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NORM in oil production in Norway

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NORM IN OIL PRODUCTION IN NORWAY

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ABSTRACT

Radioactive deposits, often referred to as LSA (Low Specific Activity) scale, can under certain conditions, be formed inside equipment used in oil production. These deposits contain elevated levels of natural radioactivity, mainly ²²⁶Ra, ²²⁸Ra and their daughter products, and represents a waste problem for the oil industry.

Most of the radioactivity from the reservoir is dissolved in produced water and discharged into the sea. Extensive measurements of levels of radioactivity in produced water and deposits have been performed for several North Sea installations, and some of the results will be presented in this paper.

Several alternatives for waste disposal are under consideration by the Norwegian authorities, and these alternatives will be briefly discussed.

INTRODUCTION

Enhanced levels of radioactivity in deposits of North Sea oil production were first discovered in 1981, and are now found in the production system of several of the North Sea oil fields. The activity concentration in the deposits range from background level to several hundred Bq/g of ²²⁶Ra (Smith 1987). Doses to workers involved in handling contaminated equipment or waste are usually very low, and the main problem related to radioactive deposits is waste disposal.

All minerals and rocks in the earth's crust contain small, but measurable amounts of naturally occurring radioactive materials - often referred to as NORM. NORM include long-lived isotopes of potassium (⁴⁰K), uranium (mainly ²³⁸U) and thorium (mainly ²³²Th). Both ²³⁸U and ²³²Th form the start of two radioactive chains containing several short-lived nuclides. Two isotopes in the uranium and thorium series are important in relation to radioactive deposits in oil and gas production - namely ²²⁶Ra and ²²⁸Ra. The activity concentration in the deposits is often higher than the natural level in the earth's crust.

Deposits can be divided into two main categories: sulphate and carbonate deposits. Sulphate deposits consists mainly of barium sulphate (BaSO₄), while carbonate deposits consist of calcium carbonate (CaCO₃). Deposits containing ²²⁶Ra, ²²⁸Ra and daughter products are often referred to as *LSA (Low Specific Activity) scale*, and are characterised by hard layers on the inside of production equipment that has been in contact with production fluid (oil mixed with production water). Sea water is injected into the reservoir to maintain the pressure as the oil is removed. Mixing of sea water and formation water creates incompatible solutions, and sulphates (mainly BaSO₄ and SrSO₄) 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 chart and has similar chemical properties. Consequently, radium is co-precipitated with barium and strontium as radium sulphate (RaSO₄), 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 and form deposits with enhanced levels of radioactivity (Smith, 1987). Contaminated sand and sludge can be found inside all equipment in oil production that has been in contact with production water. The solid material can,

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under certain conditions, be removed from the production stream, and can be attached and accumulated in tubes, valves, tanks and other types of production equipment (EPA, 1991). Carbonate deposits are formed as a result of both pressure and temperature in production strings decreasing with distance from the reservoir. The solubility of carbonate decreases and calcium carbonate is precipitated. These deposits do not contain enhanced levels of radioactivity.

Decay of ^{226}Ra and ^{228}Ra result in formation of radon - ^{222}Rn and ^{220}Rn , respectively. Radon is a noble gas, and can be released from materials containing ^{226}Ra and ^{228}Ra . ^{220}Rn - often referred to as thoron - has a shorter half life than ^{222}Rn (55 s and 3.82 d, respectively). The release of ^{220}Rn is much smaller than the release of ^{222}Rn . ^{220}Rn therefore represents a smaller radiation protection problem than ^{222}Rn .

Using the correct safety protective measures, the doses to workers involved in handling contaminated equipment and waste have been estimated to be between two and three orders of magnitude lower than the dose limits for occupational exposure (Lysebo et al., 1996, Strand et al., 1997).

ACTIVITY LEVELS IN PRODUCTION WATER AND DEPOSITS

Materials and methods

Samples of production water were taken from flotation cells and degassing tanks during normal production. It was not possible to obtain samples of deposits, sand and sludge during normal production, and these samples were taken during several revision stops in the summer of 1995. The solid samples were taken mainly from separators, tanks, pumps and valves.

Gamma spectroscopic measurements on samples were carried out in the Low Level Gamma Laboratory at the Norwegian Radiation Protection Authority (NRPA) using High Purity Germanium (HPGe) detectors with an active volume of approximately 150 cm³. A computer program calculates the activity concentration of each nuclide related to a specified reference time and the density of the sample. The natural background level in the facility is low (< 25 nGy/h) and fairly stable, and a long term average of this background spectrum was subtracted from each of the recorded spectra. For ^{60}Co the energy resolution is about 4 keV (0.3 %).

RESULTS AND DISCUSSION

Production water

The samples were taken from 11 production units during normal operation and analysed at the NRPA. The results of the measurements are shown in Table 1.

Table 1 Activity concentration of ^{226}Ra and ^{228}Ra in production water from 11 installations on the Norwegian continental shelf

Installation	Sampling point	^{226}Ra (Bq/l)	^{228}Ra (Bq/l)
Statfjord A	Flotation cell	n.d.	0.3 - 0.6
Statfjord A	Degassing tank	n.d.	0.5 - 0.7
Statfjord B	Flotation cell	3.5	1.5 - 4.2
Statfjord B	Degassing tank	0.7 - 7.6	0.5 - 1.4
Statfjord C	Flotation cell	1.9 - 2.5	1.7 - 2.1
Statfjord C	Degassing tank	2.2	2.4 - 2.7
Gullfaks A	Flotation cell	n.d.	1.3 - 2.0
Gullfaks B	Flotation cell	n.d.	1.7 - 4.3
Gullfaks C	Flotation cell	1.3	0.5 - 1.8
Veslefrikk	Degassing tank	n.d.	n.d.
Sleipner A	Degassing tank	2.5	1.1 - 3.3
Oseberg	Degassing tank	10.4	10.0
Brage	Degassing tank	7.7	7.8
Valhall	Valve	3.0 - 5.6	0.8 - 1.1

n.d. the nuclide was not detected

Parallel samples were taken from each position. With reference to Table 1, ^{226}Ra and ^{228}Ra activity concentrations appear to be in a narrow range; 0.7 - 10.4 Bq/l and 0.3 - 10.0 Bq/l, respectively. Several studies of production water in other countries show a much wider range of activity concentrations (Snaveley, 1989, API, 1991, E & P Forum, 1993). The mean concentration was 4.1 Bq/l of ^{226}Ra and 2.1 Bq/l of ^{228}Ra . This is slightly lower than the mean concentration in the studies mentioned above, and approximately three orders of magnitude higher than the mean concentration in sea water (IAEA, 1990). The highest single measurement of ^{226}Ra in our study was 10.4 Bq/l and this is six times lower than the maximum value in other studies.

Large amounts of production water are released into the North Sea each year. A total volume of $160 \times 10^6 \text{ m}^3$ was released in 1991. Assuming that the mean radium concentrations of production water in our study are representative values for the oil production of the North Seas this would correspond to a total release of $6.6 \times 10^{11} \text{ Bq}$ and $3.4 \times 10^{11} \text{ Bq}$ for ^{226}Ra and ^{228}Ra , respectively. It has been estimated that the release of production water will increase significantly in the years to come owing to the fact that some of the larger production fields will reach a later stage in the production phase. It has been

estimated that the release of production water will increase to approximately $340 \times 10^5 \text{ m}^3$ in 1998 (E & P Forum, 1993). At present Norway contributes 6 % of the total release, while Great Britain, the Netherlands and Denmark contribute 88 %, 5 % and 1 %, respectively (E & P Forum, 1993).

Deposits

Samples of deposits, sludge and sand were taken from several types of equipment during the revision stops in the summer of 1995. Samples were taken from topside equipment on 9 installations. The samples were divided into four categories of consistency. Some samples consist of a mixture of different categories, and were difficult to classify. The samples were analysed at the NRPA. The results are shown in Table 2.

Table 2 Specific activity of ^{226}Ra , ^{228}Ra and ^{210}Pb in deposits, sand and sludge from topside equipment on 9 installations on the Norwegian continental shelf. ^{228}Ra is measured as ^{228}Ac .

Installation	Sample type	Number of samples	^{226}Ra (Bq/g)	^{228}Ra (Bq/g)	^{210}Pb (Bq/g)
Statfjord A	Hard deposits	1	30.6	16.9	n.d.
Statfjord B	Hard deposits	6	27.5 - 39.0	18.8 - 33.5	0.1 - 0.3
Statfjord B	Porous deposits	4	2.4 - 24.2	1.5 - 18.8	0.2
Statfjord B	Sand	9	0.3 - 5.5	0.2 - 3.7	0.0 - 0.2
Statfjord B	Sludge	14	0.1 - 4.7	0.1 - 4.6	0.3 - 0.7
Gulfaks A	Hard deposits	2	9.0 - 9.8	8.8	0.3
Gulfaks A	Porous deposits	2	2.1 - 2.9	1.7 - 2.4	0.1
Gulfaks A	Sand	8	1.1 - 21.9	1.1 - 12.7	0.1
Gulfaks B	Porous deposits	3	0.3 - 1.3	0.3 - 1.4	n.d.
Gulfaks B	Sand	5	0.1 - 0.6	0.1 - 0.6	0.5
Gulfaks B	Sludge	1	0.2	0.2	n.d.
Gulfaks C	Porous deposits	1	0.3	0.5	n.d.
Gulfaks C	Sand	2	0.5 - 4.4	0.5 - 3.8	0.1
Veslefrikk	Hard deposits	2	4.0 - 7.7	7.6 - 12.4	n.d.
Veslefrikk	Porous deposits	1	4.3	6.6	n.d.
Oseberg	Hard deposits	1	32.3	24.9	n.d.
Oseberg	Porous deposits	2	1.6 - 4.5	2.2 - 5.4	n.d.
Oseberg	Sand	1	0.0	0.1	n.d.
Valhall	Hard deposits	2	13.4 - 21.0	2.6 - 4.0	n.d.
Valhall	Sand	1	1.4	0.2	n.d.
Snorre	Hard deposits	1	14.4	16.1	n.d.

n.d. the nuclide was not detected

The samples deposits were classified in two groups; hard and poreous deposits. The activity concentration of ^{226}Ra in the hard deposits varied between 4.0 and 39.0 Bq/g, and 3/4 of the samples had a higher activity concentration than the exemption level of 10 Bq/g of ^{226}Ra (NRPA, 1997). Only 1/4 of the samples categorised as porous deposits had a higher activity concentration of ^{226}Ra than 10 Bq/g. In a majority of the samples (3/4) the activity concentration of ^{226}Ra was higher than that of ^{228}Ra .

The mean concentration of ^{226}Ra in hard deposits in this study was 14.1 Bq/g and this value is very close to the reported mean of 13.3 Bq/g by Russo (1993). The mean concentration of ^{228}Ra was 11.3 Bq/g compared to 4.4 Bq/g reported by Russo (1993). However, the maximum concentrations of both ^{226}Ra and ^{228}Ra in our study was about two orders of magnitude lower than the maximum concentrations reported in others studies (McArthur, 1988, Miller, 1988, E & P Forum, 1987).

The activity concentration in sludge varied between 0.1 and 4.7 Bq/g of ^{226}Ra . This means that no sludge samples exceeded the exemption level, and that this type of waste is not to be treated as NORM waste. The activity concentration in sand varied from below the detection limit (0.1 Bq/g) up to 21.9 Bq/g of ^{226}Ra but only two of 26 samples had a higher activity concentration than the exemption level.

The activity concentration of ^{210}Pb was very low in all of the samples. The maximum value was 0.7 Bq/g. Measurements in the Netherlands show that deposits often has high levels of ^{210}Pb , in fact levels are often higher than those for radium (van Weers, 1996).

Based on earlier measurements by Kristensen (1994), the mean activity concentration of ^{226}Ra in waste from onshore decontamination of tubulars was estimated to 25 Bq/g of ^{226}Ra . The results varied from below 1 Bq/g to slightly above 100 Bq/g of ^{226}Ra .

WASTE DISPOSAL

So far, waste from decontamination of tubulars and other types of equipment has been sent to a temporary storage facility at Kjeller, north of Oslo. In 1996 the Norwegian authorities permitted that this type of waste could be stored temporarily at the oil company's supply bases under certain conditions. The total amounts of waste stored at different locations in Norway by the end of 1996 was approximately 130 tonnes. It is assumed that the annual amounts of waste will increase substantially in the future.

In 1997, a temporary exemption level of 10 Bq/g of ^{226}Ra , ^{228}Ra or ^{210}Pb was introduced by the NRPA (NRPA, 1997). All waste from the oil industry with activity concentrations exceeding this level has to be defined as «radioactive waste» (NORM waste), and must be stored temporarily according to directions given by the competent authorities until a final solution has been approved.

Different disposal options are under consideration by the Norwegian authorities. Several factors must be taken into consideration in this process. Norway has ratified the London and OSPAR conventions, and the final solution must be in accordance with these conventions. In addition to this, Norway wish to have a high environmental profile, and carry a strict policy with regard to release of hazardous waste. This includes solutions that involve direct release into the sea, runoff to groundwater, release of dust to the environment and dumping of contaminated equipment. The costs of the solutions must also be taken into consideration. According to Strand et al (1997) the following solutions will be of main interest:

- Reinjection of waste with other types of production waste (e.g. drilling mud)
- Onshore disposal (e.g. in closed mines, burying with concrete encapsulation or depositing at approved storage facilities)

• Export of contaminated equipment

Reinjection

Reinjection of waste means backfilling into the formation. This is usually done by hydraulic fracturing (COWIconsult, 1993). Reinjection is performed routinely for cuttings, drilling mud and production waste from cleaning of different topside equipment. Assumed that NORM waste is reinjected together with other types of waste, this method is less expensive than most other disposal options (Strand et al., 1997). However, it is not clear if reinjection is in conflict with the London and OSPAR conventions. One of the main questions is whether waste from onshore decontamination can be defined as «production waste» and brought offshore for reinjection.

Onshore disposal

NORM waste from oil and gas production is defined as low level waste. The waste has low solubility, low biological mobility and low chemical toxicity. From a radiation protection point of view, this type of waste can therefore be treated in a less elaborate way than most other types of radioactive waste. However, the concentration of ^{226}Ra in NORM waste from the oil and gas industry is three orders of magnitude higher than the mean concentration in soils and bedrock (Strand et al., 1997). Elevated levels of ^{226}Ra in developed areas can give elevated concentrations of ^{222}Rn in indoor air. It is therefore of importance that NORM waste is not disposed in areas to be developed for housing in the future. It is also important that there is no significant runoff of waste to groundwater to be used as drinking water. Under these conditions, the following solutions are assumed to be of main interest (Strand et al., 1997):

- * Depository in an abandoned mine or tunnel: NORM from oil production consist mainly of sulphate compounds. These have low mobility in biological systems and low solubility in water. Provided that there is no runoff of significance to groundwater and that the facility is not placed near drinking water supplies, it is not an important requirement that the depository has to be dry (Strand et al., 1997). By placing the waste in water the exhalation of radon and generation of dust will be insignificant, and thereby prevent doses to the lungs for workers involved in different operations.
- * Burying with or without concrete encapsulation: In areas with stable geological formations and where runoff to groundwater is of no significance, the waste can be placed in the ground and covered with a sufficient layer of soil. In other areas this may not be sufficient, and a concrete encapsulation is required. This method makes less stringent demands on the geological conditions.
- * At approved depository for inorganic waste: The largest storage facility in Norway today, and of interest in connection with NORM from the oil and gas industry, is the National Depository for Inorganic Waste near Oslo. This facility is operated with a licence for handling and storing inorganic waste only, and will need a new licence to incorporate NORM waste. Extensive consequence analysis will be required to clarify the licence conditions.

Export of contaminated equipment

Several foreign companies have permission to receive equipment from Norway in connection with maintenance and recycling. The oil industry is an international business sector, and equipment and components are often bought directly from foreign manufacturers and suppliers. Maintenance of complicated equipment often requires it to be sent to the original manufacturer or supplier. Though this practice has been limited up until now, it is regarded as an alternative to disposal of contaminated equipment and waste. It needs to be clarified whether this alternative is in accordance with Norwegian waste policy.

CONCLUSIONS

Enhanced levels of ^{226}Ra and ^{228}Ra in deposits have been found in tubulars and different types of topside equipment in oil and gas production. Assumed that necessary protective measures are introduced, studies have shown that the doses to workers in different operations both offshore and onshore are generally very low and far less than the dose limits for workers. However, measurements on samples of deposits in both tubulars and topside equipment have demonstrated activity concentrations exceeding the exemption for both ^{226}Ra and ^{228}Ra . NORM in oil and gas production represents a considerable waste problem for the oil industry, and different disposal options are under consideration by Norwegian authorities.

REFERENCES

- API (American Petroleum Institute), 1991, Produced Water Radionuclide Hazard/Risk Assessment, Phase 1, American Petroleum Institute, 1220 L Street, NW Washington, DC 20005.
- COWIconsult, 1993, Miljøaspekter ved reinjeksjon av boreavfall offshore, COWIconsult a/s - Hjellnes COWI a/s, Report for the Pollution Authorities, June 1993, Language: Norwegian.
- Environmental Protection Agency (EPA), 1985, Methodology for Characterisation of Uncertainty in Exposure Assessments, Office of Health and Environmental Assessments, USEPA Washington DC 1985.
- Environmental Protection Agency (EPA), 1991, DRAFT, Diffuse NORM Waste Characterisation and Preliminary Risk Assessment, Air and Radiation Report, ANR-460.
- E&P Forum, 1987, Low Specific Activity Scale - Origin, Treatment and Disposal, Report No. 6.6/127. Available from E&P Forum, 25-28 Old Burlington Street, London W1X 1LB.
- E&P Forum, 1993, North Sea Produced Water Fate and effect on the Marine Environment, Available from E&P Forum, 25-28 Old Burlington Street, London W1X 1LB.
- IAEA, 1990, The environmental behaviour of radium, International Atomic Energy Agency, Technical Report Series No. 310, vol 1&2, Vienna, 1990.
- Kristensen, D., 1994, Radioaktive avleiringer i oljeproduksjon - en strålehygienisk vurdering, StrålevernRapport 1994:7, Norwegian Radiation Protection Authority 1997, Language: Norwegian.
- Lysebo, I., Strand, T., Birovljev, A., 1996, NORM in Oil Production - Occupational Doses and Environmental Aspects, Proceedings from NRPS 11th Congress, Iceland, August 1996.
- McArthur, A., 1988 Development and Operation of a NORM Processing and disposal Facility for the U.S. Oil and Gas Industry, published in CRCPD Publication 88-2, 19th Annual National Conference on Radiation Control, May 18-21, 1987, Boise, Idaho, Conference on Radiation Control Program Directors, Frankfort, KY, 1988.
- Miller, H.T., 1988, Disposing of Naturally Occurring Radioactive Material in Crude Oil Production Equipment, Chevron Corp. San Francisco, CA, presented the Annual Meeting of the Health Physics Society, Boston, MA, July 4-8, 1988.

Norwegian Radiation Protection Authority, 1997, Avleiring av naturlig radioaktive stoffer i olje- og gassproduksjon, NRPA pamphlet No. 12, 1997. Language: Norwegian.

Russo, W.E., et al., 1993, Diffuse NORM Wastes - Waste Characterisation and Preliminary Risk Assessment, Contract No. 68D20155, Prepared for U.S. Environmental Protection Agency, 401 M Street S.W., Washington, D.C. 20460

Smith A.L., 1987, Radioactive scale formation, Journal of Petroleum Technology, June 1987, s. 697-706.

Snavely, E.A. Jr., 1989, Radionuclides in Produced Water - A Literature Review, American Petroleum Institute, Health and Environmental Sciences Department, Production Department, 1220 L Street, NW, Washington, DC 20005.

Strand, T., Lysebo, I., Kristensen, D., Birovljev, A., 1997, Radioaktive avleiringer i olje- og gassproduksjon, StrålevernRapport 1997:1, Norwegian Radiation Protection Authority 1997, Language: Norwegian.

van Weers, A., 1996, Personal communication.

White, G.J., 1992, Naturally Occurring Radioactive materials (NORM) in oil and gas industry equipment and wastes - a literature review, DOE/ID/01570-T158, Contract no. DE-AC07-76ID01570, Available from National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, Va 22161.