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NORM IN OIL AND GAS PRODUCTION – WASTE MANAGEMENT AND DISPOSAL ALTERNATIVES

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Abstract
NORM waste in oil and gas production includes hard and porous deposits from decontamination of tubulars and different types of topside equipment, and sludge, mud and sand. The activity concentrations of ^{226}Ra, ^{228}Ra and decay products in deposits and sludges may vary from normal levels in soils and rocks (less than 0.1 Bq/g) to more than 1000 Bq/g.

In this discussion of waste management and waste disposal, the different alternatives are separated into four categories: (1) re-injection/injection of waste, (2) sea disposal of waste or dumping of equipment with or without encapsulation, (3) land disposal of waste or equipment with or without encapsulation, and (4) scrap metal recycling of contaminated equipment.

Of the 14 disposal alternatives mentioned briefly in this paper, the following are assumed to be of main interest: (1) well injection by hydraulic fracturing together with cuttings and other types of production waste (2) injection into the well during plugging and abandonment operations, (3) depository in an abandoned mine, tunnel or other types of underground facilities, (4) land depository by burial of waste with encapsulation and/ or surrounded by a concrete barrier, and (5) at approved depositories for inorganic waste or depositories for other types of waste from the oil industry.
In a complete discussion, other environmental and waste aspects related to non-radioactive components/substances should also be addressed.

Introduction
When oil and natural gas are extracted from the ground, they are accompanied by solids and formation water. Under certain circumstances, naturally radioactive salts which are dissolved in the formation water will precipitate followed by deposition as sulphate and carbonate scales onto the inner walls of production tubulars, valves, pumps, separators and other types of topside equipment. Particles of clay and sand co-produced from the reservoir may also act as surfaces and thereby initiating scale deposition. Injection of seawater into the reservoir in order to maintain the pressure may lead to the mixing of injected water with formation water after the reservoir breakthrough, and thereby increase the sulphate concentration of the produced water followed by enhanced deposition of radiumsalts in the production system.

The activity concentrations of ^{226}Ra, ^{228}Ra and decay products in deposits and sludges may vary from normal levels in soils and rocks (less than 0.1 Bq/g) to more than 1000 Bq/g (Strand et al 1997, Lysebo & Strand 1997). However, the activity concentration is still low by comparison with the specific activity of most man-made radioactive sources, and to emphasise that the concentrations are very low the deposits are often refered to as low specific activity (LSA) scales.

Sometimes, deposition of scales may interfere with the production process by blocking transport through the production zone, flow lines and produced water lines. Consequently, the oil companies try to prevent deposition of scales through the application of inhibitors. The scale inhibitors will prevent the deposition of radiumsalts in the system but will increase the concentration and the release of radioactivity by the produced water. There has been an enormous increase in the use of inhibitors during the last decade, and owing to present and future demands to reduce the production costs, the increase in the use of inhibitors in the years to come is assumed to be significant.

In the production of natural gas, very thin layers or films containing relatively high levels of ^{210}Pb has been observed. Equipment from gas treatment and transport facilities may also accumulate very thin films of ^{210}Pb formed by decay of short-lived radon daughters plated onto the inner surfaces. However, the total amount of waste is much less and the appearance of ^{210}Pb in gas production is not a waste problem to the same extent as radium sulphates in scales and sludges.

Provided that proper personal protective equipment (dust masks, protective clothing, etc.) are used in the different operations involving handling and treatment of contaminated equipment and waste, the occupational doses are generally very low (Strand et al 1997, Lysebo and Strand 1998). Measurements and calculations have demonstrated that the doses are two to three orders of magnitude below the dose limit recommended by the International Commission on Radiological Protection (ICRP 1990) and by the National Regulatory Authority in most countries.

Owing to the large amount of material exceeding the recommended exemption levels, NORM in oil and gas production represents a considerable waste problem for the industry. The exemption and clearance levels recommended by the International Atomic Energy Agency (IAEA 1996) are based on limiting annual doses to members of the public to 10 mSv (IAEA 1988). According to the International Basic Safety Standards (IBSS, 1996), the recommended exemption values for the most important naturally occurring radionuclides that occur in NORM waste from oil and gas production are 10 Bq/g for ^{226}Ra, ^{228}Ra and ^{210}Pb and 1 Bq/g for ^{228}Th. However, the application of exemption to naturally occurring radionuclides is limited to the incorporation of radionuclides into consumer products or their use as radioactive sources (e.g. ^{226}Ra, ^{210}Po) or for their elemental properties (e.g. thorium, uranium). Therefore, NORM waste from oil and gas production are not strictly covered by these recommendations. In Norway, it was decided in 1997 that these recommendations also should be extended to include waste in the oil and gas industry (NRPA 1997). The deposits consists mainly of sulphates and carbonates and these elements are classified at non-toxic and not harmful to the marine environment. Consequently disposal to the sea is not restricted by national legislation on pollution.

Disposal alternatives

A list of different disposal alternatives are presented in Table 1. The different alternatives are separated into four categories and further into a total of fourteen disposal alternatives. In the discussion of disposal option, several aspects has to be addressed. Disposal of NORM waste has to be in accordance with national regulations and environmental policy, and international agreements and conventions. Some countries like Norway has ratified both the London Convention of 1972 (revised in 1996) and the OSPAR Convention (Convention for the Protection of the Marine Environment of the North East Atlantic) of 1992. The Norwegian authorities wish to show a very high environmental profile, and the policy regarding dumping and release of hazardous waste, including radioactivity, is very strict. Alternatives involving dumping of waste or equipment are not assumed to be acceptable at all. However, studies have shown that the release of radioactivity to sea water from dumping or burial in the sea bed of waste encapsulated in drums of stainless steel or in sealed tubulars, or other types of sealed equipment, are negligible. Anyhow, these alternatives have been rejected by political decisions. The political decisions are not based on scientific evaluations of the potential environmental and radiological consequences of release to the environment of NORM waste. Discharge of NORM as production waste (from onsite cleaning and maintenance of topside equipment) from offshore installations is not in conflict with the London Convention. However, release of production waste from offshore installations is covered by the OSPAR Convention, and owing to recent movements in a much more restrictive direction, there are reasons to believe that onsite release of NORM from offshore installations will be much more restricted in the future.

Disposal by injection of NORM waste by hydraulic fracturing has been investigated by several companies (Gardiner 1994, Fletcher 1995) and is performed routinely for re-injection of cuttings, drilling mud and different types of non-radioactive production waste from cleaning of topside equipment (COWIconsult 1993). Sometimes the injection takes place in the well during drilling or during production. The depth of the fractures depends on the depth of the well and the reservoir but is typically in the range 500 to 1000 m below the sea bed level. An alternative solution is to inject the waste into the reservoir by using the seawater injection system. A third solution is to inject the waste into the well during plugging and abandonment operations. By re-injection the waste is put back to where it comes from and studies have shown that this solution is very safe and the potential for release of radioactivity to the sea is almost zero. All three of these solutions should be regarded as very safe and acceptable from a radiological point of view. Provided that personal protective equipment are used in the operations involving handling and pre-treatment of waste, the occupational doses are generally very low and within a controllable regime. However, questions have been raised if solutions involving re-injection or injection is in conflict with the London and/or the OSPAR Conventions.

Solutions involving surface spreading, burial of waste without any kind of protective barrier or burial of contaminated equipment are assumed to be of no present interest and they will not be treated further in this discussion. A land depository has to be surrounded by a concrete barrier, and the waste has to be enclosed in proper corrosionresistant containers to prevent or to keep within controllable limits the run-off to groundwater or dispersion of radioactivity to the environment in any other way. A national depository for low and intermediate level radioactive waste has recently been established Norway, but owing to the large amount of waste and the fact that this is not only «low level waste», but perhaps more precisely should be denoted as «very low level waste», the authorities has decided that NORM waste in the future should not be brought to the National Depository. Since 1996, the oil companies have been permitted to store this type of waste temporarily at the supply bases under certain restrictions. At present, the total amount of solid NORM waste stored at the seven approved locations is approximately 100 tonns, but it is assumed that the annual amount of waste will increase substantially in the years to come.

***Table 1:* NORM waste disposal alternatives.**

Category	Disposal alternative
Injection/re-injection of waste together with cuttings and other types of non-radioactive production waste	• Well injection/re-injection into the reservoir • Well injection by hydraulic fracturing • Injection into the well during plugging and abandonment operations
Sea disposal of waste or dumping of equipment with or without encapsulation	• Disposal of solid waste into the sea • Dissolution of solid waste by use of chemicals followed by disposal into the sea • Encapsulation of the waste in drums followed by dumping or burial in the sea bed • Sealing of tubulars and other types equipment without removal of NORM followed by dumping
Land disposal of waste or equipment with or without encapsulation	• Depository in an abandoned mine, tunnel or other types of underground facility • Burial of waste with encapsulation or surrounded by a concrete barrier • Burial of waste or sealed equipment without encapsulation • Land surface spreading of solid waste with or without dilution • At approved depositories for inorganic waste or depositories for other types of waste from the oil industry • Volume reduction (of waste) and thereby classified as radioactive waste followed by deposition at national depositories for radioactive waste
Scrap metal recycling of contaminated equipment	• Equipment smelting without decontamination followed by recycling of the metal and disposal of the slag

Of the fourteen alternatives in Table 1, only five are assumed to be of main interest:
(1) injection or re-injection by hydraulic fracturing together with cuttings and other types of production waste, (2) injection into the well during plugging and abandonment operations, (3) depository in an abandoned mine, tunnel or other types of underground facilities, (4) land depository by burial of waste enclosed in corrosionresistant drums and/or surrounded by a concrete barrier, and (5) at approved depositories for inorganic waste or depositories for other types of waste from the oil industry.

For all five alternatives, the occupational doses are very low. Provided that proper personal protective equipment are used during handling of waste and equipment, conservative estimates show that the annual occupational doses are less than a few tenths of a mSv (Strand et al 1997). For the injection and re-injection alternatives (1 and 2), the environmental discharges and the doses to members of the public are almost zero. For the other three alternatives (3, 4 and 5), the release of radioactivity and the doses to members of the public are far below acceptable levels, provided that the facilities are not located in residential areas and in safe distance from surface and groundwater sources to be used as household water.

At the time being, routine discharges to the sea of solid NORM waste as result of onsite cleaning and maintenance of topside equipment, and release of radioactivity by produced water, are accepted by the Norwegian authorities. This also includes NORM waste as a result of onsite decontamination of tubulars and other types of equipment. Discharges of production waste may, however, be influenced by future changes of the OSPAR Convention (OSPAR 1998). Offshore disposal of waste generated as a result of onshore decontamination of tubulars and other types of equipment from offshore production, will on the other hand be covered by the London Convention. However, it is not clear if disposal of waste that has been brought from one offshore installation to another is in conflict with the London Convention.

In Figure 1, the different steps involving discharge and disposal of NORM in the oil industry are illustrated by a flow diagram. The steps that could be in conflict with the London Convention are illustrated by dotted arrows, while the thick solid arrows show steps that may be or could become in conflict with the OSPAR Convention. From a radiological point of view, all of the five alternatives are assumed to be acceptable solutions.

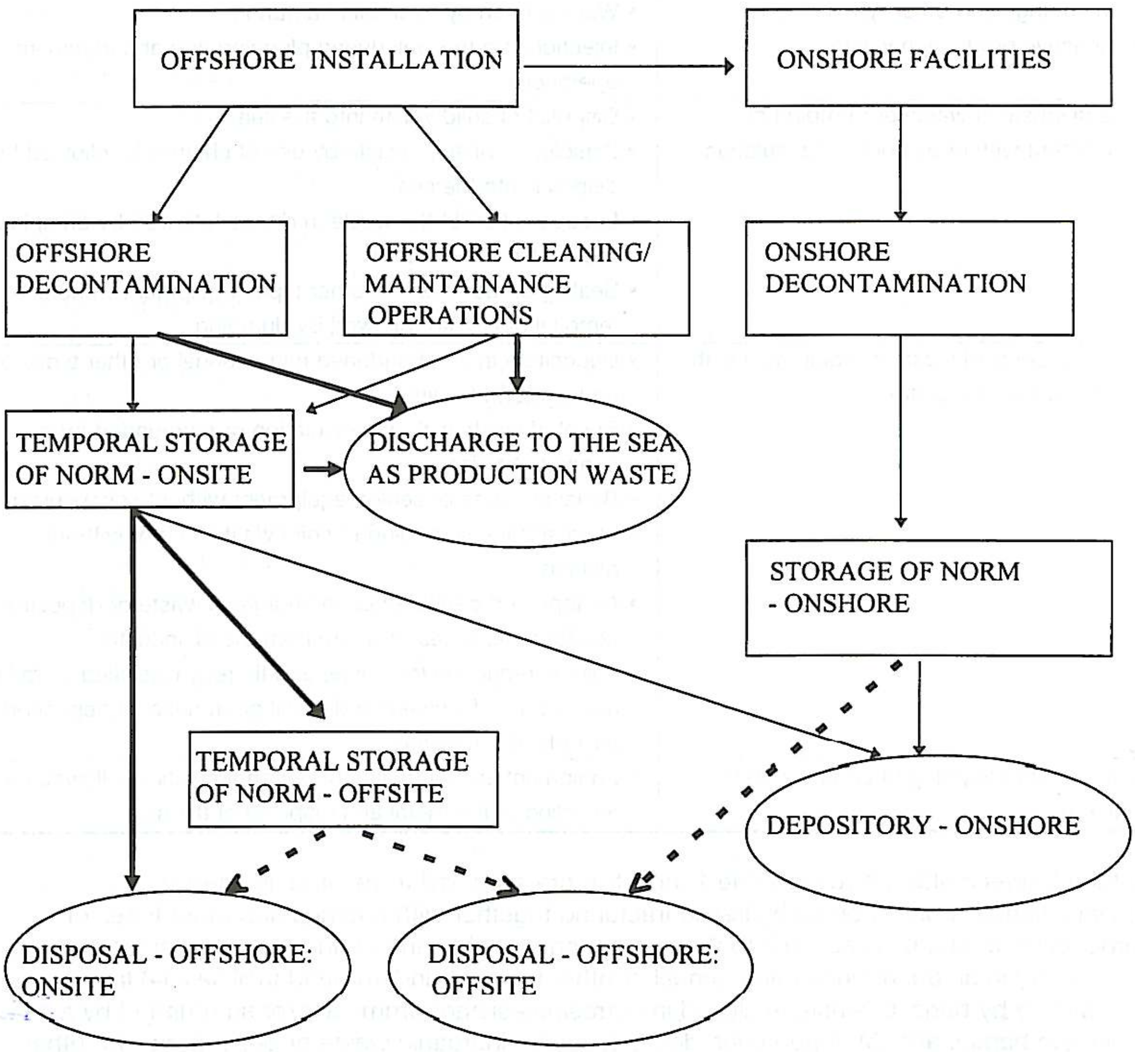

Figure 1: Disposal chart – NORM waste in oil and gas production.

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