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NORM IN OIL PRODUCTION – ACTIVITY LEVELS AND OCCUPATIONAL DOSES

Irene Lysebo and Terje Strand
Norwegian Radiation Protection Authority
P.O.Box 55, N-1345 Østerås, Norway

Abstract
Radioactive deposits, often referred to as LSA (Low Spesific Activity) scale, can under certain conditions be formed inside production equipment in oil production. These deposits contain elevated levels of radioactivity, mainly ^{226}Ra, ^{228}Ra and their daughter products.

Extensive measurements of levels of radioactivity in produced water and LSA scale have been performed for several North Sea installations, and some of the results will be presented. External exposure to workers has been measured during typical operations both offshore and onshore involving operational work and handling of contaminated equipment. Furthermore, methods and uncertainties in the assessment of internal doses based on measurements of dust release during normal operation and decontamination will be discussed.

Introduction
The occurrence of natural radio-nuclides in North Sea oil and gas production were first discovered in 1981, and enhanced levels of radioactivity are now found in the production system of several North Sea oil fields (Strand et al., 1997). The activity concentration range from background level to several hundred Bq/g of ^{226}Ra (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.

Materials and methods
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 cm^3. 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 %).

Measurements of external exposure to workers were carried out using Harshaw thermoluminicense dosimeters, of CaF_2:Dy (TLD-200). The detection limit is approximately 2.5 μGy for ^{60}Co. During field measurements, four TLD's are installed in a plastic badge, of which two of them are shielded on both sides by circular filters of 2 mm brass. The filter smoothes out the energy response in the range of approximately 60 - 200 keV. The TLD's are individually calibrated before exposure, and the individual uncertainty is reduced to approximately 1%. For further details on this method, the readers are referred to Wøhni (1993).

Internal doses can not be measured directly. Assessments of doses from inhalation or intake must be based on calculations. The dust concentration in air during different operations were measured using a pump with a filter sucking in air at a known rate. Subtracting the background dust release, the remaining dust were assumed to have the same activity concentration as the fixed scale. The internal doses were calculated using LUDEP 2.0. For further details on LUDEP, the readers are referred to Jarvis et al. (1996).

Results and discussion
Activity levels in produced water
Samples of produced water from 11 offshore production platforms were taken during normal operation. The samples were analysed at the Low Level Gamma Laboratory at the NRPA (Strand et al., 1997). In Table 1 the results from this study are compared to results from other studies.

Table 1: **Activity levels in samples of produced water in different studies.**

Study	Mean activity level of ^{226}Ra (kBq/m^3)	Mean activity level of ^{228}Ra (kBq/m^3)
Strand et al. 1997	4.1	2.1
Stephenson et al., 1990	5.9	6.1
SAIC, 1991	2.5	1.1
UKOOA, 1992	1.7	3.9
Anon, 1990	9.7	10.3

With reference to Table 1 and Strand et al. (1997), ^{226}Ra and ^{228}Ra activity concentrations appear to be in a narrow range; 0.7 - 10.4 kBq/m^3 and 0.3 - 10.0 kBq/m^3, respectively. Several studies of production water in other countries show a much wider range of activity concentrations (Snavely, 1989, API, 1991, E & P Forum, 1993). The mean concentration measured by Strand et al. (1997) was 4.1 kBq/m^3 of ^{226}Ra and 2.1 kBq/m^3 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 kBq/m^3 and this is six times lower than the maximum value in other studies.

Activity levels in deposits

Samples of deposits from several types of equipment were taken during revision stops in the summer of 1995. The samples were analysed at the Low level Gamma Laboratory at the NRPA (Strand et al., 1997). In Table 2 the results from this study are compared to results from other studies.

Table 2: **Activity levels in deposits in different studies**

Study	Location	Activity level of ^{226}Ra (Bq/g)
Strand et al., 1997	Norway	0.1 – 39.0
McArthur, 1988	USA	0.4 – 3700
Miller, 1988	USA, San Francisco	1.9 – 1110
E&P Forum, 1987	Great Britain	1 – 1000

The mean concentration of ^{226}Ra in 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).

Doses to workers

Table 3 summarises doses to workers during different operations onshore and offshore, including maintenance and decontamination.

Table 3: **Doses to workers in connection with handling and cleaning of contaminated equipment**

Location	Dose (mSv/yr)	Measured/ estimated	Reference	Comment
			External doses	
Onshore	0.024	Measured	Strand et al., 1997	10 % of working time spent on decontamination
	0.27	Measured	Reed et al., 1991	100 % of working time spent on decontamination
	0.32	Measured	Reed et al., 1991	100 % of working time spent on decontamination
Offshore	0.04	Measured	Kristensen, 1994	Decontamination personnel
	0.03	Measured	Reed et al., 1991	Safety personnel
	0.23	Measured	Reed et al., 1991	Decontamination personnel
	1	Estimated	Reed et al., 1991	Decontamination of separators, 10 operations/year
			Internal doses	
Onshore	0.027	Measured	Strand et al., 1997	Dust release 0.2 mg/m³, particle size 1 mm
	0.4	Measured	Reed et al., 1991	100 % of working time spent on decontamination
Offshore	0.027	Estimated	Strand et al., 1997	As onshore
	0.017	Estimated	Kristensen, 1994	
Intake	-			Negligible compared to doses from inhalation

External doses up to 1 μSv/d above background radiation during an onshore decontamination operation were measured by the NRPA. However, the workers at this decontamination facility are involved in such operations only 10% of their annual working hours. The total annual effective dose for the workers was estimated to 0.024 mSv/yr. External doses during onshore decontamination in the United States and United Kingdom have been reported by Reed et al., (1991). Reported doses in the United Kingdom varied from below the detection limit (< 0.1 mSv/yr) up to 1 mSv/yr to an annual mean of 0.27 mSv/yr. In the United States, the mean effective dose in same type of operations was 0.32 mSv/yr. Taking into account that personnel in the UK and USA are involved in decontamination work on full-time basis, our results from Norway are very close to the results reported by Reed et al. (1991).

External doses during different operations offshore have been measured by the NRPA. None of the measurements showed levels above the background. Measurements of external doses to offshore workers in Norway performed by Kristensen (1994) show doses up to 0.04 mSv/yr. External doses to offshore workers in the British sector were measured to 0.03 mSv/yr for safety personnel and 0.23 mSv/yr for decontamination personnel (Reed et al., 1991). The doses to safety personnel are considerably lower than the doses to decontamination personnel. Safety personnel measure the radiation levels before the operations commence, but are otherwise not involved with the operations. The fact that external doses in the British sector of the Continental Shelf are higher than in the Norwegian sector may be attributed to the fact that operations involving handling of contaminated equipment occur more frequently in the British sector. The external dose to workers involved in decontamination of separators were estimated to 0.1 mSv/y per operations by Reed et al., (1991). Assuming ten such operations per year, the total dose to workers involved in this type of work will be approximately 1 mSv/yr.

The internal dose from inhalation depend strongly upon particle size. Based on filter measurements Kristensen (1994) has estimated the mean particle size in deposits to 1 μm. Dorrian and Bailey (1995) report particle sizes between 3.0 and 3.5 μm during dry decontamination with sand blasting. In assessing the doses to workers from inhalation, the mean particle size are assumed to be between 1 and 5 mm (Strand et al.,1997). Calculations show that the total dose to the lungs varies little in the size range in question (Strand et al., 1997). For further discussion on the effect of particle size, the readers are referred to James & Roy (1987) and ICRP (1990 & 1994).

During decontamination of production tubulars the average dust concentration in air was measured to 0.2 mg/m³. These results are in very good agreement with measurements by Reed (1991), which show an average dust concentration of 0.15 mg/m³. Very high concentrations have been measured by others. Dixon & Hipkins (1983) report concentrations up to 100 mg/m^3, with a mean concentration of 5 mg/m^3. The activity level in the dust released during decontamination was measured to 30 Bq/g of ^{226}Ra and 20 Bq/g of ^{228}Ra, and the ratio between ^{226}Ra and ^{228}Ra was approximately 3:1 (Kristensen, 1994). The dose rate from inhalation for different dust concentrations are shown in Table 4.

***Table 4:* Dose rate from inhalation for different dust concentrations (Strand et al., 1997)**

	Dust concentration (mg/m^3)			
	0.15	0.20	5	100
Dose rate (μSv/hr)	0.11	0.15	3.78	75.5
Annual dose (mSv/yr)	0.02	0.03	0.68	13.6

[1]Assumed 180 hours spent in direct contact with contaminated equipment (Ørgersen, 1996)

As shown in Table 4, the dust concentrations in air during decontamination operations must be very high to reach the dose limit for occupationally exposed workers of 20 mSv/yr (Statens strålevern, 1995). The internal dose to Norwegian workers are expected to be 0.03 mSv/yr (Strand et al., 1997). The internal doses from onshore cleaning in the British sector have been calculated to 0.4 mSv/yr by Reed et al., (1991). Taking into account that these calculations are based on the assumption that cleaning personnel spend all their working hours doing this type of work, there is good agreement between the two studies.

Measurements and calculations of the internal doses from offshore decontamination have not been performed in the Norwegian sector, due to problems with getting access to platforms to perform measurements. Offshore decontamination is usually performed manually by scraping, sand blasting or high pressure water jetting. Offshore operations involving direct contact with contaminated scale are however nor performed frequently, and the doses are assumed to be at the same level or most probably lower than during onshore decontamination. The doses in the Norwegian sector were estimated to 0.017 mSv/yr. Measurements and calculations by Reed et al., (1991) show doses of 0.4 mSv/yr. These calculations are, however, based on full-time work and no use of personal protective equipment. Taking these facts into account, the results of these two studies seems to be in very good agreement.

Conclusion

Provided that the recommended safety measures (Lysebo & Strand, 1997) are taken during handling of contaminated equipment and waste, doses to workers are assumed to between two and three orders of magnitude lower than the dose limit for occupational exposure (Lysebo et al, 1996, Strand et al., 1997). Radioactive deposits represent a considerable waste problem for the oil and gas industry, and options for final disposal are currently being considered by the Norwegian authorities.

References

Anon, 1990, «Study of Produced water in the State of Louisiana» State of Louisiana, Baton Rouge.

API (American Petroleum Institute), 1991, «Produced Water Radionuclide Hazard/Risk Assessment, Phase 1», American Petroleum Institute, 1220 L Street, NW Washington, DC 20005.

Dixon D. W., Hipkins J., 1983, «Hazard assessment of work with ores containing enhanced levels of natural radioactivity», Radiological Protection Bulletin, mars 1983.

Dorrian, M. D. and Bailey, M. R., 1995, «Particle Size Distribution of Radioactive Aerosols Measured in Workplaces», Radiation Protection Dosimetry, Vol. 60 No. 2, 1995.

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, 1987.

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, 1993.

IAEA, 1990, «The environmental behaviour of radium», International Atomic Energy Agency, Technical Report Series No. 310, vol. 1 & 2, Vienna, 1990.

ICRP, 1990, «Annual Limits on Intake of Radionuclides by Workers Based on the 1990 Recommendations», International Commission on Radiological Protection, Publication 60, Pergamon Press, November 1990.

ICRP, 1994, «Human Respiratory Tract Model for Radiological Protection», International Commission on Radiological Protection, Publication 66, Pergamon Press, Oxford, 1994.

ICRP, 1995, «Dose coefficients for intakes of radionuclides by workers», International Commission on Radiological Protection, Publication 68, Pergamon Press/Elsevier, Oxford, 1995.

James A. C. and Roy M., 1987, «Dosimetric lung models», The Martinus Nijhoff Publishers for The Commision of European Communities, 1987

Jarvis N. S., Birchall A., James A. C., Bailey M. R., Dorrian M. D., 1996, «LUDEP 2.0, Personal Computer Program for Calculating Internal Doses Using the ICRP publication 66 Respiratory Tract Model», National Radiological Protection Board, Chilton, Didcot, Oxon OX11 0RQ .

Kristensen D., 1994, «Radioaktive avleiringer i oljeproduksjon - en strålehygienisk vurdering», Strålevern Rapport 1994:7, Statens strålevern 1994, 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.

Lysebo I., Strand T., 1997, «NORM in Oil Production in Norway», Proceedings from the International Symposium on Radiological Problems with Natural Radioactivity in the Non-Nuclear Industry, Amsterdam September 8 - 10, 1997.

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, pres. at the Annual Meeting of the Health Physics Society, Boston, MA, July 4-8, 1988.

Reed G., Holland B. and MacArthur A., 1991, «Evaluating the real risks of radioactive scale in oil and gas production», Presentation at the First Int. Conf. on Health, Safety and Environment, Hague, The Netherlands, 10-14 November, 1991, Technical Paper SPE-23383.

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

Science Applications International Corporation (SAIC), 1991, «Produced Water Pollutant Variability Factors and filtration efficacy Assessments from the Three Facility Oil and Gas Study», EPA contract No. 68-CO-0035.

Smith A. L., 1987, «Radioactive scale formation», Offshore Technology Conference, Journal of Petroleum Technology, June 1987

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, 1989.

Statens strålevern, 1995 «Persondosimetri for yrkeseksponerte», Strålevern hefte nr. 8, November 1995, Norwegian Radiation Protection Authority Pamphlet No. 8, Language: Norwegian

Statens strålevern, 1996, «Avleiringer av naturlig radioaktive stoffer i olje- og gassproduksjon», Strålevern hefte nr.12, January 1997, Norwegian Radiation Protection Authority Pamphlet No. 12, Language: Norwegian

Stephenson M. T., Supernaw I. R., 1990, «Offshore Operators committee 44 Platform Study Radioniclide Analysis Results», Offshore Operators Committee, New Orleans, Louisiana, 1990.

Strand T., Lysebo I., Kristensen D., Birovljev A., 1997, «Radioaktive avleiringer i olje- og gassproduksjon», Strålevernrapport 1997:1, Norwegian Radiation Protection Authority Report 197:1, Language: Norwegian

UKOOA, 1992, «UK north Sea Oil and Gas Industry: Environmental Inputs, Impacts and Issues», A report prepared by Environment and Resource Technology Ltd, 1992.

van Weers A., 1996, personal communication ECN Petten, The Netherlands

Wøhni T., 1993, «Dosemeter for low level external radiation», Radiat. Prot. Dosim., 48 (4), pp 347-350, 1993.

Ørgersen A., 1996, personal communication, CCB, Ågotnes, Norway