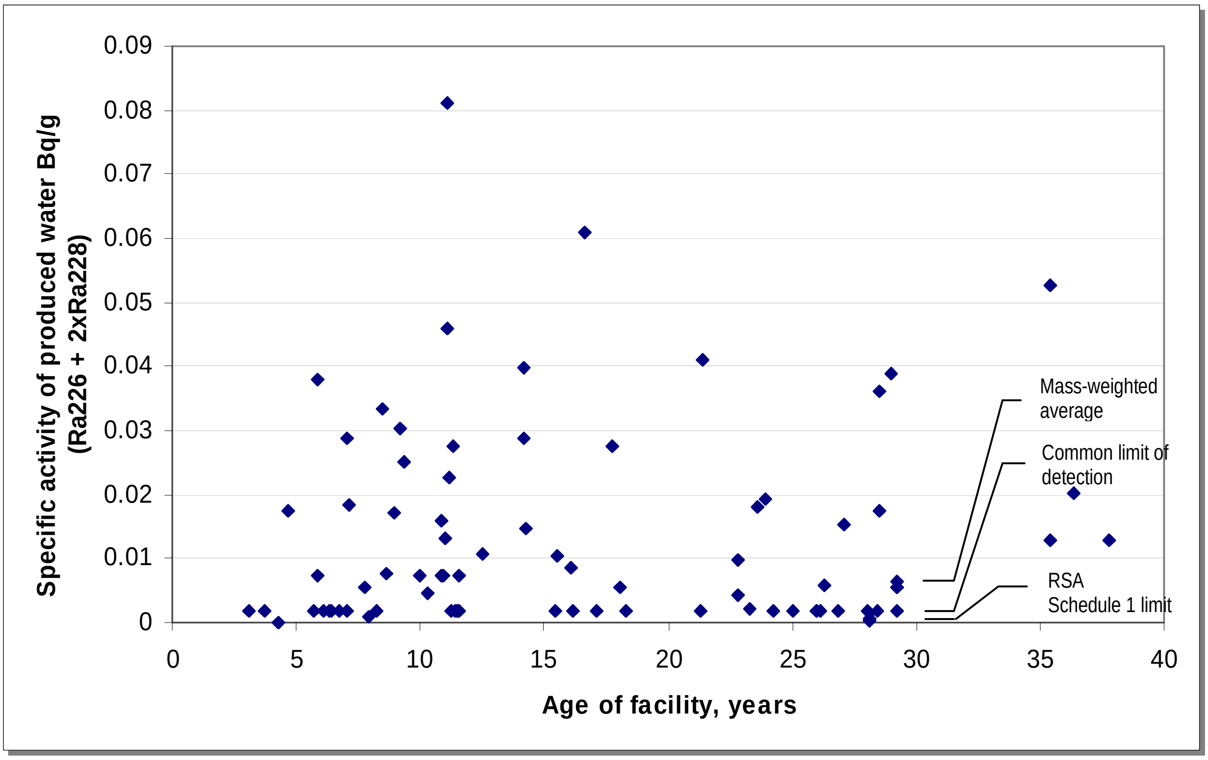
- 2004-2010: one significant facility and sufficient smaller developments to account for two significant facilities, *i.e.* three facilities per year.
- 2010-2020: two significant facilities per year.
- 2020-2040: one significant facility per year.

For each new facility, NORM arisings of all forms are attributed on the basis of the current facility average. It is assumed that new facilities will have a lifespan of 15 years, which is based on the typical production profiles submitted in Environmental Statements for recent new developments.

6.2.5 Produced water

For produced water, the coverage of facilities is very high but temporal coverage is only since 2003. The age of the facility and the activity in the produced water were examined to find any correlation, but none was observed as can be seen from **Figure 19**.

Figure 19. Facility age versus activity in produced water



Note: 'mass-weighted average' means the sum of the activities divided by the sum of the volumes, rather than the average of the sampled activities.

For the purposes of this study, produced water volumes have been projected up to 2040. Two sets of data on produced water forecasts from DTI were reviewed but they did not extend beyond 2010 and consequently a different basis for projection is used in Section 6 for forecasting.

A mass weighted average activity 33,800 Bq/t, calculated from the UKOOA produced water data has been used to calculate the activity of future discharges as discussed below.

It is assumed that future produced water remains at a constant rate per facility and that all attributes of NORM remain constant over time. In reality, produced water cuts tend to increase over time but this does not necessarily mean that the rate of discharge increases as the installed equipment has a finite capacity. Since there are a large number of developments at many different ages, it is assumed that taking the current average of NORM arisings is a reasonable approximation.

Unrelated to NORM, OSPAR has a target to reduce the total oil in produced water discharges by 15% of 2000 levels by 2006 (OSPAR Recommendation 2001/1 for the Management of Produced Water from Offshore Installations). It is assumed that in meeting this target, 10% of existing produced water discharges (i.e. 10% of oil in water) will be reinjected by or in 2006, with the remaining 5% oil reduction being achieved through operational improvements. It is then assumed that no further existing discharges will be re-injected as there will be no driver to do so. This is a professional judgement based on knowledge of Operator's intentions; however this matter is still very much open to debate on the solutions, and solutions are also conceivable that involve re-injecting all the 15% or none of it.

Under the same OSPAR Recommendation, there is a presumption that new developments will re-inject any produced water unless there is a strong case for discharging it. It has been assumed that 75% of new developments will re-inject produced water and 25% will argue a 'strong case' to discharge it to the sea.

6.2.6 Workovers

For workovers, it is reported that any NORM arisings are normally discharged into the process on the host facility and are ultimately counted in vessel cleanouts and other discharges and as a result are rarely monitored directly. Discussions with cleaning contractors suggest that 0.5 tonnes per well is a typical figure, with up to 12 tonnes for a well that had been completely obstructed by scale. Specific data on two workovers with discharges direct to sea was sourced from an Operator, and the data identified 0.85 tonnes of NORM solids and a further 139 tonnes of exempt solids (contaminated mud). 23 workovers were undertaken in 2003 (DTI, 2004) and it is assumed that 21 of these gave rise to 0.5 tonnes of NORM and 2 gave rise to 12 tonnes of NORM. This is profiled into the future in proportion to the number of facilities in existence. The uncertainty of projecting from such data may be high, and there may also be double-counting where the NORM is discharged into the process and accounted for elsewhere.

6.2.7 Terminals

Data for terminal arisings was particularly patchy. In some ways this is inevitable as there are relatively few terminals, and with several years between cleanouts, it is hard to trace disposals and to derive an annual amount.

Significant arisings will occur in a year when there is a terminal cleanout, and there may be ten years between such cleanouts. In order to report an annual average, the average of known disposals over the last ten years has been taken. In any one year, however, the arisings are likely to be either well below or well above this figure.

6.3 Forecasts

The forecasts are presented in the form of:

1. Mass of NORM solids;
2. Total activity in NORM solids; and
3. Total activity in produced water.

Figure 20 forecasts the mass of NORM solid arisings and **Figure 21** forecasts the activity in NORM solid arisings.

It should be noted that the 'jagged' appearance of decommissioning forecasts in **Figure 21** is a result of whole numbers of facilities being forecast for decommissioning, and the relatively high NORM concentration in decommissioning solids.

Figure 22 presents the forecast for activity in produced water. Note that only the lower two data series are discharged directly to sea, and a proportion of the activity to terminals is also discharged to sea.

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

Figure 20. Forecast of mass of NORM solid arisings

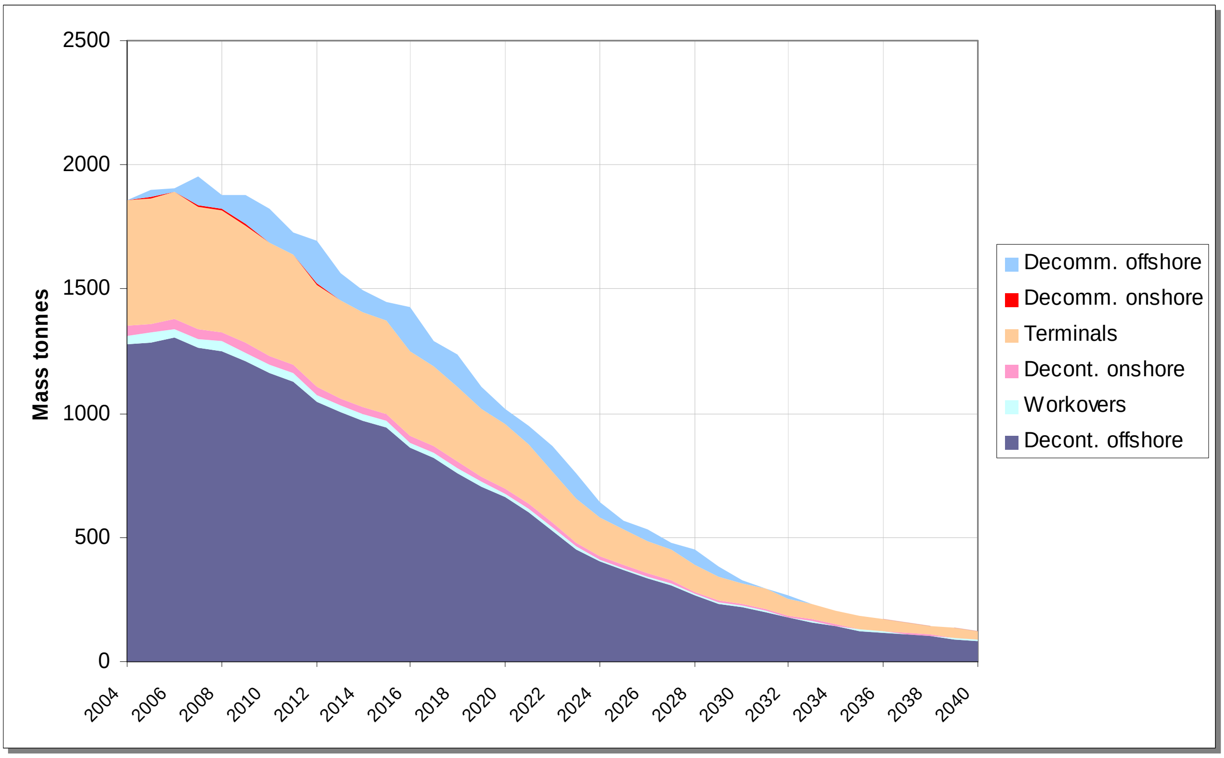


Figure 21. Forecast of activity in NORM solid arisings

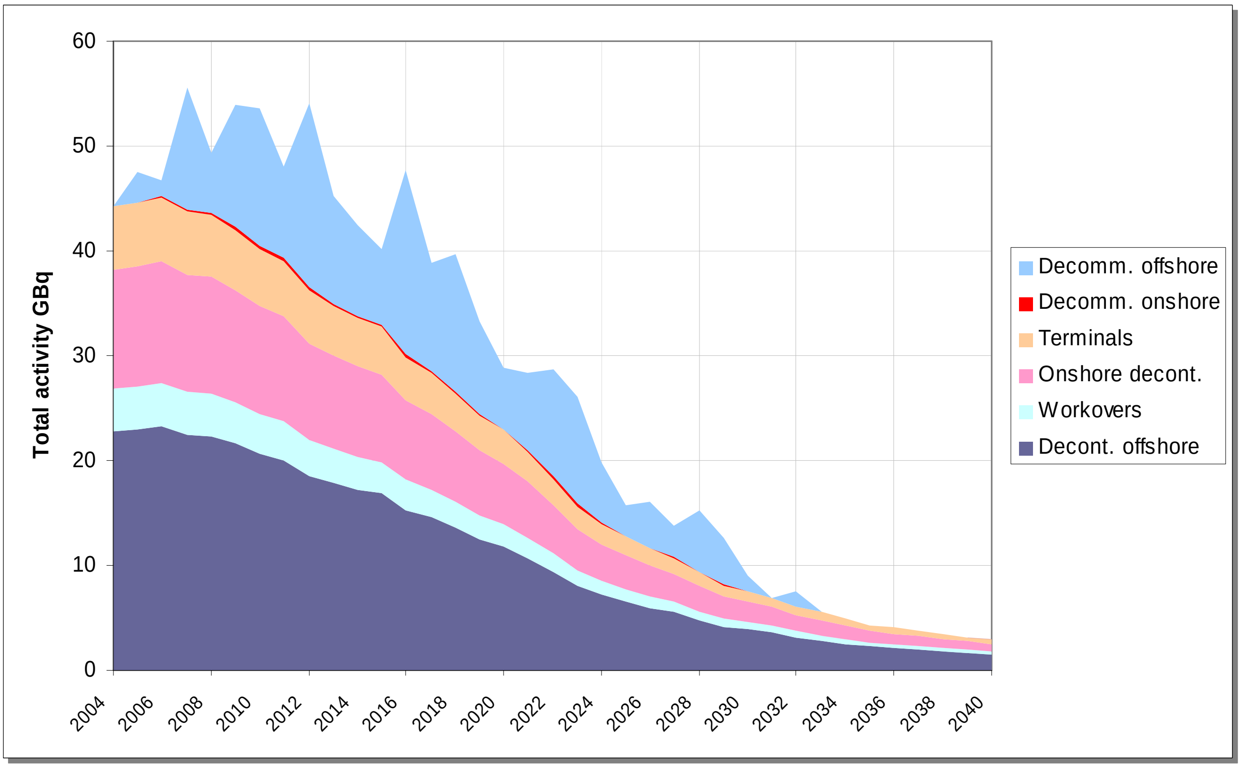
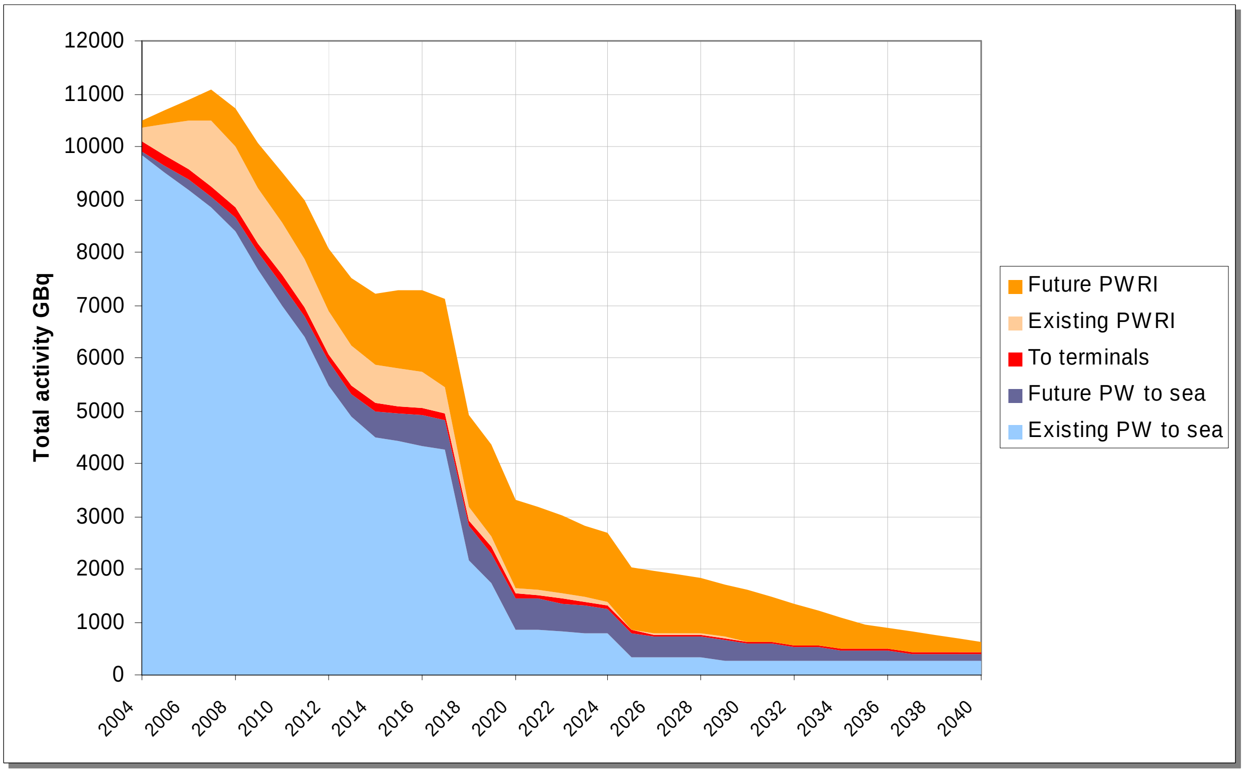


Figure 22. Forecast of activity in produced water



7 CONCLUSIONS

Phase 1 of this project has quantified the main NORM waste streams from oil and gas production and the conclusions from the quantification exercise are summarised by subject below.

There is considerable variation between facilities and it is apparent that meaningful trends would only be evident if several years' records from a selection of platforms were analysed. These records exist, often offshore, but would require research beyond then scope of this study. Consequently estimates and predictions are based on data at the broadest level.

NORM origins
The origin of the radionuclides in NORM is well known and documented as progeny of the primordial ^{238}U and ^{232}Th decay series, although transport and deposition mechanisms are less well understood. Most literature refers mainly to mineral scales and sludges containing radium isotopes and these account for the vast majority of oilfield NORM by mass. More recently the occurrence of metallic NORM (as a thin metallic film or a black deposit in sludges) from gas and condensate processing equipment has been investigated. This contains the ^{222}Rn daughters ^{210}Pb and ^{222}Po. There is much less published information on this type of NORM. It is also reported that there is a third type of NORM resulting from direct deposition of ^{210}Pb transported in solution.

Data acquisition
Questionnaires were returned for 82 facilities and further detailed information was supplied by several operators. This covered a wide range of facility types and locations.

Produced water analyses were obtained for 96% of produced water discharges, supplemented by further analyses from some Operators.

Offshore decontamination reports to the regulators (EEMS and RSA returns) do not accurately quantify exempt disposals. One Operator's detailed records were used to estimate offshore decontamination totals.

Detailed records of onshore decontamination were received.

A reasonable level of detail on decommissioning wastes was obtained although firm historic records were difficult to source. Predicted decommissioning arisings have consistently been far higher than actual disposals.

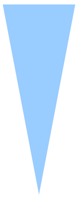
Consistent or comparable data on terminal arisings could not be obtained.

Data on NORM from workovers was limited. Most NORM from workovers is understood to be discharged into the treatment processes and is counted in the arisings from those processes.

NORM occurrence
The vast majority of NORM occurs in oil production infrastructure. The main areas where NORM accumulation is encountered are locations where there is oil and water and where physical conditions change, *e.g.* in the well itself, in separators, degassers, heat exchangers and in water or hydrocarbon storage vessels.

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

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



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

Scale inhibitors are widely used offshore both in downhole treatments (squeezes) and in topsides processing. Treatments are designed to minimise scale accumulation in order to maximise production. This does not reduce the amount of NORM nuclides present but does keep more of them in the produced water.

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

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

Current arisings

A summary of estimated current arisings is given in **Table 11**. The following observations are made:

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

Forecasting NORM generation

It is predicted that the activity discharged in produced water, from the sum of existing and future platforms, will decrease to approximately one tenth of its current value by 2040.

The generation of NORM solids is expected to increase slightly to 2010 and then decrease by around 50% to 2040.

Arisings from decommissioning are predicted to increase to a plateau between 2012 and 2025 in line with predictions for platform decommissioning. All other arisings, accounting for more than 90% of the total, are predicted to decrease from the current level in line with the number of facilities in the UKCS.

General comment

Within the scope of the current project NORM quantification has stopped at the major terminals with hydrocarbon import pipelines. From informal discussions, however, it appears that some of the terminals receiving tankered hydrocarbons also have NORM or would be expected to have NORM, as tankers routinely ship water (and agitated bottom sludges) along with oil and ballast water. There are informal references to NORM in tanker sludges but no data on activities or volumes.

From the available data and informal advice from terminals it is reasonable to expect NORM to occur in the downstream oil and gas industry, however this is beyond the current scope of this project.

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9 APPENDIX 1 - OPERATOR QUESTIONNAIRE

Qu. no.	Question
1	**Your facilities** This includes platforms and FPSOs. Questions for onshore terminals are on the sheet named 'Terminals'. It is assumed that NORM issues for tiebacks are dealt with under the host platform.
	OPERATOR NAME
1.1	We have your company listed as operator of the facilities listed to the right. Is this correct?
1.2	Please correct the list if necessary and add any additional facilities in the spare columns to the right.
2	**NORM/LSA occurrence.** NORM/LSA as used in this questionnaire refers to all scales, deposits and liquids containing naturally occurring radionuclides from the reservoir, not just to solid LSA scale
2.1	At each facility, has radioactive scale or deposits been identified?
2.2	Has NORM/LSA been identified on equipment carrying liquids or equipment carrying only gas?
2.3	What form of NORM/LSA scale is present?
2.4	If there are solid NORM deposits *e.g.* sludges, what form are the solid NORM deposits in?
2.5	If you have had radiological sampling and laboratory analyses carried out what naturally occurring radionuclides have you encountered on your facilities?
2.6	Other? please state
2.7	Have standard chemical analyses of the scale/ deposits been carried out?
2.8	Which mineral types were present? Please state which metal compounds and % composition if known, or attach relevant analyses.
a	Sulphates- which? (*e.g.* Ca, Ba, Sr)
b	Carbonates- which?
c	Sulphides- which?
d	Silicates?
e	Oxides?
f	Other? Please describe.

2.9 Have you had any particular recurrent problems with regard to NORM on any of your facilities?(For example, scaling in separators, NORM in pigging waste)

3 **Scale prevention measures**
It is assumed that most if not all facilities will have some form of scale prevention program in place.

3.1 Is a scale inhibition programme in place?
3.2 Where are the scale inhibitor injection points on your facilities?

3.3 Do you subcontract your scale management ?
3.4 If so, to whom?
3.5 How has your use of scale inhibitor changed over time?

3.6 Other - please state.

4 **Provision of NORM data. Volume/weight/activity**
EEMS data is being provided by UKOOA/DTI. We are seeking data on NORM/LSA generation and characterisation beyond that reported in EEMS. Any data supplied will not be presented in an attributable form to the regulators

4.1 Please attach RSA 93 (SEPA/EA) returns for NORM disposals for all of your facilities for 2002.
4.2 Who undertakes your radiological analyses?
4.3 Do you give Genesis permission to obtain NORM analytical data direct from this company?
4.5 If no, please attach analytical data
4.6 Who undertakes your NORM decontamination?
4.7 Do you give permission for Genesis to obtain NORM disposal data from equipment removed from your facilities from this company?
4.8 If no, please attach analytical data
4.9 Have you ever sent radioactive material to an onshore disposal facility *e.g.* Dounreay or Drigg?
4.1 If so, please describe

4.11 **Annual NORM arisings from vessel clean outs**
a Volume m^3
b Annual mass kg
c Activity Bq/g
4.12 **Annual NORM arisings from pigging waste**
a Volume m^3
b Mass kg
c Activity Bq/g

4.13 **Pigging waste activity by pipeline type**
a Oil lines Bq/g
b Gas lines Bq/g
c Gas/condensate Bq/g
4.14 **Other NORM arisings**
Protective clothing
a Mass kg
b Activity Bq/g
Bulk solids, sludges
c Mass kg
d Activity Bq/g
e Other - please describe source, mass and activity *e.g.* wastes from workovers

4.15 Have you carried out any unpublished studies on NORM/LSA?
4.16 Would you be willing to allow Genesis access to these? This information will not be attributable in the SNIFFER reports and may greatly assist the aims of the project.

5 **Produced Water**
The results of the UKOOA 2003 produced water radiological analysis programme are being supplied separately.
5.1 Do you have any other radiological analyses of produced water other than that already supplied to UKOOA?
5.2 If yes please supply the values. If it is easier, please attach the sheets of the analytical report.
a Sampling location:
b Activity (Bg/g) of:
Ra 226
Ra 228 (Ac 228)
Pb 210
Po 210
Any others - please describe
5.3 For 2002, how much produced water is:
a Discharged to sea m^3/year
b Reinjected m^3/year
c Sent onshore in export lines m^3/year

6 **NORM/LSA equipment decontamination**
This is to ascertain what equipment is decontaminated offshore and onshore and what methods are used

6.1 Do you carry out any offshore NORM decontamination of equipment?
6.2 How is this decontamination carried out?
6.3 What type of equipment do you clean/have cleaned offshore?
a Tubulars

b Valves
c Pumps
d Process vessels
e Other - please state

6.4 Is this decontamination of mineral scale? If so, please state:
a Method of removal
b Please give details of removal process(es) and name(s) of the contractor(s) who undertake this.
6.5 Do you remove Pb 210/Po 210 NORM deposits in gas equipment offshore?
a Method of removal
b Please give details of removal process(es) and name(s) of the contractor(s) who undertake this
6.6 Do you send NORM contaminated equipment *onshore* for decontamination?
a To which contractor?
6.7 What types of equipment do you generally send onshore for NORM removal?
a Tubulars
b Valves
c Pumps
d Process vessels
e Other? please state

6.8 Do you classify NORM-contaminated equipment being sent onshore as waste?
6.9 What percentage of your equipment sent for decontamination is classified as 'exempt' under RSA 93?

7 **NORM monitoring**
The questions in this section are concerned with what and where you monitor for NORM. This will help quantify NORM generation and identify good practices.

Monitoring in these questions means instrumental measurement of the presence of natural activity.
7.1 Please list the NORM monitoring points for each facility

7.2 Do you monitor oil line solids for NORM when BS&W is measured?
7.3 If you have monitored oil line solids have you sent samples for radiological analysis?
7.4 Do you monitor produced sand for NORM before disposal ?

7.5 If you have monitored produced sand have you sent samples for radiological analysis?

7.6 Do you monitor your produced water (if any) for NORM ?

7.7 If you have monitored produced water have you sent samples for radiological analysis?

7.8 Do you operate facilities where pigging wastes from oil/gas lines are received?

7.9 Do you monitor the pigging wastes for NORM?

7.10 Have you ever found NORM in pigging wastes from

- **a** Oil lines
- **b** Gas lines
- **c** Gas/condensate lines
- **d** Other - please state

7.11 Have samples of pigging waste been taken for radiological analysis?

7.12 Have you carried out any detailed NORM/LSA surveys at any facilities?

7.13 What was surveyed:

- **a** Downhole?
- **b** Topsides process?
- **c** Oil export system?
- **d** Water treatment system?
- **e** Storage vessels for:
  - Water
  - Oil
  - Gas
  - NGL

7.14 Were these NORM surveys carried out during shutdown?

7.15 Do you have any *in situ* NORM monitoring which does not require shutdown?

8 **NORM in process equipment**
Process equipment may be a routine source of NORM contamination and may present disposal issues on decommissioning

8.1 Please list the main process areas where you have had NORM/LSA accumulation.

8.2 Does your facility have any process equipment currently unused but not yet decommissioned ?

8.3 Does or could this contain a scale or deposits?

8.4 Has this been monitored for NORM?

8.5 Please describe any relevant findings, or if easier, attach pages of investigative/analytical report.

8.6 How often, as a general rule, are process vessels opened up:
a for inspection? (number of months)
b for cleanout? (number of months)

9 **Disposal of NORM solids**

9.1 Does each offshore facility have scale grinding and disposal facilities (macerator/blender)?

9.2 Do your facilities have cuttings processing and re-injection equipment installed which could be adapted for NORM disposal?

9.3 Is it possible you will use cuttings/reinjection equipment for NORM solids disposal, subject to approval?

9.4 Are you intending to install other equipment to reinject NORM solids?

9.5 What water injection facilities exist at each facility?

9.6 Are you intending to reinject produced water in the future?

9.7 What is the reinjection capacity at your facilities? m^3/day

9.8 How do you generally dispose of NORM solids such as pigging waste or sludges?

9.9 Name of contractor if applicable.

9.10 Have you ever encountered difficulties, of any kind, in storing, transport or final disposal of NORM? please give details

9.11 At your onshore depots, do you operate 'gate alarms' or other automatic boundary monitoring for movements of equipment or waste?

9.12 What percentage of your NORM solids is classified as 'exempt' under RSA 93?

9.13 Do you have any NORM waste minimisation procedures?

9.14 If so please describe *e.g.* name of contractor responsible

9.15 Other comments on existing/potential NORM/LSA solids disposal routes

10 Terminals (see next section

11	**Final comments**
11.1	Please make any final comments you wish to make on any aspect of NORM.

10	**Terminal operators** Additional questions for operators of onshore terminals
	OPERATOR NAME
10.1	We have your company listed as operator of the facilities listed to the right. Is this correct?
10.2	Please correct the list if necessary and add any additional facilities in the spare columns to the right.
10.3	Please attach RSA 93 (SEPA/EA) returns for NORM disposals for all of your facilities for 2002.
10.4	What is the main source of your NORM arisings? Other - please state.
10.5	How do you dispose of NORM solids? Name of waste facility/ies or contractors.
10.6	Do you operate 'gate alarms' or other automatic boundary monitoring for movements of equipment or waste?
10.7	Do you use scale inhibitor to control scale from produced water arriving at the terminal?
10.8	What annual volume of water do you receive in your incoming oil lines? m^3/year
10.9	Is the natural activity of the water arriving in the oil lines monitored:
a	By instruments?
b	By sampling and analysis?
10.10	Where does your water discharge occur? Other - please specify
10.11	Is the water discharge monitored for natural activity?
10.12	What is the annual total water discharge from terminal m^3/year
10.13	If the above figure includes non-produced water, *e.g.* ballast water, please specify the % which is produced water
10.14	Do you use instruments to monitor pigging waste for NORM?
10.15	Have you recorded significant natural activity in pigging waste using instruments?
10.16	If you have had radiological analysis carried out -What range of levels of specific activity have been recorded?
a	Ra 226 Bq/g
b	Ra 228 (Ac 228) Bq/g

c	Pb210 Bq/g
d	Po210 Bq/g
e	Any others: please describe
10.17	Where did the active pigging waste originate?
10.18	What percentage of your NORM solids is classified as 'exempt' under RSA 93?
10.19	Do you have unused / mothballed process trains, individual items of equipment on your site ?
10.20	Have these been investigated for scale/deposits and/or monitored for NORM?
10.21	If so, please describe results
10.22	Please describe any other significant issues for NORM relating to terminals

11	**Final comments on Terminals**
11.1	Please make any final comments you wish to make on any aspect of NORM relating to Terminals.