NORM in the Norwegian Oil and Gas Industry – Activity Levels, Occupational Doses and Protective Measures

T. Strand

Norwegian Radiation Protection Authority and Department of Physics, University of Oslo
P O Box 55, N-1332 Østerås, Norway, e-mail: terje.strand@nrpa.no

Abstract. Naturally occurring radioactive materials, NORM, in the oil and gas industry consist of hard and porous deposits (scale and sludge) on the inner surfaces of production tubing and different types of topside equipment in direct contact with the production stream. The activity concentration of radium (^{226}Ra, ^{228}Ra) and the decay products of deposits and sludge vary over a wide range from levels slightly above the background to several hundred becquerels per gram. The activity concentration of ^{210}Pb is relatively low in hard deposits but may reach thousands of Bq/g in the very thin layers found on the inner surfaces of gas production, transport and storage equipment. In Norway, NORM is classified as radioactive waste if the activity concentration of ^{226}Ra, ^{228}Ra or ^{210}Pb exceeds 10 Bq/g. At the time being, hundreds of tons of waste are being stored temporarily at the coastal oil supply bases and at the onshore decontamination facilities. Owing to the large amount of material, this type of waste represent a considerable waste problem for the Norwegian oil industry and the amount of waste may increase significantly as a result of future decommissioning of offshore installations. Given that sufficient protective equipment is being used, the annual occupational doses in the different working operations are generally very low. This paper will focus on the activity levels, occupational doses and protective measures during the production phase and onsite maintenance operations, and during handling and cleaning of NORM contaminated equipment.

1. Introduction

Enhanced levels of radioactivity in deposits (scale, sand, and sludge) of North Sea oil and gas production was first discovered in 1981, and are found in the production system of several of the main production fields [1]. The activity concentration in the solid dry material varies from background level to several hundred Bq/g of ^{226}Ra and ^{228}Ra [2]. Doses to workers involved in different operations handling and treatment/cleaning of contaminated equipment or waste are usually very low – two to three orders of magnitude below the dose limit for workers – and the main problem related to radioactive deposits is waste disposal [3,4].

Deposits in the oil and gas production can be divided into two main categories: sulphate and carbonate deposits. Sulphate deposits consist mainly of barium sulphate ($BaSO_4$), while carbonate deposits consists of calcium carbonate ($CaSO_4$). Deposits containing ^{226}Ra, ^{228}Ra and their daughter products are often referred to as LSA (low specific activity) scale, and are characterised by hard of porous layers on the inside of production equipment that has been in direct contact with the production steam (oil mixed with production water). Sea water is injected into the reservoir to maintain the pressure as the oil is extracted. The mixing of sea water and formation water creates incompatible solutions, and sulphates of barium and strontium are precipitated. Radium in geologic formations will, under certain circumstances, leak from the formation and be dissolved in the formation water. Like barium and strontium, radium is part of group IIA in the periodic system and has similar chemical properties. Consequently, radium is co-precipitated with barium and strontium as radium sulphate complex, even though its solubility product is not exceeded. Turbulent flow in the production system can cause the precipitated sulphate salts to attach to the walls or sand and form deposits with enhanced levels of radioactivity. Contaminated sand and sludge can be found inside all types of equipment in oil production than has been in contact with the produced water.

At the time being approximately 200 tonnes of solid LSA waste from the oil industry are temporarily stored in approved facilities at the supply bases in Norway. The Norwegian oil industry has estimated the annual increase in the next ten years to come to be between 20 to 30 tonnes. However, the amount of waste could increase significantly as a result of decommissioning activities in Norway of several production platforms from both the Norwegian and the UK sector of the North Sea. The largest project so far was the decommissioning of Maureen Alpha which took place at Aker Stord south of Bergen in 2002. This platform contained a total of approximately 4 tonnes LSA waste. Since this production platform was from the British sector of the North Sea, the contaminated equipment was returned back to UK for decontamination and disposal of the waste. Based on production data and analysis of samples of the produced water during the production phase, this installation was not considered to be among most NORM contaminated installations. Some of the large installations in the Norwegian sector which are going to be decommissioned in the future will most probably contain much more NORM waste, and thereby contribute significantly to the total amount of waste to be disposed in the years to come.

Several disposal alternatives have been considered [5,6]. A Norwegian expert group concluded that well injection or re-injection by hydraulic fracturing together with cuttings and other types of production waste or a depository in an abandoned mine or tunnel, or a near surface depository with encapsulation and surrounded by a concrete barrier, are the best options [7]. However, the Norwegian Authorities concluded that well injection or re-injection of waste generated as a result of onshore decontamination of offshore equipment, and thereafter taken offshore for disposal, is in conflict with international conventions for the protection of the marine environment.

2. Activity levels

27 samples of produced water were collected from 11 offshore production installations during normal operations. The samples were analysed by high resolution gamma ray spectrometry at NRPA, Norway. The concentration of ^{226}Ra varies between 0.7 and 10.4 Bq/l while the concentration of ^{228}Ra varies between 0.3 and 10.0 Bq/l. The mean concentrations of ^{226}Ra and ^{228}Ra were calculated to 4.1 and 2.1 Bq/l, respectively. The mean concentration of radium in produced water in our study is slightly lower than the mean level in other studies [2], and approximately three orders of magnitude higher than the mean concentration in sea water. The concentration of radium in the production water varies from one production installation to another and throughout the production phase with generally higher concentrations in the last phase of the production after breakthrough in the reservoir of injected sea water. Samples of production water are collected and analysed on routine basis during the production and these data, together with geochemical data, could be used in assessments of the potential for enhanced concentrations of radium in deposits on the inner surfaces of the down-well production string.

69 solid samples from different types of equipment and of different consistency of deposits (hard deposits, porous deposits) sand and sludge were collected from 9 offshore installations during revision stops. Most of the samples are from some of the larges oil production platforms in the Norwegian part of the North Sea (Statfjord A & B, Gullfaks A, B & C, Veslefrikk, Oseberg, Valhall, Snorre). The results of the analysis by using high resolution gamma ray spectrometry (HPGe detectors) at NRPA are shown in Table I. The activity concentration of ^{226}Ra and ^{228}Ra in hard deposits varied between 4 and 39 Bq/g (mean value 21 Bq/g) and between 2.7 and 33 Bq/g (mean value 14 Bq/g), respectively. In porous deposits the concentration of ^{226}Ra and ^{228}Ra varied between 0.3 and 24 Bq/g (mean value 12 Bq/g) and between 0.3 and 19 Bq/g (mean value 8 Bq/g), respectively. Only ¼ of the samples which were classified as porous deposits had a higher concentration of ^{226}Ra or ^{228}Ra than the Norwegian clearance level of 10 Bq/g. The concentration ^{226}Ra in contaminated sand and sludge varied from less than the detection level (0.1 Bq/g) to 22 Bq/g and 4.7 Bq/g, respectively. Only two of the 41 samples of sand and sludge had a higher activity concentration than 10 Bq/g. The activity concentration of ^{226}Ra was significantly higher than ^{228}Ra in 75% of the samples. The level of ^{210}Pb was very low in all of the samples. The maximum value of 0.7 Bq/g was found in one of the sludge samples. This level is several orders of magnitude lower than reported maximum levels from combined oil and natural gas production in the Netherlands [8].

Table I. Analysis on samples of deposits, sand and sludge from 9 Norwegian offshore installations

	Number of samples	**^{226}Ra (Bq/g)**		**^{228}Ra (Bq/g)**		**^{210}Pb (Bq/g)**
Hard deposits	15	21	(4.0 – 39)	12	(2.6 – 33)	< 0.3
Porous deposits	13	12	(0.3 – 24)	8.2	(0.3 – 19)	< 0.2
Sand	26	4.0	(<0.1 – 22)	2.5	(<0.1 – 13)	< 0.5
Sludge	15	2.5	(<0.1 – 4.7)	2.1	(<0.1 – 4.6)	< 0.7

The average activity concentration in hard deposits is very close to the average of 25 Bq/g based earlier measurements on samples from onshore decontamination of tubulars Norway. These results varied from a few Bq/g to more than 100 Bq/g. The highest single measurement of ^{226}Ra from a Norwegian installation was nearly 500 Bq/g and was reported almost ten years ago. This value is significantly lower than reported maximum values of 3700 Bq/g from offshore production in USA [9] and 1000 Bq/g from onshore production in Syria [10].

3. Occupational doses

External doses to personnel involved in offshore maintenance and decontamination operations of NORM contaminated equipment were measured by thermoluminescence dosimeters, TLDs, at some of the platforms where NORM contamination of the production system had been confirmed by measurements on samples of scale and sludge. The results of the readings were compared with reference dosimeters which were placed on the same platforms but in safe distance from radiation sources and thereby exposed to natural background radiation, only. Offshore, the background level is very low and the detection level significantly lower than onshore. The results of the measurements show that the doses were very low and not significantly different from background readings for most of the dosimeters. For personnel frequently involved in cleaning of separators, vessels etc., the average annual effective doses were estimated to be in the range between 10 and 100µSv/yr. The mean external doses to offshore safety and decontamination personnel in the British sector of the North Sea were measured to 30 µSv/yr and 230 µSv/yr, respectively [11]. In UK, the annual dose to workers heavily involved in decontamination of separators (ten operations per year) was estimated to 1 mSv/yr and this dose estimated is assumed to be conservative since such operations takes place only once or twice a year on each platform.

External doserates of up to 1 µSv/d above the background level were measured during routine onshore cleaning operations of tubulars at one of the Norwegian decontamination facilities. The workers at this facility were involved in such operations only 10 % of the annual working hours. The total annual effective dose was estimated to 24 µSv/yr. For workers involved in such operations on full-time basis the annual doses are very close to reported results of measurements in UK and USA [11].

Internal doses by inhalation was estimated based on measurement of the particle size distribution during dry decontamination operations and dust generations during decontamination by high pressure water jetting at one of the Norwegian decontamination facilities. The mean particle size varied between 1 and 5 µm and the generation of dust varied between almost zero to 1 mg/cm^2. By using an activity concentration of 30 Bq/g for ^{226}Ra and ^{20}Bq/g for ^{228}Ra in the calculations, and assuming that the workers spent 10% of their annual working hours involved in such operations, the annual effective dose was estimated to be in the range 20 - 100 µSv/yr. The dose by ingestion is insignificant. For more details on these calculations the readers are referred to Strand et al [2].

4. Protective measures

Provided that recommended safety measures are introduced during handling and treatment of contaminated equipment and waste, the occupational doses are assumed to be two to three orders of magnitude lower than the dose limit for radiation workers. Safety measures could involve wearing personal protective equipment (proper dust masks to limit inhalation doses, safety glasses to avoid contamination of eyes, and gloves and protective clothing to avoid contamination of the skin) during cleaning and maintenance operations of NORM contaminated equipment and during handling and treatment of accumulated NORM waste [12]. In order to avoid contamination of the surroundings, personal protective equipment, safety boots and tools/instruments should be controlled for contamination and if necessary cleaned before reuse and/or before it can be taken out of the working area.

Personal protective equipment is highly recommended for workers at onshore decontamination facilities in order to limit internal exposure due to inhalation of dust generated as a result of the cleaning process. It is important that the accumulated waste is kept wet in all stages of the process in order to prevent dust generation and contamination of the surroundings. Decontamination at the onshore facilities in Norway is carried out by using high pressure water jetting, only. Dry abrasive techniques are generally not recommended but such methods are frequently being used to clean contaminated surfaces during repair, replacement and refurbishment of smaller items. In such operations, the inhalation doses may be significant if effective respiratory protection is not being used.

Onsite cleaning is sometimes necessary when accumulated material in top-side equipment interferes with the oil production. Removal of material from vessels and separators are carried out on routine basis during revision stops or maintenance operations on the production system. This material sometimes consists of NORM contaminated scale and sludge, and personal protective equipment is necessary in order to limit exposure. These operations are assumed to be among the most critical offshore work operations which could lead to significant doses from handling and treatment of NORM contaminated objects. As mentioned earlier, the external doses are very low and for this type of work personal dosimeters (TLD dosimeters) are not generally required on routine basis.

NORM in oil and gas production represents a considerable waste problem for the industry owing the large amount of material generated and therefore it has been suggested to reduce the volume by separation of radium sulphates from the waste followed by disposal of a smaller amount of intermediate level waste. Such processing of the waste would have involved working with activity concentrations several orders of magnitude higher than the radium concentration in scales and sludge, and therefore comprehensive safety measures would have been necessary to limit occupational exposure.

5. Conclusions

Owing to the large amount of material, NORM in oil and gas production represent a considerable waste problem for the Norwegian oil industry and the amount of waste may increase significantly as a result of future decommissioning of offshore installations. Based on measurements on samples of hard deposits or hard scales collected from offshore installations the average activity concentrations of ^{226}Ra and ^{228}Ra were calculated to 21 and 12 Bq/g, respectively. Provided that recommended safety measures are introduced during different working operations involving handling or cleaning of contaminated equipment and handling of the waste, the doses to workers involved in these operations are very low – according to our estimates less than 0.2 mSv/yr.

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