Assessment, Treatment and Management of NORM in the Norwegian Oil and Gas Industry

P. Varskog[1] and H. Aamlid[2]

[1] *Norse Decom AS, Kjeller, Norway*
[2] *Statoil ASA, Stavanger, Norway*

1. Abstract

The origin of the NORM waste (LSA Scale) in the oil industry is the formation of sulphate and carbonate precipitates inside tubulars and other production equipment during oil production. The radioactivity is caused by the co-precipitation of small amounts of radium together with the macro quantities of barium and strontium.

LSA Scale in the terms as a waste problem occurs either when production equipment is taken ashore for cleaning or as a part of the final waste handling during decommissioning of oil installations. Especially production tubulars and oil-water separators may contain tonne quantities of LSA scale often mixed with other materials. A survey of the LSA Scale temporarily stored at the supply bases in 2002 showed the following typical macro composition in decreasing order: sulphates, sand/clay, steel and corrosion products and oil components. The activity concentration of radium-226 varied between 10 Bq/g (the current exemption level) and 100 Bq/g, with an average of 23 Bq/g. The content of radium-228 and lead-210 was found to be typically 10 – 50 % of the radium-226 concentration.

Since becoming aware of the problem in the late 1980's, the industry has integrated the management of LSA Scale as a part of the corporate HSE systems and procedures. LSA Scale and LSA Scale contaminated equipment are routinely identified offshore using field instruments and brought to shore for cleaning and temporary storage. Radioactive doses to involved personnel are regarded as small: 0.05 mSv/year for offshore workers and 0.8 mSv/year for the industry workers who perform cleaning of contaminated equipment and handling of LSA Scale on a regular basis. By today, a total of 250 tons of LSA Scale is temporarily stored at the oil industry supply bases along the Norwegian Coast awaiting a final storage solution.

Guidelines for exemption levels and handling of LSA Scale from the Norwegian Radiation Protection Authority have been in place since 1997. These guidelines are currently under revision and new ones are expected to surface in 2006.

Marilee Williams, Editor
Proceedings of the 9th EAN ALARA Workshop
18-21 October 2005
Augsburg, Germany

2. Origin and composition

LSA Scale, a subclass of NORM, is formed on the inside of the oil and gas production equipment (tubulars, christmas tree, valves, bends etc.). At least four different types of LSA Scale have so far been identified as characterised by differences in process of formation and chemical and physical properties (Table 1).

Table 1. Summary of the four different types of LSA Scale found on the Norwegian North Sea Sector.

Scale type	Main constituent	Main radionuclides	Production type
Sulphate scale	Ba/Sr sulphate	^{226}Ra, ^{228}Ra	Oil
Carbonate scale	Ca carbonate	^{226}Ra, ^{228}Ra	Oil
Lead scale	Steel	^{210}Pb	Gas
Sulphide scale	Iron sulphide	^{226}Ra, ^{228}Ra, ^{210}Pb	Oil and gas

Sulphate scale. Formed in a process where radium co-precipitates with barium and strontium to form hard scales of sulphate on the inner steel surfaces. The specific activity of the scale is dependent on the contribution of dissolved radium from the bedrock surrounding the oil reservoir and the properties and amounts of water that also present in the reservoir (i.e. the “produced water”). Due to its association with the water phase, aboard an oil-producing platform the barium sulphate type LSA Scale, when formed, is predominantly present in the production equipment up to the point where water and oil are separated including the water discharge system. This includes: production tubulars, Christmas trees, risers, topside tubes until the oil-water separators and the pipes from the oil-water separators to the produced water discharge point. LSA Scale has in rare occasions also been found in the oil production systems after water separation like e.g. oil metering systems or other equipment creating turbulence in the oil stream. Due to the high-energy gamma radiation from the daughters of ^{226}Ra and ^{228}Ra the presence of significant amounts of sulphate scale can often be detected from the outside of the production equipment.

Figure 1. Flakes of LSA Scale in an opened oil production tube.

Carbonate scale is formed in a process where radium co-precipitates with calcium to form scales of carbonate on the inner steel surfaces on the oil production equipment. The scale is acid soluble and is probably most often re-dissolved and discharged to sea together with the produced water. The discharge of naturally occurring radionuclides to the North Sea has been evaluated and assessed in a report made on request by the Research Council of Norway (ND, 2003).

Lead scale is formed in a process where ^{210}Pb after being produced by disintegration of ^{222}Rn dissolved in the gas stream is attached to the inner steel walls of the gas production equipment. With time $^{210}Pb^{0}$ that is formed can be adsorbed on the inner steel surfaces of the gas production systems. The scale becomes a part of the component steel itself and is invisible to human eye. The presence of lead-scale cannot be detected from the outside of the equipment due to the absence of high-energy gamma radiation. Lead-scale however is easy to identify with the use of contamination monitors if access to the inner surfaces is possible.

Sulphide scale is formed in a process where radium and/or ^{210}Pb co-precipitates with iron and heavy metals (e.g. Hg and stable Pb) to form sulphides on the inner steel surfaces on the oil and gas production equipment. This scale type has so far been found only in rare occasions. It is believed that this scale type is formed in a process where equipment steel reacts with H_2S and sulphur containing compounds in the oil stream to form iron sulphide.

Although all four types of LSA Scale has been found and identified in the Norwegian oil industry, only the radium bearing sulphate scale has so far been present in amounts large enough to be an issue in a waste or HSE context.

In 2003 Norse Decom, a subsidiary of Institute for Energy Technology (IFE), Norway, performed a survey on the mechanical, chemical and radiological composition of LSA Scale comprising more than 90 % of the then stored amounts. More than 130 samples were collected and analysed with respect to physical composition, contents of major radionuclides (^{226}Ra, ^{228}Ra and ^{210}Pb) and contents of heavy metals. The results (Table 2) showed that the major constituents in LSA Scale disregarding the water are sulphate, sand/clay, heavy oil components and corrosion products (rust and steel particles). More than 95 % of the stored LSA Scale was found to be of the sulphate scale type and all of it from oil production.

Table 2. Overview of main constituents in stored LSA Scale from the Norwegian North Sea Sector.

Oil company	**Mass (tons)**	**Composition (weight %)**				
		Water	Heavy oil components	Sulphates	Corrosion products	Sand/clay
Company A	166	23.6	7.4	45.7	8.5	14.8
Company B	4.1	15.9	1.4	77.9	2.0	2.8
Company C	0.5	11.8	1.5	75.4	6.8	4.5
Company D	17.0	45.4	6.6	39.0	6.1	2.9

The activity concentration of ^{226}Ra (Table 3) was found to vary from 10 Bq/g (the current exemption and clearance level (NRPA, 1997)) to 100 Bq/g. For ^{228}Ra and ^{210}Pb the activity concentrations were considerably lower: typically 10-50 % of the ^{226}Ra concentration. It should be noted, however, that on very rare occasions both ^{228}Ra and ^{210}Pb (but not in the same samples) have been found to be higher than the corresponding ^{226}Ra concentrations. In the case of high levels of ^{210}Pb it is believed that this is connected to the presence of non-supported ^{210}Pb in iron sulphide precipitations (sulphide scale). In other cases the ^{210}Pb level will be considerably lower than the ^{226}Ra because of the lack of time to build up radiological equilibrium between these two nuclides.

Table 3. Average activity concentrations and activity concentration ranges (in brackets) for stored LSA Scale from the Norwegian North Sea Sector.

Oil company	Activity concentration (Bq/g)		
	^{226}Ra	^{228}Ra	^{210}Pb
Company A	21.5 (9.7 – 74.1)	11.2 (3.3 – 28.9)	2.4 (<0.2 – 11.8)
Company B	19.3 (16.3-23.6)	7.3 (6.4-8.6)	2.7 (2.0-3.7)
Company C	20.8	9.6	1.8
Company D	40.4 (4.9-100)	3.7 (0.4-13-3)	13.8 (2.3-49)

The survey showed that both the composition and the activity concentrations for the LSA Scale varied greatly between the different oil production installations. Within an installation also large variation was found indicating differences even between the oil producing wells on the same field. The LSA Scale waste as it is produced in a given maintenance or cleaning operation is almost always from one specific part of the oil producing system and a limited time period. It has been shown that on this level (e.g. all LSA Scale from one production tubular string or a given separator system as it is emptied) the properties of the LSA Scale are fairly constant both in main composition and activity levels. When performing LSA Scale assessments probably the most important aspect of this is the ^{226}Ra: ^{228}Ra isotope ratio, which has to be both known and constant in order to perform “in the field” classifications of LSA Scale.

3. Identification

To classify materials according to the exemption and clearance criteria there is a need for fast and reliable measurement methods. To send samples of materials suspected to be LSA scale to a commercial laboratory for determination may yield accurate results within 5-10 % accuracy, but is time consuming and therefore often impractical when quick answers are needed in order to avoid delays during e.g. maintenance shut-downs or other time critical operations.

On demand from the industry therefore, IFE and Norwegian Radiation Protection Authority (NRPA) in 1997 developed a field measurement method (Ramsøy *et. al.* 1998a, 1998b) for classification of LSA Scale using hand-held contamination monitors together with especially designed calibration standards. The method based on measurement of the total beta radiation from a sample may give reliable results within 10-20 % accuracy. To be able to calculate results in terms of activity concentrations (Bq/g) the radium isotope ratio (^{226}Ra: ^{228}Ra) for the material in question must be known. Therefore, to use the field method, a few samples needs to have been analysed in a radiological laboratory.

Classifications using field measurement methods have proven to be as least as reliable as laboratory analyses in large classification and assessment jobs due to the former method's swiftness facilitating a large number of samples and the possibility for re-sampling in case of questionable findings.

Laboratory measurements of LSA Scale radionuclides are best performed on low-energy gamma germanium detectors for accurate determination of ^{210}Pb (47 keV) and the 186 keV gamma line of ^{226}Ra. Direct measurement of ^{226}Ra avoids the practical problems of gaining and maintaining radon equilibrium in the samples.

4. Radiation protection

During normal operation the production equipment (tubes and vessels) is not open to the surroundings and the LSA Scale that eventually might be on the inner surfaces is shielded from the working environment by the steel walls of the production equipment.

Except from the areas surrounding the oil/water separators, elevated radioactive dose rates from LSA Scale are rarely seen aboard offshore oil and gas installations. Whereas only minor quantities of LSA Scale may have been deposited on the inner walls at a given point of most of the production equipment, the separators may contain ton quantities of LSA Scale containing sediments. At close distance to the separators the dose rates may reach levels of 10 – 20 µSv/hour.

Radiation protection measures are important therefore, mostly during maintenance shutdowns when the production equipment is opened for cleaning or replacement of used components. Typically, the work involved is manual and often dependent of that workers enter e.g. the separator tanks through manholes in order to perform the necessary tasks.

The maintenance work involving the highest dose rates is the pulling and on-deck handling of production tubulars. Typically a dismantled production tube string consists of 200 to 350 of 12 meters tubes. Given a few millimetres of LSA Scale as a coating on the inside of the tubes this adds up to several tons of LSA Scale gathered in a small space as the tubes are stacked on the deck of the drilling platforms. Due to very limited free space aboard these platforms, work has often to be performed in the neighbourhood of the tube stacks and workers frequently has to pass the stacks on their way to or from other work areas.

Even though means to minimise exposure to gamma radiation sometimes has to be put in place, e.g. for the workers involved in handling of LSA Scale contaminated production tubulars, the radiation protection measures with respect to LSA Scale is almost entirely connected to avoiding internal exposure through inhalation or digestion. Typically, the procedures focus on simple means like avoiding "dust production" and the use of dispensable protective clothing and dust masks. On the administrative level the possibility for exposure to LSA Scale in most cases invokes the necessity for "Safe Job Analysis" – a qualitative assessment of the risks involved in performing a certain task.

Since becoming aware of the LSA Scale issue in the late 1980's the industry has implemented procedures for LSA Scale involved activities and protective means into the corporate HSE systems.

The typical annual doses to workers from LSA scale connected work are 0.05 mSV and 0.8 mSv for offshore and onshore workers, respectively (Kristensen, 1994). The average annual dose from natural and medical radiation in Norway is 4 mSv.

5. Waste management

LSA Scale and LSA Scale contaminated objects are routinely identified and handled during cleaning and maintenance operations as a part of the normal waste handling. Typically, measurements are made offshore after dismantling of production equipment to state the presence or absence of LSA Scale. If classified or suspected as LSA Scale containing, the equipment is sorted out, packed, marked according to transport regulations and sent ashore for cleaning.

Figure 2. Identification of LSA Scale contaminated tubes during decommissioning of an oil producing platform.

The cleaning of LSA Scale containing equipment is performed by specialist companies at the onshore oil bases spread along the Norwegian coast from Stavanger to Harstad. The preferred cleaning method today is high-pressure water jetting working at pressures up to 2000 bars. The LSA Scale is collected in plastic drums and sent to temporary storage in an approved storage facilities (also at the bases). By today a total of 250 tons of LSA scale with a total of 5.75 GBq of ^{226}Ra is held in temporary storage in Norway.

After cleaning the equipment (production tubulars, valves etc.) is either reused or sent for recycling as scrap steel. In either case the equipment has to meet the relevant clearance levels and in practise be certified “free of LSA Scale”.

During decommissioning of oil installations typically whole structures are brought to shore for deconstruction and dismantling. In most major decommissioning projects performed in Norway so far, i.e. Brent Spar, Maureen Alpha and Frøy, assessment and handling of LSA Scale have been an integrated part of the project. Brent Spar and Maureen Alpha, though being dismantled in Norway, originated from the British North Sea Sector. In both these cases the LSA Scale was deemed to be British and was transported back to Great Britain for final storage.

6. Final storage

At present there is no final storage solution LSA Scale in Norway. It has been decided by Norwegian authorities that LSA Scale in any form cannot be stored in Norway’s one LILW repository, KLDRA-Himdalen. Two different commercial vendors offering LSA Scale storage in rock cavern repositories have been competing to take care of the Norwegian LSA Scale. In October 2005 it was decided by the Norwegian government that the Gulen Repository situated in the Sogn og Fjordane region was the preferred alternative. It is expected that the repository can be opened at the end of 2006.

7. References

Kristensen, D., 1994. Radioactive scale in oil production – a radiological assessment. NRPA Report 1994:7. Norwegian Radiation Protection Authority, Østerås, Norway. 84 pp. (In Norwegian).

ND, 2003. Naturally occurring radionuclides in the marine environment – an overview of current knowledge with emphasis on the North Sea area. Norse Decom, Kjeller, Norway. Report: ND/E-19/03. 57 pp.

NRPA, 1997. Precipitation of Naturally Occurring radioactive Substances in Oil and Gas Production.

Strålevernhefte 12. Norwegian Radiation Protection Authority. Østerås, Norway. 14 pp. (in Norwegian)

Ramsøy T., et.al., 1998a. Reliable methods for monitoring of LSA scale on equipment off-shore and on-shore. Institute for Energy Technology, Kjeller, Norway. Report: IFE/KR/F-98/0.

Ramsøy T., et.al., 1998b Methods for Monitoring of NORM on Equipment Offshore and Onshore. In proceedings of NORM II, Second International Symposium on the Treatment of Naturally Occurring Radioactive Materials, November 10-13, 1998, Krefeldt, Germany.