HANDLING AND DISPOSAL OF NORM IN THE OIL AND GAS INDUSTRY

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ABSTRACT
Naturally occurring radioactive materials, NORM, in oil and gas production includes hard and porous deposits (scales or sludges) in tubulars and different types of topside equipment as well as condensates extracted as liquids from natural gas. The activity concentrations of $^{226}$Ra and $^{228}$Ra in scales and sludges covers a broad range; from normal levels in soils and rocks (less than 1 Bq/g) up to more than 1000 Bq/g. Generally, the activity concentrations are lower in porous deposits and sludges than in scales. The activity concentration of $^{210}$Pb is relatively low in hard deposits but may reach levels of thousands of Bq/g in sludges and in the very thin layers found in gas production.

Huge amounts of NORM waste exceeding the exemption level of 10 Bq/g of $^{226}$Ra and $^{228}$Ra are generated as a result of both onsite and offsite decontamination of tubulars and different types of topside equipment. Onsite decontamination is the preferred option when components cannot reasonably be removed and replaced or need no other treatment before reinstallation or continued use. One example of onsite decontamination is the removal of accumulated sludges from separators and systems handling produced water. Offsite decontamination is carried out when onsite decontamination cannot be performed effectively and radiologically safe, when components will have to be refurbished by specialised companies prior to their reuse, and when components not to be reused for their original function has to be cleaned. An other increasing problem is handling and treatment of waste from decommissioning of oil and gas production facilities.

This paper describes different disposal alternatives of NORM waste from the oil and gas industry. The discussion will focus on the following four disposal alternatives which has considered to be of most interest: (1) re-injection by hydraulic fracturing together with cuttings and other types of production waste (2) injection into the well bore during plugging and abandonment operations, (3) land depository by burial of waste with encapsulation or surrounded by a concrete barrier, and (4) depository in an abandoned mine, tunnel or other types of underground facilities.

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 (1,2). 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 referred 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. These inhibitors are organic compounds they may also increase the biological uptake of radioactivity. 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 (1,3). Measurements and calculations have demonstrated that the doses are two to three orders of magnitude below the dose limit for workers recommended by the International Commission on Radiological Protection (4).

Owing to the large amount of material exceeding the recommended clearance 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 (5) are based on limiting the annual doses to members of the public to 10 µSv (6). According to the International Basic Safety Standards (7), 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 values 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 in oil and gas production is 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 (8), and the exemption values to be used as clearance levels.
The deposits consist mainly of sulphates and carbonates and these elements are classified at non-toxic and not harmful to the environment. Consequently disposal of this type of waste is not restricted by the legislation on pollution. In a complete discussion, the environmental aspects related to the non-radioactive components/substances should also be addressed.

**DISPOSAL**

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 and these decisions are not necessarily based on scientific evaluations of the potential environmental and radiological consequences of release to the environment.

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 (9), there are reasons to believe that onsite release of NORM from offshore installations will be treated in a much more restrictive way in the future. Future disposal by injection of NORM waste by hydraulic fracturing has been investigated by several companies (10, 11) and is performed routinely for re-injection of cuttings, drilling mud and different types of non-radioactive production waste from cleaning of topside equipment (12). Hydraulic fracturing consists of adding pulverised waste to a carrier fluid and pumping the mixture into the well at sufficiently high pressure to create fractures in the permeable formations. 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, and below both existing and potential sources of drinking water. The fractures extends up to several hundred meter from the well bore. The waste is trapped between the fracture walls and is incapable of re-entering the well bore. A well used for this purpose can be fractured multiple times and the capacity of one well can be up to more than hundred thousand of tonns of solid waste. When the well is no longer required for this purpose, it is usually plugged with cement to prevent migration of fluids in the well bore. 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. Well
tubing with accumulated deposits may be left in place or placed in an well being plugged and abandoned.

By re-injection and injection the waste is put back to where it comes from and studies have shown that these solutions are very safe, and that the potential for release of radioactivity to the sea bed and sea water is almost zero. All three of these solutions should be regarded as 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 (e.g. crushing), the occupational doses should be 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 landspreading with or without dilution, burial of waste without any kind of protective barrier or burial of contaminated equipment is assumed to be of minor interest. A land depository has to be surrounded by a protective barrier, and the waste has to be enclosed in proper corrosion resistant 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 permanent monitoring program will be needed and no intrusive activities or construction of occupiable structures on the site should be permitted in the next thousands of years.

A national depository for low and intermediate level radioactive waste was recently finished in Norway. This is an underground facility (13). Owing to the large amount of waste, and the low specific activity, the authorities has decided that NORM waste should not be brought to this new 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 in Norway is approximately 120 tonnes, but it is assumed that the annual amount of waste will increase substantially in the years to come.
Table 1. NORM waste disposal alternatives.

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| 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 of 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  
• Landspreading 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 is assumed to be of main interest:
• injection or re-injection by hydraulic fracturing together with cuttings and other types of production waste  
• injection into the well during plugging and abandonment operations  
• depository in an abandoned mine, tunnel or other types of underground facilities  
• land depository by burial of waste enclosed in corrosion-resistant drums and/or surrounded by a concrete barrier.  
• 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 (1). For the injection and re-injection alternatives, the environmental discharges and the doses to members of the public are almost zero. For the other three alternatives, the release of radioactivity and the doses to members of the public are well within 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 (9). 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. 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.

REFERENCES