Master’s degree thesis

LOG950 Logistics

Management of low radoactive waste

- Comparatve analysis from the Norwegian oil and gas Industry -

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Summary

The operations in the oil and gas industry in Norway are highly regulated with the purpose to achieve high efficiency and at the same time high safety and environmental performance. The waste management activities from the industry present particular importance due to their potential impacts to the environmental and to human health. The waste management process in this industry is rather complex and requires specialized services with a high degree of expertise. This paper will explore the waste management operations of Naturally Occurring Radioactive Material (NORM) in Norway. The radioactive characteristics of high concentrations of NORM wastes present serious health hazards to humans. The Norwegian oil and gas industry is characterized by its strong focus on health, safety and environment (HSE) protection. In order to reduce potential exposures and provide security and control over NORM during waste management operations, the procedures become more complex, costly and regulated by the authorities.

The aim of this paper is to find potential improvements for the operational processes of the NORM waste management.

In order to reach the goal of this paper, the author presents Norwegian up to date practices from the actors involved in the waste management process of NORM and compares them with the best practices recommended for these operations in the industry with the intention to find clear differences between the operations that could be implemented.

The Supply Chain Management theory, Transaction Cost Analysis and institutional Theory serve as tool to analyze the structure of the SC, the transaction and relations between the actors of the SC and the behavior towards the environmental operations. The utilization of the theories is fundamental to explain and support the findings and conclusions in this paper.

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List of abbreviations

CPA Climate and Pollution Agency

HSE Health, safety and environment

IAEA International Atomic Energy Agency

MPE Ministry of Petroleum and Energy

NPCA Norwegian Pollution Control Authority

NPD Norwegian Petroleum Directorate (coordinating authority for all offshore operations)

NRC National Research Council

NRPA Norwegian Radiation Protection Authority

OGP International Association of Oil & Gas Producers

OLF Norwegian Oil Industry Association (Oljeindustriens Landsforening)

PL Production license

In connection with transportation classification:

ADR European Agreement Concerning the International Carriage of Dangerous Goods by Road

IMDG International Marine Hazardous Goods (concerns the transportation of hazardous goods on the open seas)

IMO International Maritime Organization

1 Introduction

Greater knowledge about the environmental damage caused by pollution and the misuse of our resources has led to stricter regulations to the industries that contribute to the degradation of our environment. The oil and gas industry in Norway is a perfect example of those industries that are highly regulated and monitored because of their environmental impacts.

The oil and gas industry in Norway is a big source of waste and at the same time one of the greatest sources of the Norwegian economic growth. It is clear that nations cannot reduce pollution from waste by reducing the nation's growth. Thus, economic growth should be developed in a sustainable way. Winkler and Kaluza (2006) state, that a movement towards sustainability is only possible if we manage to develop concepts that integrate economic and ecological goals. Moreover, they said that in order to do sustainable development, sufficient waste management is rather important.

The generation of waste by the oil platforms in Norway from drilling operations (drilling waste, oils, produce waters, etc), maintenance of the platform (paintings, solvents, scrap metals, etc) or by the personnel on the platform (food waste, cans, bottles etc) needs to be removed in an efficient manner in order to comply with the strict health, environmental and safety (HES) regulations, thus waste management is needed (Cirnat and Chirila 2007).

The waste created in the offshore platforms also opens new business opportunities to waste management companies that utilize this waste as "raw materials" to develop new products for industrial customers, to create energy or to dispose the waste in a more efficient way than oil and gas companies could do.

Within the waste management operations in the oil and gas industry the management of hazardous waste especially the one categorize as low radioactive waste requires special attention due to their potential hazard to the environment and to human health, particularly for those persons working in the industry. Radioactive wastes do not only create health or environmental problems but make the waste management process much more complex and costly. The radioactive waste is originated when the "Naturally Occurring Radioactive Materials" (NORM) located in sedimentary rocks in the seabed are removed, enhanced and bring it up to the surface (oil and gas facilities) throughout the common operations for extracting and processing oil and gas. Sometimes the NORM will concentrate in solid and liquid forms in the oil and gas production facilities.

1.1 Description of the process

The waste disposal process starts on offshore platforms where the waste is created (see figure 1 next page). Then the waste is brought to the shore by using the supply vessels. Oil companies mostly do not own the supply vessels that go back and forth from the supply base to the oil platforms. So the oil firm usually outsources the service with the help of logistics providers. The level of outsourcing is subjective to cost, expertise and assets at risk (Aas, Buvik, Cacik. 2008). Once the waste is on shore, in the supply base, a waste management company ,hired by the oil company, (the waste management company handling radioactive waste is selected by national authorities) will be in charge for the disposal/ recycling/ best use of the waste. From this point onwards, the different types of waste will follow alternative paths using a diverse number of companies through the disposal processes where hopefully the waste is made use of in the best possible manner, e.g. reuse/ recycled/ energy recovery/ disposal. This supply chain is so vast that some of the waste will end up in different countries in Europe.

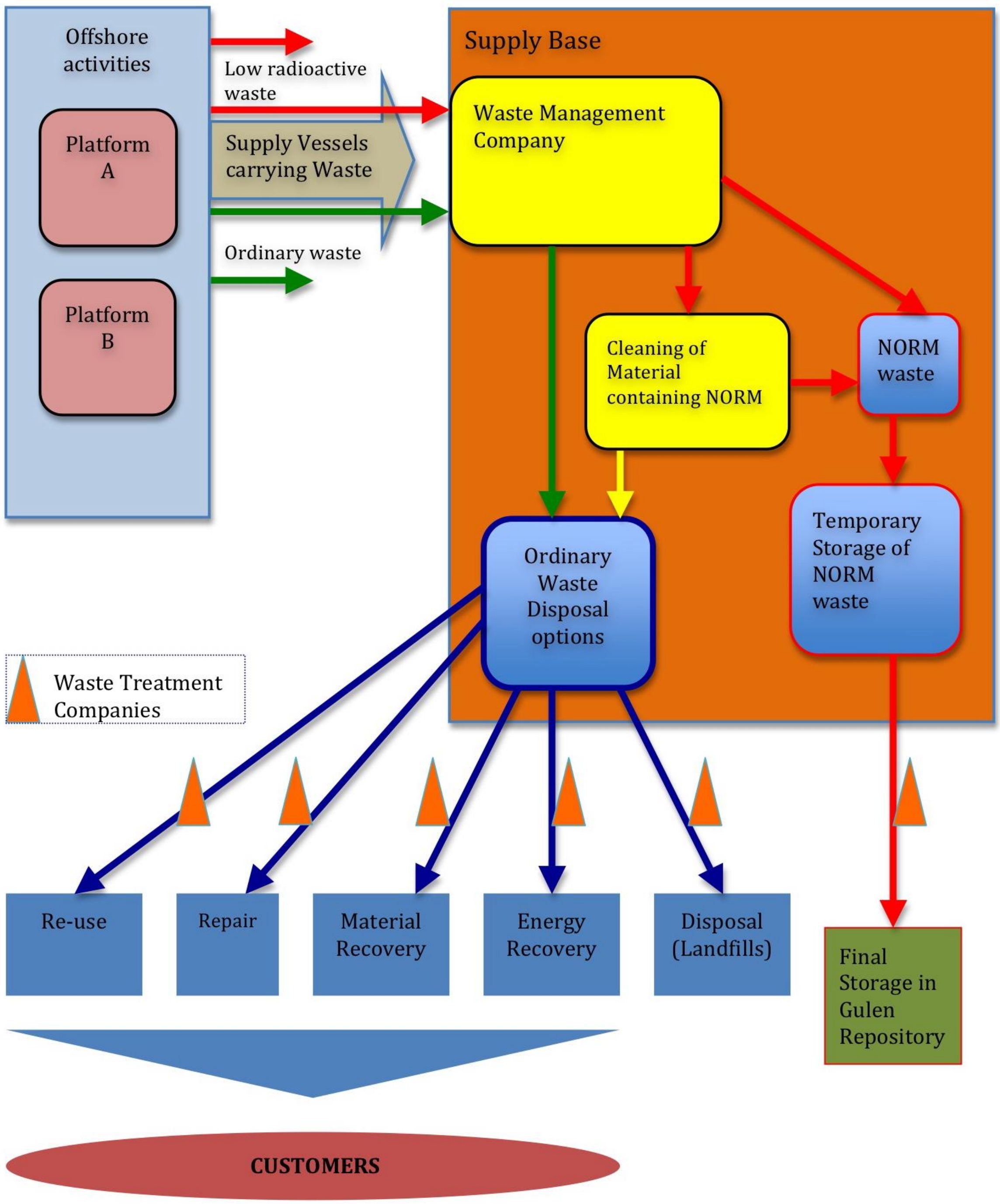


Figure 1: The physical flow/ supply chain of waste (own figure)

The waste management and disposal process for waste containing radiation differs from the non-radioactive waste (red arrows figure 1). It is more complex and costly due to regulatory and operational constraints developed to control, manipulate and dispose wastes containing NORM. The regulations are enforced in order to avoid hazardous radiation exposures to workers in the industry, public in general and protect the environment we live in. Most of the constraints associated with radioactive waste affect the handling, transportation and disposal options. Besides, they require more processes such as decontamination previous disposal selection.

This paper will explore and analyze the waste management process for low radioactive material from “cradle to grave” in Norway. In order to analyze and evaluate the waste management operations in Norway, they will be contrasted against an international compilation of recommended practices to develop optimal waste management operations. It is relevant to mention that the analysis has a health, environmental and safety (HSE) perspective; so when referring to optimal or efficient operations the “cost” attribute of a process has little significance. This is reflected in this paper as the best solution to perform an activity is also the most “safety”, “secure”, “clean”, “green” solution.

One part of the analysis of the waste management process in Norway will explore the regulatory regime for the oil and gas industry due to its strong influences on the management operations for radioactive and non-radioactive wastes.

1.2 Structure of the thesis

This thesis can be split up into four main parts and consists of seven chapters in total.

Part I: Chapter 1 and 2

Chapter 1 gives an introduction into the topic and illustrates the basic waste management and disposal process to give the reader an overview of the setting.

Chapter 2 describes the methodology that is used throughout the thesis and states the goal of the thesis, the research problem and develops the research questions. Furthermore, the data collection is classified and outlined.

Part II: Chapter 3 and 4

Part II builds up the theoretical as well as practical background knowledge for part III and serves thus as a basis for it.

Chapter 3 presents the theoretical framework for this thesis that is including three theories, namely the Supply Chain Management Theory (SCM), the Transaction Cost Analysis (TCA) and the Institutional Theory. Connections between the theories are pointed out and the relevance of each one within the setting of the topic is highlighted.

Chapter 4 provides the literature review and is subdivided into four main areas. The first part sheds light on waste itself, its definitions, different types, waste treatment, responsibilities and authorities involved. The second part conveys detailed information of NORM waste, including origins, sources, radiation levels and potential health hazards. The third part introduces the reader to management of NORM and the connected considerations to it, such as monitoring, controlling, handling and transport, decontamination, disposal options, documentation and finally training and awareness of staff. The fourth and last part of the literature review gives a short overview of hazardous and NORM waste in Norway as well as specific key figures for it.

Part III: Chapter 5

Part III of the thesis contains the comparative analysis of management of low radioactive waste in Norway. It follows a similar structure as in part II regarding operations associated with the management of NORM in the Norwegian Continental Shelf and presents actual practices done by several actors within the NORM waste management disposal process. This part serves as input on the conclusions in the subsequent fourth part. Moreover, it is the basis for the answer of research question A.

Part IV: Chapter 6 and 7

Based on part III, Chapter 6 presents conclusions on how the regulatory framework affects the waste management operations by taking theory mentioned in part II into consideration. It therefore answers research question B.

Chapter 7 rounds up the thesis by naming limitations and further research areas.

2 Methodology

Based on the type of research, the case study is the most suitable strategy for my master thesis. Case studies do not possess control over the behavioural events and focuses on contemporary events (Yin 2009). Moreover, case studies rely on different sources of evidence. The aim of the research is not to describe or explain a situation or setting, but rather to discover *"How to improve…"* something. Therefore, an exploratory approach is needed.

The unit of analysis is a supply chain, but the focus will be one echelon, which is the waste management company. I think that a single case study with multiple units of analysis is appropriate. Yin (2009) suggests being careful to not consume most of our attention in subunits of analysis because then we might ignore the holistic aspects of our case study, if this happened; the orientation of our case study can be shifted.

2.1 Research problem and research questions

This thesis has two purposes: the first one is descriptive and educational and has the intention to present the reader an interesting contemporary topic showing environmental aspects about waste management in general as well as presenting some detailed information about how companies deal with low radioactive waste in Norway.

The second purpose is strictly academic and has the intention to find potential improvements in the waste management operations regarding NORM.

There are two research questions that will lead to finding potential improvements. The first question has the intention to reveal practical operational processes to be implemented for the improvement of the waste management process of NORM in Norway throughout the comparison of Norwegian practices with the international practices by identifying clear differences that could be adopted here in Norway.

Question A) Is there any significant difference between the operations found in the literature review and the current operations in Norway regarding the management of NORM waste?

The second question is developed with the purpose to find national industrial conditions (public/ private) that could potentially affect the efficiency of the waste management process for low radioactive waste. If potential local industrial constraints are identified, they could be analyzed and modified in order to improve the process of waste management for NORM in Norway.

Question B) How does the regulatory framework affect the waste management operations?

2.2 Data Collection

The data collection can be divided into primary and secondary. The main difference between these is that primary data is being founded and collected by the researcher (data that is not available), while secondary data is available data collected by third persons. Primary and secondary data can once more be divided in two categories, internal and external.

This thesis will use primary and secondary data. Quantitative and qualitative data will also be required. The Primary data is the data collected throughout the meetings and interviews. Primary data gave me valuable information about the current waste management practices and actors involved in the waste management supply chain, the level of process integration between members of the SC and also to obtain information about communication and monitoring levels between actors. The secondary data was collected throughout scientific journals, local and international documents referring to official regulations involved in waste management, radiation related topics and the oil and gas industry in the Norwegian Continental Shelf. Moreover this thesis makes use of several recommended guidelines from public and private institutions related to operations in the waste management process for NORM wastes originated in the oil and gas processing facilities. Other sources are Master theses and industry statistics published by the regulating authorities.

3 Theoretical Framework

The relevant literature for this Master thesis will be related to three aspects.

- Transaction Cost Analysis (TCA)
- Supply Chain Management theory (SCM)
- Institutional Theory

3.1 SCM & TCA

A unique situation occurs in this supply chain that is: the oil companies are legally responsible for the correct disposal of the waste through the whole supply chain until it is recycled, reused, energy recovered, or ends up in the landfills. Considering the latter, the oil company needs to know if the waste is being recycled in a proper manner. In order to create an effective disposal of the waste, efficient waste management is needed. There are over 70 different types of waste that each creates a specific SC. This implies a greater level of coordination within the different echelons of the SC. Supply Chain Management as a management theory seeks synchronization and convergence of intra-firm and inter-firm operational and strategic capabilities into a unified, compelling market place force (Ross 1998).

"Related to integrated behaviour, mutually sharing information among supply chain members is required to implement a SCM philosophy, especially for planning and monitoring process." (Mentzer et al. 2001)

In order to develop a successful SCM it is important to determine a) who are the key members of the SC who wish integrate processes with, b) what are the processes to link with between the members and c) how deep is this process going to be integrated (Lambert et al. 1998). In the present supply chain there are many monitored process links. The big waste management companies, the 4th part logistics operators and oil companies typically have a modern and integrated communication system (Enterprise resource planning (ERP) usually SAP) (Halskau and Uthaug 2010).

To accomplish such coordination with so many different companies involved in the process of waste disposal is rather complicated and costly for the oil companies.

Referring to the latter and based on TCA perspective (Williamson 1981), when the internal cost to do a process internally overweight the transaction cost of outsource, companies would rather outsource. Outsource companies (e.g. Waste Management companies, rigs contractors and transportation companies in this proposal) produce money providing good service at lower cost for the oil companies because:

- They have special knowledge that creates competitive advantage
- They face lower costs than their customers (wages, overhead, efficiency)
- They leverage/ better prices for raw material, equipments with suppliers than their customers
- Economies of scale and/or scope (Ellram and Billington 2001).

Outsourcing creates a win-win situation for both parts, that is, the waste management companies and the oil companies.

There is connection between SCM theory and Transaction Cost Analysis (TCA). The level of coordination and integration necessary for a successful SCM, will influence inter-firm transactions. The interplay between these theories is also mentioned in Aas, Buvik and Cakic (2008 pg, 283).

TCA focuses on the transactions made between firms. The way these transactions are made is critical to establish cost efficient governance structures (market, hybrid, hierarchy). Specific assets, internal uncertainty surrounding the transactions and the frequency of exchange between buyer and seller represent the core dimensions of the transactions (Buvik 2001). Williamson (1971) explains that when relevant investments are made, and there is a certain degree of uncertainty (internal/environmental) chances for opportunistic behaviour arise. He remarks that is imperative to device machinery "to work things out". These devices exist in this supply chain to reduce uncertainty such as the intensive involvement of monitoring and IT communication and coordination systems. These advances in information technology have decreased information asymmetries problems (Tate et al. 2009).

The companies involved in the waste management process in this particular SC, seem to have an authority structure commanded by the oil companies. This is to be expected, as the oil company is responsible for the waste. This includes the proper management and disposal option, and also responsibility for any accident regarding waste contamination (no matter which member in the SC causes the accident). The oil companies develop contracts not only to promote the proper management of the waste through incentives/penalties, or to establish "how to do" operations, but also to transfer the responsibility (economical sanctions) to the actors involved with accident or any other breach of the contract.

Not only the use of monitoring and contracts are present in order to reduce risk and information asymmetries; certifications such as ISO 9000/14001 can establish parameters about companies' performances. These certifications help to reduce information seeking costs and also risk associated with environmental performance from subcontractors of the oil and gas companies.

3.2 Institutional Theory

The institutional theory describes how organizations are influenced from external sources (Zucker 1987). Several costly investments and *"how to do"* things regarding waste management processes from the offshore industry are basically a reaction to the high external pressure from the environment. These environmental pressures are translated into norms, international pollution regulations, or Norwegian policies that affect e.g. the way the oil and gas industry set parameters for safety operations or perform some actions, such as disposal methods for the waste emanated by the platforms. It is important to point out the high relevance of the regulatory power that aligned the Norwegian oil and gas industry, and how this power can influence the supply chain and moreover affect the transaction between important echelons. *"Government pressures have a higher impact on firms that face greater monitoring such as paper manufacturers and oil and gas refineries"* (Tate, Dooley, and Ellram 2011). Winter and May (2001), describe how strict governmental environmental related regulations can motivate organizations to develop sustainable initiatives. When organizations start behaving according to external pressures the organization actions become institutionalized (Oliver 1997). These actions are commonly adopted, as companies are well aware of the negative consequences by non-compliance of the environmental regulations.

Relative to the actions adopted in the SC analyzed in this thesis, the implementation of the environmental practices by the members is of proactive (cooperative) nature. Tate, Dooley and Ellram (2011) explain that proactive adoption of environmental practices may improve the performance of the entire supply chain, and that using this practice can create a differentiation from other SC.

Institutional theory is important to be used as a theoretical framework as it helps to understand behavioural attitudes of the companies involved in the waste management SC.

4 Literature Review

4.1 Waste

The first part of the literature review will include definitions of waste, what types of waste can be found, waste treatment and the according responsibilities and finally regulations as well as authorities involved in the process.

4.1.1 Definitions

As this thesis is regarding Norway as a geographical area, waste will be defined according to the Norwegian Oil Industry Association (OLF 2004, pg.10):

"For the purpose of the Pollution Control Act, the term waste means discarded objects of personal property or substances. Surplus objects and substances from service industries, manufacturing industries and treatment plants, etc. are also considered as waste. Waste water and exhaust gases are not considered waste."

The criteria relating to waste require that at least one of the following must be met:

1. Discarded: the owner has given the material up and intends to get rid of it; the owner's evaluation should weigh heavily.

2. Superfluous: the material cannot be used in an appropriate manner without undergoing major treatment; can be determined based on an objective evaluation."

Definition of hazardous waste: "*Any waste which it is not suitable to handle together with consumer waste because it may cause serious pollution or pose a risk to humans and animals."*

Definition of waste management: "All activities associated with handling and administration of waste."

4.1.2 Types of waste

There are three main categories of waste that can be differentiated: ordinary, dangerous and hazardous waste. Table 1 gives an overview of this and examples for each type of waste.

Table 1: Types of Waste (Halskau and Uthaug 2010)

ORDINARY WASTE	DANGEROUS WASTE	HAZARDOUS WASTE
Residual waste	Waste oil	Radioactive waste-low radioactive waste (LRW)
Sorted residual waste	Oil contaminated materials	Quick-silver (hg)
Food waste	Oil filter without metal sheath	
Contaminated food waste	Oil filter with metal sheath	
Cardboard and brown paper	Solvents	
Paper	Paint unhardened	
Plastic foil	Liquid paint	
Hard plastic	Spray cans	
Wood	Acids	
Iron and metal	Bag wastes	
Glass	Empty barrels and cans	
EE waste	Fluorescents tubes	
	Lead batteries	
	Batteries	
	Oil based cuttings from drilling	
	Oil based drilling slam or drilling liquid	
	Oil based slops / oil emulations	
	Water based cuttings from drilling	
	Water based drilling slam / drilling liquid	

Each type of waste produced on the offshore platform has detailed instructions about where to sort them and how to be handled/ transported from the platform to the shore. Moreover, each type of waste is going to be (should be) categorized by labelling the containers with a code and colour. Special attention and labelling is done in the process of disposal of hazardous materials.

Oil companies pay for the transport of the waste from the oil platforms to an onshore base. They also pay the receiver of the waste. The sorting of the waste in the offshore platform must be done in a proper manner (different containers, packaging, labels, codes for the different waste etc.). If sorting is done incorrectly, e.g. different categories of waste placed in the same container or any sorting differing from the waste plan, the contract agreement is called deviation. The occurrence of deviation implies that the waste service company has to re-distribute the waste for better recycling. Respective sanctions (established in agreement based in contracts) should apply to the entity that caused the deviation (Halskau and Uthaug 2010; OLF 2004). Deviation could have serious consequences such health hazards for people and environmental contamination if waste containing NORM is not sorted correctly and mixed with non-radioactive wastes.

4.1.3 Waste treatment

The waste should be treated in four different ways. Following the concepts of sustainability and life cycle assessment, the Norwegian regulations rate the best to least good disposal/recycling options as follows (OLF 2004):

1. Recovery/reuse: No changes in the physical property of the product are made. Check, repair, and clean is usually done. An example for this is glass bottles.

2. Recycling/material recovering: The material is saved to produce a new product. Aluminium for cans or recycling of paper to make paper bags are examples.

3. Energy recovery/incineration: The waste is burned to create energy. The energy recovered can for instance be used to heat the water for households of a community.

4. Disposition in land fields (land fillings). Bad disposition and utilization of land filling can create serious environmental and health problems to the neighbour communities. Therefore, this should be done according to high environmental norms and restrictions.

The Norwegian authorities denote that the term recycling does not include the following disposal options:

- incineration without energy recovery
- land filling (landfills with or without gas recovery).

Regarding radioactive waste, there is another form of disposition, which is final storage in a repository tunnel.

4.1.4 Waste treatment responsibility

The oil and gas companies who produce waste are legally responsible for its correct disposal. *"The Pollution Control Act's emphasis regarding waste places a special responsibility on the party that has generated the waste to ensure that all the waste undergoes final treatment as set out in the regulations. This means that even if the waste is delivered to a service provider for further handling a special responsibility is placed on the producer of the waste (an OLF member company/operator on behalf of the licensees/PL) to ensure that the service provider deals with the waste in accordance with stipulated requirements/regulations. This applies to waste from fixed installations, mobile units on contract, vessels (e.g. pipelaying, supply, standby vessels) and waste produced onshore by the operator's own activities."* (OLF 2004, pg. 10)

4.1.5 Regulations and Authority

National central authorities established a general framework about how firms should handle, collect and treat the waste but at the same time they leave a high degree of power to the local authorities (e.g. municipalities) to accommodate solutions that fit the regional structures. National authorities utilize a number of instruments (e.g. legislation, taxes, economic incentives) aimed at the municipalities, business and industry in order to promote effective waste management. The number of regulations is expected to increase in the years to come. Future measures are developed to reinforce and serve as a complement to the existing regulations (CPA 2010b).

The regulative framework for the operations in the Norwegian Continental Shelf (NCS) is set by the Norwegian Parliament (Stortinget) and executive power concerning policies is in the hands of the government. The responsible for the resource management for oil and gas sector, lies with the Ministry of Petroleum and Energy (MPE), who's supported by the Norwegian Petroleum Directorate (NPD) (Skogekker 2009; NPD 2010).

The national authorities mostly involved in the waste management of radioactive waste are (compare figure 2):

- The Norwegian Pollution Control Authority is the authority in charge concerning the hazardous and non-hazardous waste.
- The Ministry of the Environment regulation relating to classification and marking etc

of hazardous chemicals

- The Norwegian Radiation Protection Authority Regulations relating to radiation protection and use of radiation
- There are also private institutions working closely with the governmental institutions such as the Norwegian Oil Industry Associations.

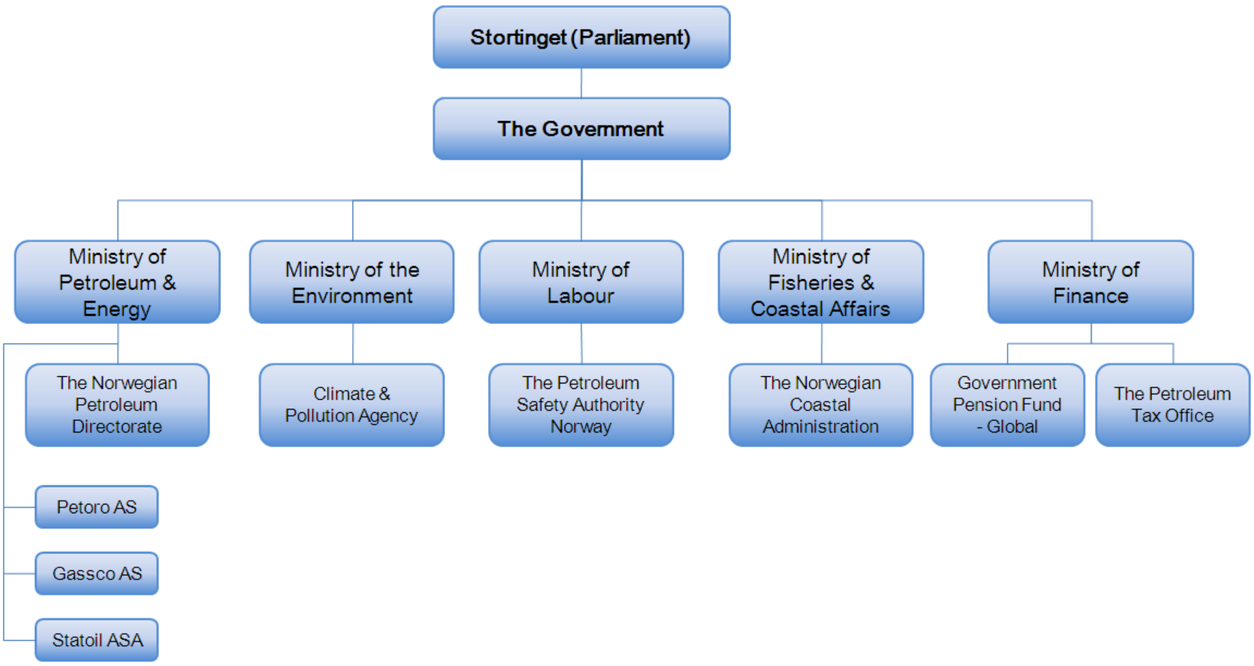


Figure 2: Regulation and Authority bodies for the oil and gas industry in Norway (NPD 2010)

4.2 NORM and NORM waste

The second part of the literature review gives an overview over NORM and NORM waste. It includes such as origins of NORM, radiation that can be emitted by NORM, decay series occurring in NORM, as well as sources of this waste in the oil and gas industry and the potential health hazards related to NORM.

4.2.1 Origins of NORM

Radionuclides of natural origin like Uranium and Thorium are present in the environment in which we live. A radionuclide is a specific type of atom which decays or changes from one state of energy to another in a determined period of time through the process of shedding radioactive particles (alpha and beta), commonly accompanied by gamma radiation (Edmonson, Jelliffe, and Holwand 1997). These radionuclides exist in small amounts (parts per million, (ppm)) in sedimentary rocks formations (see table 2). During the oil and gas extraction processes different decays of these radionuclides such as Ra-226 and Ra-228 are being enhanced upon unique conditions (due to changes in temperature, pressure, acidity etc) and brought to the surface with the oil and gas products (OGP 2008; NRPA 2004).

Table 2: Mean range of Thorium and Uranium concentration in sedimentary rock (OGP 2008)

	Thorium (Th)			Uranium (U)		
	(ppm)		Bq[^{232}Th]/g	(ppm)		Bq[^{232}Th]/g
Sedimentary Rock Class	mean	range	mean	mean	range	mean
Detrital	12.4	0 – 362	0.05	4.8	0.1 – 80	0.06
Sandstone & Conglomerate	9.7	0.7 – 227	0.04	4.1	0.1 – 62	0.05
orthoquartzites	1.5		0.006	0.5	0.5 – 3	0.005
arkoses	5		0.02	1.5		0.02
Shale	16.3	5.3 – 39	0.07	5.9	0.9 – 80	0.07
grey/green	13		0.05	3	3 – 4	0.04
black					8 – 20	
Clay	8.6	1.9 – 55	0.03	4.0	1.1 – 16	0.05
Chemical	14.9	0.03 – 132	0.06	3.6	0.03 – 27	0.04
Carbonates	1.8	0 – 11	0.007	2.0	0.03 – 18	0.02
Limestones	3		0.01	13		0.16
Evaporites				< 0.1		< 0.001

During the extraction of crude oil and gas, NORM is coming to surface in the pipes along with the crude, gas and produced water and accumulates in sludge, scale and scrapings (See figure 3). NORM can also be found on the interior surfaces of gas processing equipment and vessels in form of a thin film. Especially Radon decay elements occur as a film on the inner surface of inlet lines, treating units, pumps, and valves principally associated with propylene, ethane, and propane processing streams (ESR 2011).

The amount of NORM brought to surface will vary substantially from one to another extraction facility depending on the geographical location (different soil), the extraction techniques and other factors. The only way to identify the levels of NORM in the different parts in the facilities is by conducting surveys. (See section 4.3.2 for survey details).

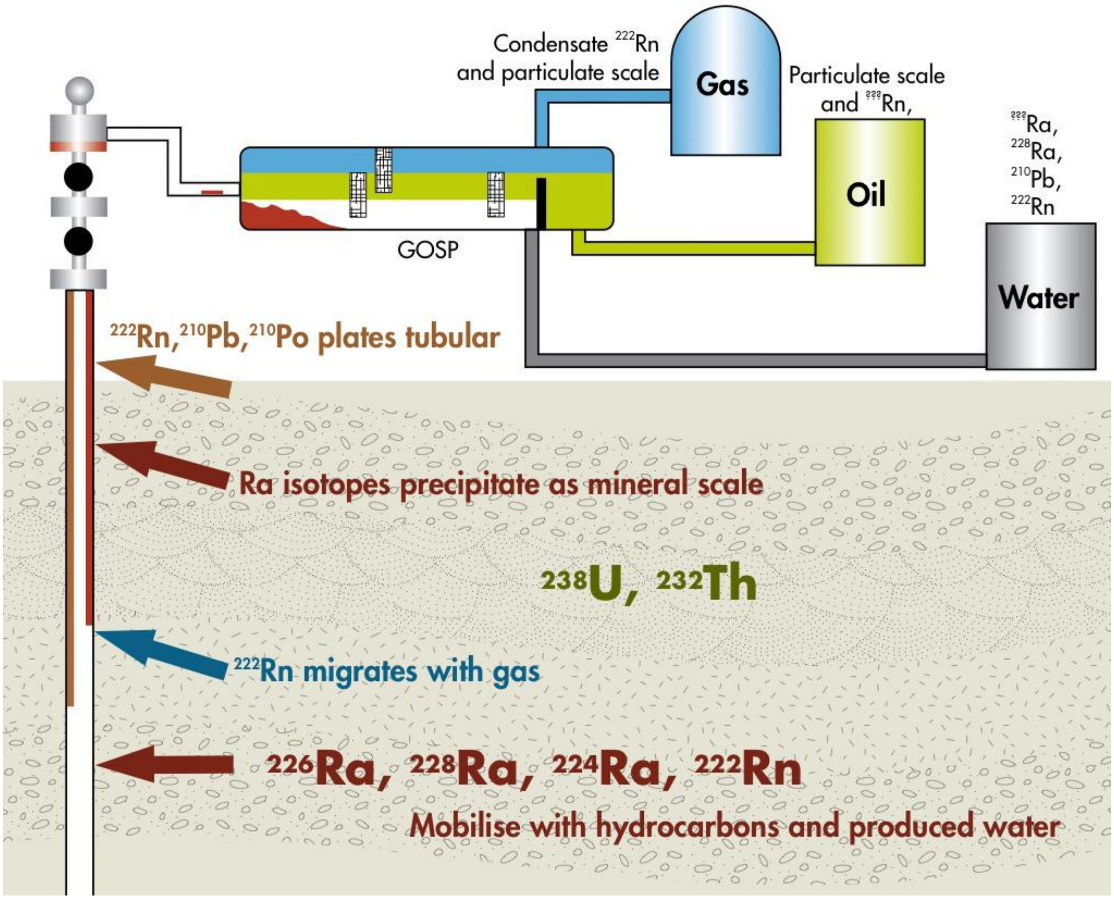


Figure 3: Extraction and accumulation of NORM through the extraction processes in the oil and gas industry (OGP 2008)

4.2.2 Radiation emitted by NORM

The radiation emitted by NORM is classified in Alpha (α), Beta (β) and Gamma (γ).

Alpha radiation: because of their structure, alpha particles tend to lose their energy very fast. A paper sheet or the outer layer of human skin can stop them. Alpha particles are hazardous to a person's health only if a radioactive source of alpha emitting particles is inhaled or ingested.

Beta particles are much smaller than alpha and they interact more slowly with materials. They can be stopped by thin layers of metal or plastic and like alpha particles they are considered hazardous only by ingestion or inhalation.

Gamma emitters are related with alpha and beta decay and are a form of high-energy electromagnetic radiation that can penetrate further than alpha and beta radiation. To avoid gamma rays, thick layers of lead or other dense materials are needed. Gamma particles are considered as an external hazard to living tissues such as the human body (OGP 2008).

Figure 4 displays graphically how these radioactive particles can be stopped.

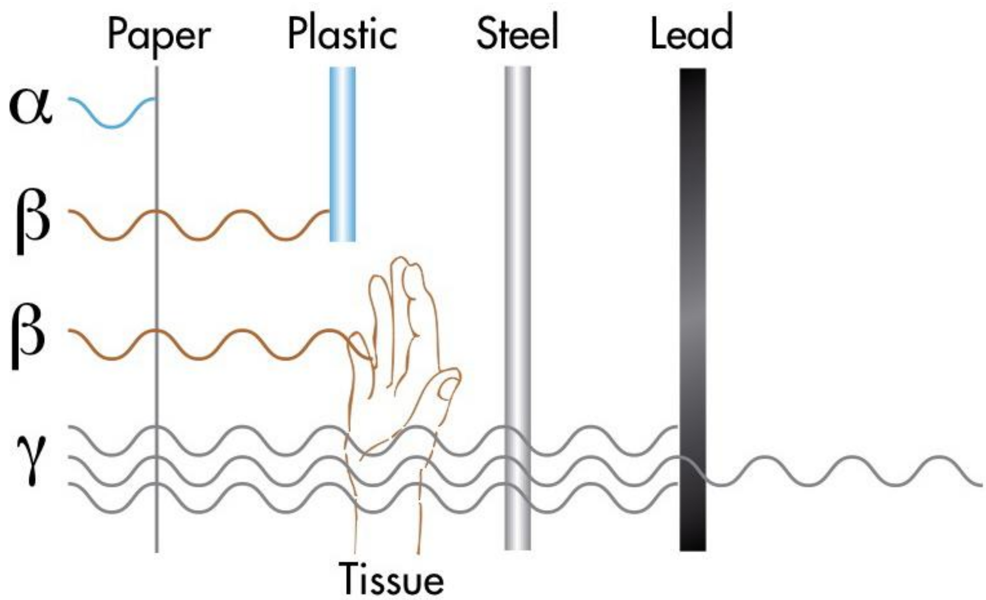


Figure 4: Illustration of ionizing penetration of particles alpha, beta and gamma (OGP 2008)

4.2.3 NORM and NORM decay series occurring in the oil and gas industry

The mayor radioactive elements that are enhanced by the oil and gas industry and that have potential hazardous effects on the environment and humans due to their radiotoxicity and long half-lives, are Radium-226 belonging to the Uranium-238 decay series and Radium-228 that belongs to the Thorium-232 decay series (OGP 2008; F. Bou-Rabee et al. 2009; IAEA 2003).

The Uranium and Thorium decay series, their radioactive half-lives and by which medium these are being transported, are found in the appendix A and B respectively.

As one can see, Thorium decay series are solely transported with water, while Uranium progeny is transported in more various ways (water, gas, condensates of oil or sludge).

The main radionuclides present in the oil and gas industry that create a health hazard for the human health and the environment are listed in the table below.

Table 3: Characteristics of NORM radionuclides (Kinsey 1996)

Radionuclide	Half-life	Mode of decay	Main decay products
Ra-226	1600 y	Alpha	Rn-222 (noble gas)
Rn-222	3.8235 d	Alpha	Short lived progeny
Pb-210	22.30 y	Beta	Po-210
Po-210	138.40 d	Alpha	Pb-206 (stable)
Ra-228	5.75 y	Beta	Th-228
Th-228	1.9116 y	Alpha	Ra-224
Ra-224	3.66 d	Alpha	Short lived progeny

4.2.4 Sources of NORM and NORM waste in the oil and gas industry

NORM can be found in different places. The most important are scale, sludge and scrapings, produced water, thin films in the interior of pipes gas processing facilities, oil processing facilities and sea water injection systems. The problem associated with NORM is that depending on the level and type of radiation, NORM can be hazardous for the human health and the environment. Contaminated items with NORM, waste arising from waste treatment activities and waste derivates from decommissioning activities are the major sources of NORM exposure to the persons that work in these activities. More details of the NORM sources are given in the next paragraphs.

4.2.4.1 NORM in scale form

Scale is formed when the brine in the formation water is moving through the tubulars and thus submitted to changes in temperature, pressure or acidity. Then the solutes tend to precipitate creating scale in sulphates forms such as $BaSO4$ and $SrSO4$, carbonates forms such as $CaCO3$ and silicates. When the Radium tends to co-precipitate with barium (Ba), Strontium (Sr) and silicates of calcium (Ca), it forms radioactive scale. The build-up of scale inside the tubulars can have a major effect in the extraction of crude as it reduces the flow of volume of the pipes (OGP 2008; NRC 1999; Reaburn et al. 1988). It is also found in the gas extraction pipes (due to evaporation). Studies have found out that the pressure used to re-inject the water into the reservoirs is one of principal cause of the formation of scale (F. Bou-Rabee et al. 2009; Al-Masri and Aba 2005).

The table below shows measurements of hard scale found in the inside surface of tubulars and the type of radionuclide present in it.

Table 4: Activity concentration in Hard Scales (Jonkers et al. 1997)

Radionuclide	Reported range (Bq/g)
U-238	0.001 – 0.5
Ra-226	0.1 – 15,000
Pb-210	0.02 - 75
Po-210	0.02 – 1.5
Th-232	0.001 – 0.002
Ra-228	0.05 - 2,800

Figure 5 below shows scale formation inside pipes used for oil extraction.

Figure 5: Scale formation inside pipes used for oil extraction (Varskog and Kvingedal 2009)

4.2.4.2 NORM in scrapings and sludge

Not all radioactive molecules containing radium are in form of scale. They can also be found in sludge (often oily), produced sands and scrapings (see table five and six). Other radionuclides such as Lead-210 and Polonium-210 can also be found in pipelines scrapings as well as sludge which in turn is commonly found in tank bottoms, gas/ oil/ water separators, dehydration vessels, liquid natural gas (LNG) storage tanks and in waste pits (OGP 2008; IAEA 2003). Activity concentrations vary between production facilities; a list of findings is presented in the next table.

Table 5: Activity concentration in sludge (Jonkers et al. 1997)

Radionuclide	Reported range (Bq/g)
U-238	0.005 – 0.01
Ra-226	0.05 – 800
Pb-210	0.01- 1,300
Po-210	0.004 – 160
Th-232	0.002 – 0.01
Ra-228	0.5 - 50

Table 6: Activity concentration in scrapings (Jonkers et al. 1997)

Radionuclide	Reported range (Bq/g)
Ra-226	0.01 – 75
Pb-210	0.05- 50
Po-210	0.1 – 4
Ra-228	0.01 - 10

4.2.4.3 NORM in gas processing facilities

Pipes and equipment dedicated to only handle natural gas do not contain sludge or scraps. However, in the separation of natural gas by liquefaction, Radon-222 will follow the gas stream from the reservoir. The concentration of its decay products will tend to produce a thin radioactive film in the interior surfaces of the gas processing equipment such as pipes, compressors, valves, scrubbers and others. The activity concentration of Radon-222 in gas processing plants can be found in table 7. The decay products of Radon-222 can become a hazard for the workers and environment if they get in contact with short-lived gamma radiation from Bismuth-214 or long-lived radiation from Lead-210 and Polonium-210 (OGP 2008; IAEA 2003; NRC 1999).

Table 7: Activity concentration in gas processing plants (Jonkers et al. 1997)

Radionuclide	Reported range (Bq/m^3)
Rn-222	5 – 200,000
Pb-210	0.005- 0.02
Po-210	0.002 – 0.08

4.2.4.4 NORM in seawater injection systems

It has been mentioned that sulphate-reducing bacteria have the ability to enhance the Uranium that is located in the bio-fouling deposits. The Uranium exists in parts per billion in the seawater and does not represent a significant hazard unless the seawater systems use large amounts of seawater during its life. High concentrations of Uranium (up to 2%) have been found in seawater systems, presenting a hazardous risk for the workers at site and the workers in the process of waste disposal (OGP 2008).

4.2.4.5 NORM in produced water

The largest amount of waste produced by the oil and gas industry is produced water. The ratio between oil produced and produced water is about 1×10^{-1} or 0,33 meaning that for each one cubic meter oil extracted, three cubic meters of produced water is co-produced. The ratio in the gas production is significantly smaller (5×10^{-5}) e.g. 1.000.000 m^3 of gas produced require only the co-production of 50 m^3 of water.

The produced water comes with the production flow mixed with the oil and gas. When separated from the solids, the oil and gas and the water is further treated to remove small particles by using different processes such as centrifugation filtration, skimming and adsorption. After these processes the water is discharged to the sea or is re-injected into the sea bottom (OGP 2008; Betti et al. 2004).

The problem with the produced water is that it contains elevated levels of NORM e.g. Ra-226 and Ra-228 which have a long half-life (see table 3) (NRPA 2004).

Table 8: Activity concentration of NORM in produced water (Jonkers et al. 1997)

Radionuclide	Reported range (Bq/L)
U-238	**0.0003 – 0.1**
Ra-226	**0.002 – 1,200**
Pb-210	**0.05 - 190**
Ra-224	**0.5 - 40**
Th-232	**0.0003 – 0.001**
Ra-228	**0.3 - 180**

Produced water contains hydrocarbons and dispersed oil. Organic chemicals can also be found. These are introduced by the operator for production or technical issues, for example to reduce scaling or corrosion in the pipes (IAEA 2003). A summary of NORM characteristics and the locations it can be found is displayed in table 9.

Table 9: Summary of NORM characteristics and general locations (IAEA 2003)

Type	Radionuclide	Characteristics	Occurrence
Ra scales	Ra-226, Ra-228 Ra-224 and their progeny	Hard deposits of Ca, Sr, Ba sulphates and carbonates	Wet parts of production installations Well completions
Ra sludge	Ra-226, Ra-228 Ra-224 and their progeny	Sand, clay, paraffins heavy metals	Separators, Skimmers tanks
Pb deposits	Pb-210 and its progeny	Stable lead deposits	Wet parts of gas production installations Well completions
Pb films	Pb-210 and its progeny	Very thin films	Oil and gas treatment and transport
Po films	Po-210	Very thin films	Condensates treatment facilities
Condensates	Po-210	Unsupported	Gas production
Natural gas	Rn-222 Pb-210, Po-210	Noble gas Plated on surfaces	Consumers domain Gas treatment and transport systems
Produce water	Ra-226, Ra-228 Ra-224 and/or Pb-210	More or less saline, large volumes in oil production	Each production facility

4.2.5 Health hazards related to NORM

4.2.5.1 Hazard identification

The exposure to ionizing radiation has several detrimental effects on human's and animal's health. Radionuclides found in NORM are scientifically proven to cause cancer in humans (NRC 1999). Leucemia and cancer to stomach, bone, thyroid, esophagus, and the brain are examples of cancer related to ionizing irradiation (OGP 2008). There is also non-carcinogenic hazards found in NORM related to kidney damage caused by the Uranium toxicity (NRC 1999).

Health effects related to ionizing irradiation exposure will vary depending on the type and level of concentration of ionizing energy, the time period exposed to the energy and the amount of energy absorbed.

It is important to clarify that severe health effects like cancer are caused by *high* exposure to ionizing radiation whereas the levels of NORM ionizing radiation in the oil and gas production and waste decommission activities is relatively low due to national and international regulations. Concerning international regulations, one of the most participative institutions is the International Atomic Energy Agency (IAEA), which has been implementing a number of actions related to the management and regulation of NORM and waste containing NORM such us the Basic Safety Standards (BSS) applied to all European countries including Norway. Regarding to radiation exposures, BSS recommends the following (F. Bou-Rabee et al. 2009):

- *A maximum annual dose limit of 1 mSv (100 mrem) to members of the public, with a provision for allowing higher doses in any single year, provided that the average over five consecutive years does not exceed 1 mSv per year.*
- *The limit on an effective dose for exposed workers shall be 100 mSv (10 rem) in a consecutive five-year period, subject to a maximum effective dose of 50 mSv (5 rem) in any single year.*
- *Establishing the so-called clearance levels for releasing materials and items with concentrations and total activity below specific levels.*

4.2.5.2 Human exposure to NORM

Radiation exposures can be classified into external exposure (when the radiation source is outside the body) and internal exposure (when the radioactive source is inside the body via ingestion, inhalation or alike).

External exposure is primarily caused by gamma emitting radionuclides. External exposure is in general very low and it is unlikely that the radiation doses exceed the annual limits for workers in the oil and gas processing facilities. There are exceptional cases where the built up of scales and sludge in tubulars may produce significant dose rates inside some components (see table 10 to observe doses rates).

Table 10: Observed external radiation levels at the outside of processing facilities (OGP 2008)

Facility	Radiation Level# (μSv/h)
Crude oil processing/treating	
• down hole tubing, safety valves (internal)	up to 300
• well heads, production manifolds	0.1 – 2.5
• production lines	0.3 – 4
• separator scale (internal)	up to 200
• separator scale (external)	up to 15
• water outlets	0.2 – 0.5
Associated/natural gas processing/treating	
• downhole tubing	0.1 – 2.2
• piping, filters, storage tanks, reflux lines	up to 80
• sludge pits, brine disposal/injection wells, brine storage tanks	up to 50
NGL processing	
• filters	up to 90
• NGL pump	up to 200
• C_3 storage tanks	up to 60
• NGL/C_3 shipping pumps, C_3 reflux pumps, elbows, flanges	0.1 – 2.8

Basic safety measures to avoid external contamination are (IAEA 2003):

(a) Minimizing the time duration of any necessary external exposure;

(b) Establish distances to be maintained between any accumulation of NORM (installation part) and potentially exposed people;

(c) The use of protective shields between the NORM and potentially exposed people.

Internal exposure to NORM as mentioned earlier happens due to ingestion or inhalation of radionuclides. Workers and other persons can be affected particularly during maintenance, transportation of waste and/ or contaminated equipment, during the decontamination of equipment and also during the disposition process of waste itself (IAEA 2003).

Sometimes the cleaning of contaminated waste generates airborne radioactive material, especially when dry abrasive cleaning techniques are used. Inhalation of radioactive particles could become a significant hazard if effective personal protective equipment (PPE) is not utilized or safety controls measures are not followed.

Elemental measures against internal exposure published by the IAEA are (IAEA 2003; IAEA 2004):

(a) The use of protective clothing in the correct manner to reduce the risk of transferring contamination;

(b) Refrain from smoking, drinking, eating, chewing (e.g. gum), applying cosmetics (including medical or barrier creams, etc.), licking labels, or any other actions that increase the risk of transferring radioactive materials to the face during work;

(c) Use of suitable respiratory protective equipment as appropriate to prevent inhalation of any likely airborne radioactive contamination;

(d) Apply, where practicable, only those work methods that keep NORM contamination wet or that confine it to prevent airborne contamination;

(e) Implement good housekeeping practices to prevent the spread of NORM contamination;

(f) Observe industrial hygiene rules such as careful washing of protective clothing and hands after finishing the work.

The figure 6 presents an interpretation of internal and external contamination.

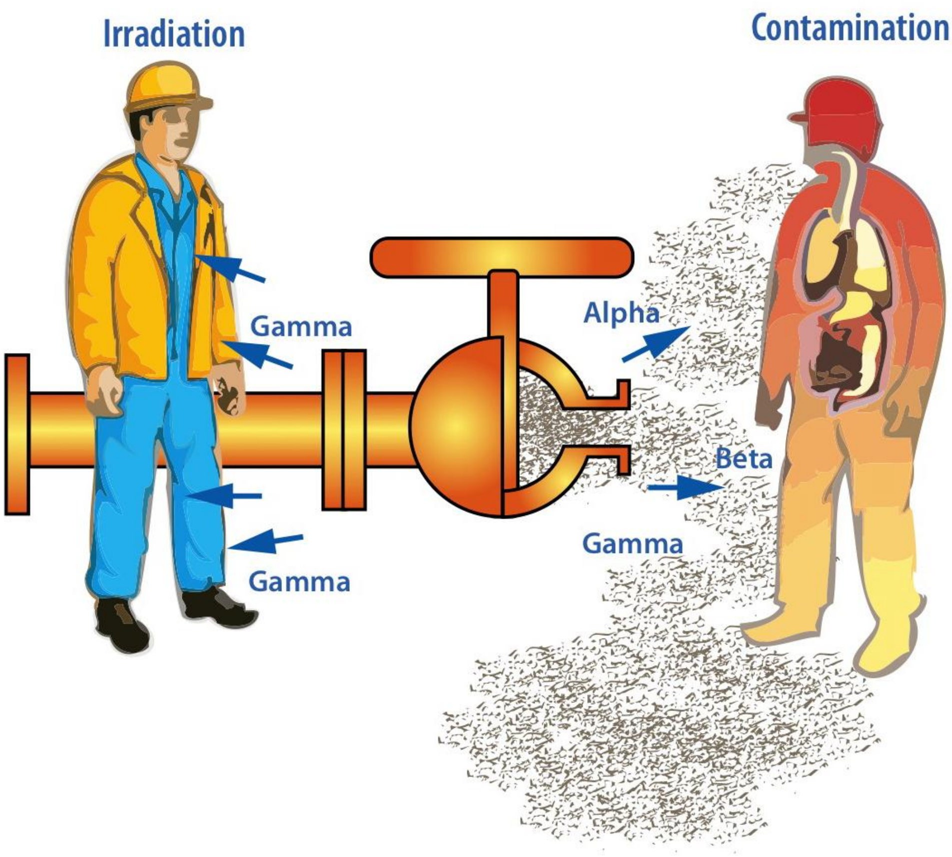


Figure 6: NORM exposure scenarios (OGP 2008)

It is important to clarify in this chapter that there is not such as an accurate test that identifies which exact level of radiation creates what sort of health hazard to a specific person. The health conditions of humans are decisively different between one another and medical tests in general only give indications, rather than precise answers when it comes to identifying who really suffers from a health problem and who does not.

It needs to be pointed out that the exception levels for exposure to NORM given/ recommended by the international and national authorities are low; sometimes persons from the public sector are exposed to higher doses (Norwegian Ministries 2010) than for workers in the oil and gas industry or the waste management process of it. These exemption levels are based on low radioactive doses that do not pose and adverse health hazards to people.

Even medical surveillance is often practiced on persons working around NORM to ensure their health is good. The most secure way to prevent any health hazard is through safe operating practices. The education of workers, monitoring and control over NORM sources and the activities around them will minimize personnel exposure and the health hazard associated. In order to do so, proper management operations need to be implemented.

4.3 Management of NORM waste

The third part of the literature review gives details about the management of NORM waste, considering aspects such as how to monitor and control NORM waste itself, procedures for handling equipment contaminated with it, decontamination procedures as well as disposal options. Furthermore, transport issues are highlighted, documentation requirements and finally training and awareness for staff handling and working with NORM.

4.3.1 Waste management considerations with respect to NORM

Various solid and liquid wastes containing NORM are produced (generated/ enhanced) in large volumes by the oil and gas facilities during production. Other NORM waste (mostly solid) is produced when decontamination operations are held and also during decommission and rehabilitation of an oil and gas production facility, waste management facility and/ or treatment facilities. Depending on the radioactive level of these wastes, they could have radiological effects on the workers associated to the waste, as well as on other personnel or members of the public who may be exposed to the radiation if the wastes are not managed correctly and these radionuclides end up spread in the environment. Besides the radioactive hazards of NORM, these wastes might possess other chemical characteristics adverse to human health or the environment (IAEA 2003).

In the oil and gas industry the NORM waste is mainly produced water, sludges and scales, contaminated items, wastes arising from waste treatment activities and wastes arising from decommissioning activities.

NORM concentrations in produced water are low, but the volumes are large. Contrarily, the volumes of solid waste are low but the NORM concentrations are higher. Radionuclides with long half-lives need special attention. High concentrations of long half-lives as founded in scales (Ra-226 1600years and Ra-228 5.75 years) have important implications in the management of NORM wastes especially for the disposal options.

The management of NORM waste can be divided into the following processes:

1. NORM monitoring
2. NORM control procedures
3. Control of NORM waste
4. Control of NORM contaminated equipment
5. Decontamination
6. Disposal options
7. Transport of norm
8. Documentation
9. Training and awareness

The process cycle for NORM operations can be observe on appendix C.

4.3.2 NORM monitoring

In order to manage NORM waste effectively, it is necessary to find out where it is being produced. This requires an assessment of all operations that identifies potential NORM contamination (OGP 2008).

In order to identify existing NORM in some areas, monitoring is necessary. To measure NORM a direct analysis can be done onsite with the use of dosimeters, both in the offshore and onshore facilities. Indirect measures are also possible by taking samples and send them to an analysis to a laboratory. Measurement surveys can be subdivided by their objective:

Baseline surveys:

The purpose of the baseline surveys is to identify sources of NORM in the facilities and the radioactive levels in these locations. These surveys give valuable information to establish the type of protection that is needed in the specific areas and which control procedures are necessary.

Pre-shutdown surveys:

The main priority is to determine the areas with NORM accumulation and thus where NORM contamination is suspected. (For example to look for NORM levels in a oil/gas separator previous to a shutdown). If the radiation instrument shows presence of gamma radiation, it will be necessary then to use contamination control measures. Moreover, it might indicate that the NORM waste has to be handled in a properly controlled manner.

Operational assessments:

Operational surveys are needed in order to identify NORM contamination in a fast manner during routine operations such as previous intrusive work on a pipe due maintenance or the clean-up of potentially contaminated equipment. It is important and necessary that field workers know how to operate the portable radiation instruments and are able to analyze/ interpret the results (OGP 2008).

Figure 7 presents the NORM survey process and requirements schematically.

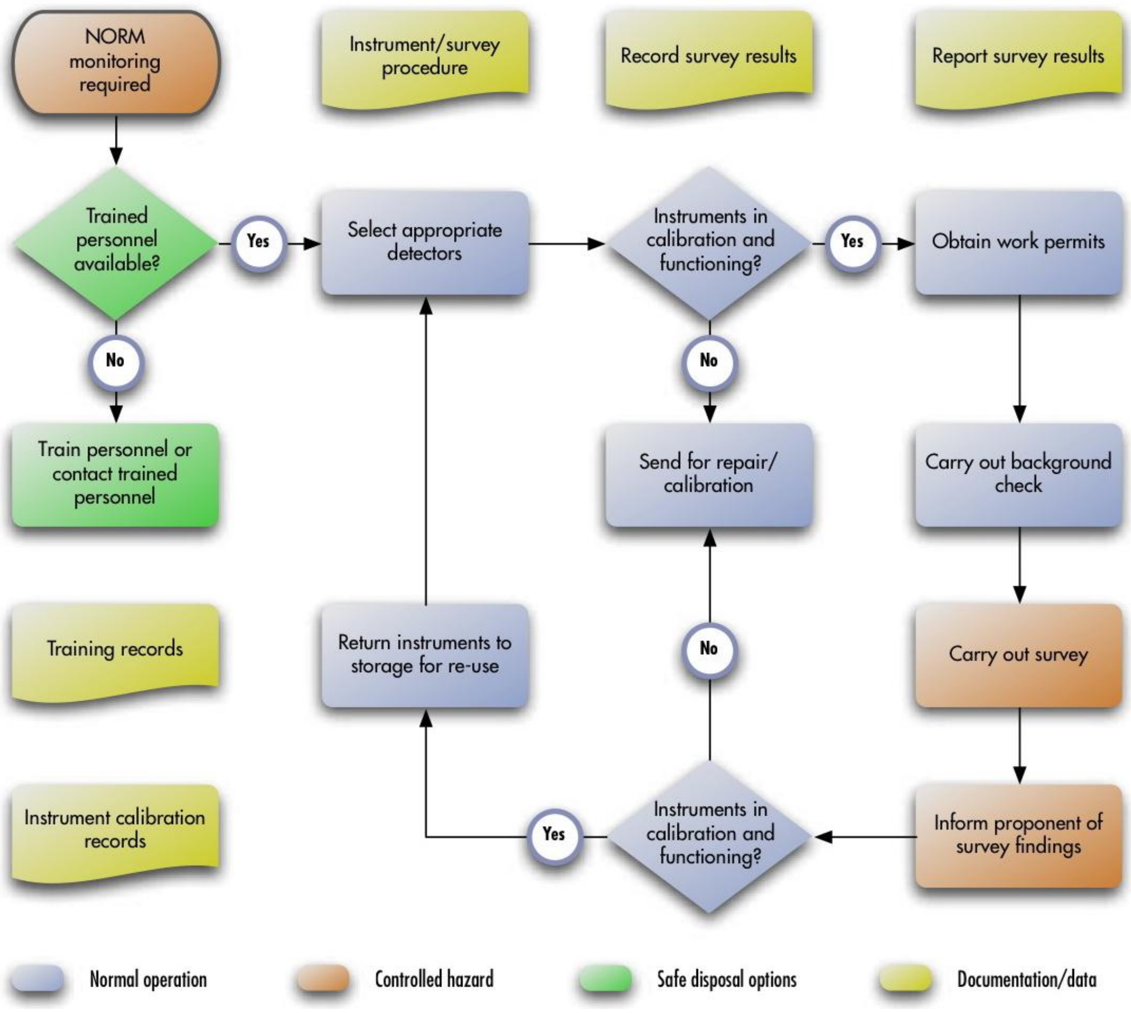


Figure 7: Schematic display of NORM survey process requirements (OGP 2008)

4.3.3 Control of NORM procedures

Once NORM levels are found in specific areas through surveys, and operations are required in these locations, control measures need to be taken. As part of controlled procedures the following actions are necessary: (OGP 2008)(IAEA 2003)

- Delimit the work area. The area covered should be as small as possible, but big enough so that all workers and equipment needed can fit and allow a safe work.
- Special trash bins are necessary to place contaminated trash with NORM, including the protective clothing used. The protective clothes should be disposed when leaving the delimited area.
- Use the minimum number of workers to perform the work efficiently.
- Before operating in the areas with NORM, it is important to protect the ground. It should be covered with a plastic or a waterproof material able to resist intact (braking tearing or ripping). A catchpan or a drip-tray can also be used as ground cover if suitable for the work. The ground cover needs to be big enough in order to prevent any leakage or waste contaminating the area (See figure 8).
- Use visible radiation warning signs like “Caution: NORM Material”
- Previous to the operations, all workers assigned for the work should attend a safety meeting. The meeting should address aspects like necessary work and safety equipment, radiation and contamination levels, operations that might cause radioactive material to become airborne and emergency actions to be taken in different scenarios etc.
- When starting the operations, dry material should be completely wetted (and also during the work) to avoid the radioactive material to become airborne.
- If openings of tubulars or other equipment expose internal NORM contamination, these should be sealed or wrapped by plastic or other suitable materials.
- Tubulars or other equipment with no current use, but containing NORM, should be clearly labelled as “NORM Contaminated Materials” and located in specific areas with restricted access to workers/public.
- All NORM waste generated during cleaning operations should be stored in drums or containers and labelled as such. Samples of waste should be analyzed to determine radioactive levels.

- All equipment and tools used should be checked for loose contamination and radiation levels before leaving the delimited area. If the radioactive readings show positive contamination, this equipment should be treated as such.
- After the work in the assigned areas is finished, these should be inspected for loose contamination. If loose contamination is found, they should be cleaned and drummed in a fast manner.
- Once the work area has been inspected and proved to be free of loose surface contamination, the signs and delimitation marks can be removed.

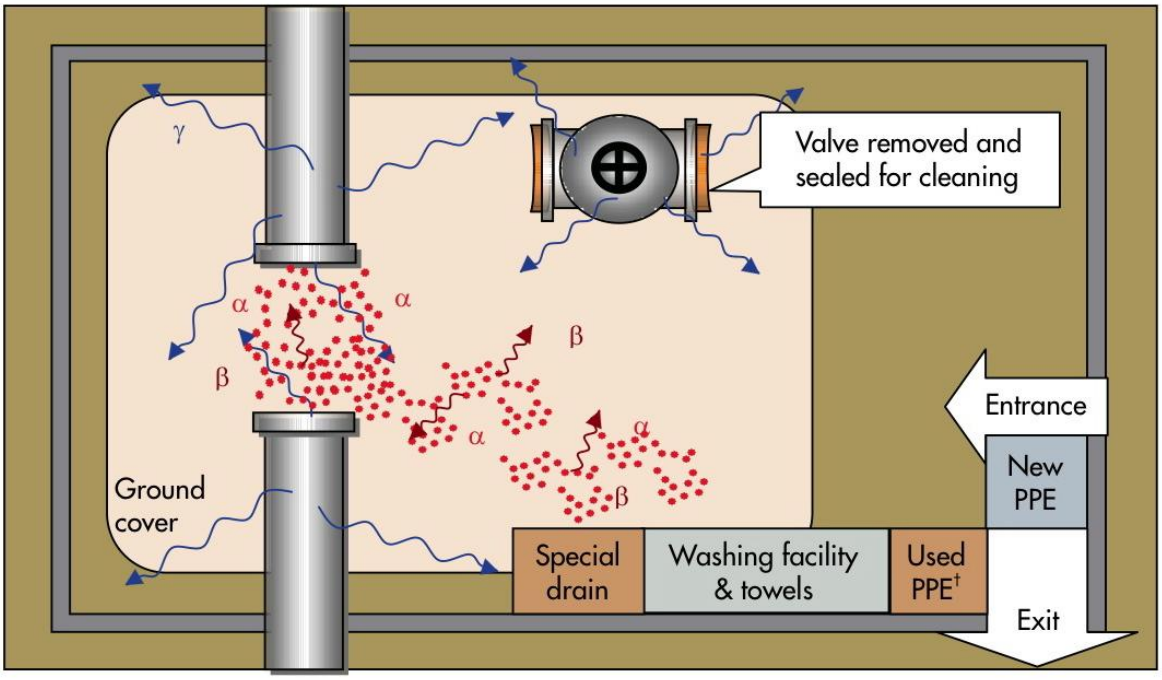


Figure 8: NORM control contamination requirements (OGP 2008)

4.3.4 Control of NORM contaminated waste

The waste contaminated with NORM needs to be handled and disposed in a proper manner following the national and international regulations linked to the disposal of NORM waste.

Before the final disposal of NORM waste, short-term (e.g. in the offshore platforms) and interim storage (e.g. supply bases) is required. NORM waste should be stored in suitable containers that comply with certain requirements (to see container requirements see appendix D. When stored or disposed, records should be developed. These records should include (OGP 2008):

- *Waste material description (scale, sludge, scrapings, etc)*
- *Volume of waste material*
- *Mass*
- *NORM level (activity per unit weight) of waste material.*
- *Method of disposal*
- *Disposal location*
- *Organization/facility where the NORM waste was generated*
- *Any other relevant information.*

A typical control process of NORM waste during shutdown operations can be found in Appendix E in more detail.

4.3.5 Control of contaminated equipment

All equipment contaminated with NORM should be handled, stored and transported in a secure manner to avoid environmental contamination and in order to provide security to the workers. It is very important to be able to identify which equipment is contaminated, what the conditions of transport of this equipment are, and where the specific area of storage is.

To mention an example: a pipe containing NORM scales that for some reason is not identified and is transported with non-radioactive materials to the supply base can end up to be stored with the non-radioactive pipes for a short period. Later it is sent to a facility for cleaning/ fixing/ recycling. This scenario creates potentially substantial exposure to workers and spread of NORM scales in the environment.

A list of basic requirements for the control of contaminated equipment is given below; all contaminated equipment should: (OGP 2008; IAEA 2003)

- Have particular storage area
- Be tagged as NORM contaminated equipment
- Handled by employees trained in NORM
- Not be sent to other facilities without informing the recipients about the NORM

content

- Be disposed (if necessary) in approved NORM disposal facilities.
- Be decontaminated following NORM decontamination protocols.

In addition, routine checks should be performed in the storage areas to ensure that the protective measures are in order. Records of the NORM contaminated equipment should be kept all the time.

A typical process for the control of NORM contaminated equipment can be found detailed in appendix F.

4.3.6 Decontamination

Decontamination of a plant and equipment contaminated with NORM, generate different types of waste streams. It is common that these wastes will contain not only radioactive particles but also other compounds (heavy metals and chemicals), such as zinc, mercury and lead. This may cause constrains in the decontamination and disposal options, and of course increases the level of safety measures to be taken when decontaminating.

The risk for exposures and accidents rises significantly for workers during decontamination processes. Accidents related with high pressure water jetting (HPWJ) can be dangerous and could prevent the victim from total recovery.

The main objectives decontamination processes are:

- Free the components from NORM material
- Generate the minimum NORM waste (by maximizing NORM decontamination)
- Prevent NORM from spread
- Ensure worker protection from any hazard related to the decontamination process (Worker protection is described in detail in Appendix G)

HPWJ is proven to be one of the most successful and cost-efficient methods for decontamination and practiced in most countries.

When using HPWJ or other abrasive/ mechanic methods, it is important to take the following into consideration: (OGP 2008)

Changing facilities for workers: This is the entrance to the NORM controlled area where decontamination will take place. After the cleaning process, the clothes used by the workers cannot exit this area.

Handling area: This is where the potentially contaminated materials are checked with radioactive measuring tools , to assure levels of radiation and segregate (if materials are clean of NORM). This area is also used for quarantine of NORM equipment.

Strip down area: in this area wellheads, valves and other equipment is taken apart

Burning Bay area: This area is designated for grinding and the use of oxy-propane cuttings. This area requires the use of HEPA filtered extract ventilation systems to capture airborne. Besides that, other ventilation systems, e.g. elephant trunks are used for the control and removal of dust. It is mandatory for the personnel in the area to use respiratory protective equipment (RPE). The floor should be watered, should be fire resistant and capable to handle heavy materials.

Water jetting area: The area should have the same requirements that the burning bay area has but should in addition have, a) a floor that is resistant to the high pressure of the HPWJ and b) a liquid recirculation system which is needed so that the "waterwaste" is continually re-circulated and filtered. The waste contained into the setting tank of the recirculation system should be measured for radiation and disposed appropriately.

(OGP 2008; IAEA 2003)

4.3.7 Disposal options for NORM contaminated waste

Disposal options are influenced by the characteristics of the waste e.g. activity concentration, type of radiation, half-life period and physical form. Disposal site factors like climate, geology, ground water and surface water can also influence the suitability for a specific kind of waste to be disposed.

Optimal dispositions should establish safe, practical and cost-effective disposal methods for NORM waste. They should also be designed to provide protection to human health and the environment. It is relevant to develop appropriate risk assessment programs aligned with the local and international regulations. The absence of such a program can lead to negative environmental impacts (e.g. contamination of underground water or contamination of soil that could become a residential or agricultural area in future years) and the associated remediation cost. Other important criteria for choosing disposal methods are technical feasibility and general acceptance from the regulatory institutions as well as the general public.

The disposal methods for NORM waste used nowadays by the oil and gas industry can be subdivided into five categories: Land based management; Salt cavern disposal; Offshore discharge; Land fill and Underground injection. Their characteristics are presented in the next table:

Table 11: Description of disposal methods (OGP 2008)

Disposal method	Description
Land spreading	It involves disposal by spreading sludge and scale on the surface/ open lands in an area where NORM was not originally present above background levels.
Land spreading with dilution (land farming)	Land spreading with dilution involves mixing of the applied NORM thoroughly within the top 8 inch (20.3 cm) layer of soil using agricultural equipment in an area where NORM was not originally present above background levels.
Non-retrieved line (surface) pipe	Buried line pipe used at a facility could be abandoned in place after being flushed to remove any oil or gas present.
Burial with unrestricted site use	Burial with unrestricted site use involves burial of NORM with at least 15 feet (4.6m) of cover that is level with the surrounding terrain, minimizing erosion potential.
Commercial oil industry waste facility	Disposal in a commercial oil industry waste facility assumes burial with other oilfield wastes where NORM represents less than 7% of the total waste volume.
Commercial NORM waste facility	A NORM waste disposal site is designed to contain NORM for long periods and its control may revert to a national authority for permanent monitoring and restricted future use after closure.
Commercial low level radioactive waste facility	A low-level radioactive waste disposal is defined and licensed under national regulations with numerous protective features and restrictions.
Plugged and abandoned well	Well abandonment operations provide an opportunity to dispose of NORM.
Well injection and hydraulic fracturing	Sludge and scale wastes could be injected or fractured into formations that are isolated geologically and mechanically.
Equipment release to smelter	Smelting may be a viable option for NORM contaminated tubular and other equipment.

The selected disposal option for the NORM waste should also take into consideration, the potential hazards for humans and the environment that derivate from the non-radioactive elements associated with NORM waste such as hydrocarbons or toxic metals.

4.3.8 Transport of NORM contaminated equipment

If possible, NORM contaminated equipment and/ or NORM waste should be mobilized in exclusive vehicles, i.e. no other cargo can be transported in the same vehicle. When this is not possible which occurs in the supply vessels, a container tag and designed especially for the transport of NORM should be used (see container requirements in appendix D). All personnel who dispatch or receive this equipment should be notified.

Operators of trucks and vessels should be provided with a contingency plan and they should know how to implement them in case an emergency situation occurs.

Vehicles transporting materials/ equipment/ waste containing NORM should be handled according to the regulations for safe transport of radioactive materials. They should also have the required qualifications and documentation according to the local and international radiation authorities such as the IAEA.

Records of all NORM transportation should be kept with detailed information about:

- Material description (scale, sludge, contaminated equipment etc)
- the volume and/or quantity,
- transportation method,
- the origin and destination of the waste and
- other relevant information that local authorities find pertinent.

4.3.9 Documentation

There are two types of documentation: the first one is related to the operations that are required to handle the transport of materials/ wastes containing NORM and the measurement of activity concentrations of NORM. These are related to physical characteristics, volume, activity concentrations and also to location.

The second type of documentation is regarding the management of the NORM, such as organizational responsibilities, NORM monitoring approaches, training requirements, instructions for control of NORM contaminated equipment and how to prevent/ reduce contamination from NORM.

4.3.10 Training and awareness

Training and awareness is probably the most important tool to develop and execute an accurate NORM management system. The personnel involved in managerial and practical NORM operations need to be educated about NORM. Appropriate training has huge potential to reduce accidents especially related to health hazards and environmental contamination. Some of the information given on the trainings will vary depending on the personnel position within the NORM management process structure. The training can be dived by working areas. (OGP 2008)

All personnel involved in NORM work should know about:

- Origins of NORM
- Radiation and contamination
- Biological effects
- Risk associated with radiation exposure to NORM
- Worker NORM protections
- Emergency response procedures

Personnel involved in surveys should know the previous information and in addition:

- Survey instruments
- Legal NORM limits
- Survey documentation
- Sampling operations (including air sampling)
- Types of laboratory analysis
- Area posting requirements
- Practical sessions involving actual surveys for NORM to be included on the curriculum

Personnel involved in supervisions and managerial aspects of NORM should know the previous information and additionally:

- Waste management programmes
- Surveying plans and programmes
- Record keeping requirements
- Shipping and transporting of radioactive materials
- The Annual Limits on Intake (ALI) and Derived Air Concentrations (DAC)
- Disposal options
- Liability minimizations

4.4 *Information about Norway's hazardous waste*

The fourth part of the literature review shall give a short overview over the hazardous waste found on the Norwegian Continental Shelf. This part includes such as sources of waste, waste types and volumes, disposal options and some details about NORM levels in Norway.

4.4.1 The Norwegian Continental Shelf (NCS), source of oil and economic growth

The oil and gas industry is the largest industrial sector in Norway. Oil production in Norway started in 1971, at the Ekofisk field after its discovery in 1969. Since then, various oil reservoirs have been discovered and by 2010 over about 3 000 billion Norwegian kroner in current monetary value has been invested for the extraction oil and gas in the NCS. In 2008 Norway was ranked the 6th largest oil exporter and the 2nd largest gas producer in the world. The NCS is about 2.2 million km^2 and is divided into three sections: the North Sea, the Norwegian Sea and the Barents Sea. The exploration activity in the NCS had a record in 2009 as 72 exploration wells were completed thanks to 21 new discoveries in the North Sea and 7 in the Norwegian Sea.

The oil and gas industry has contributed significantly to the Norwegian economic growth; this can be attributed to the taxation regime. Since the Ekofisk discovery, the industry has generated values of about 8 000 billion Norwegian kroner.

After the year 2000, oil production started to decline in the NCS (see figure 9). The NPD estimates that by 2014 the oil production will be less than 1.6 million barrels a day. This value represents half of the production compared to the best oil producing years.

Figure 9: Oil production on the Norwegian Shelf (OLF 2010)

Contrarily, the gas production in Norway has doubled since the year 2000 when production of gas was 49,748 million sm^3 compared with the 103,464 million sm^3 produced in 2009. (See appendix H)

The forecast for the extraction of petroleum derivates is expected to be steady in the next years in the NCS. Studies from the NCS claim that more than half of the recoverable resources have not been extracted yet. The recent trend of a decrease in the oil production and increase in gas production is the expected scenario for the future.

(OLF 2010; NPD 2010)

4.4.2 Waste types and volumes on the NCS

The production and drilling operations in the Norwegian oil and gas industry on the NCS generate enormous volumes of waste (OLF 2010).

Joint guidelines that were established for the waste management in the offshore oil activities in Norway provide the overall objective that the operating companies first and foremost should generate as little waste as possible and at the same time to recycle as much of the generated waste as possible. The classification of waste is done according to the OLF guidelines for waste management in the offshore activities. As mentioned in the introduction, the waste can be classified into hazardous and non-hazardous waste.

In 2009, the total amount of non-hazardous waste was 19 508 tonnes, while the generation of hazardous waste was almost eight times higher with 153 000 tonnes. As the figure 10 below shows, hazardous waste thus accounts for almost 90% of all the waste produced from the offshore activities in 2009.

Figure 10: Amount of waste produced on the NCS in 2009 (own figure)

The distribution of non-hazardous waste types from the offshore activities on the NCS for 2009 is presented in the figure 11. Metal, residual waste, wood and food-contaminated waste account together for already 88% of all non-hazardous waste generated.

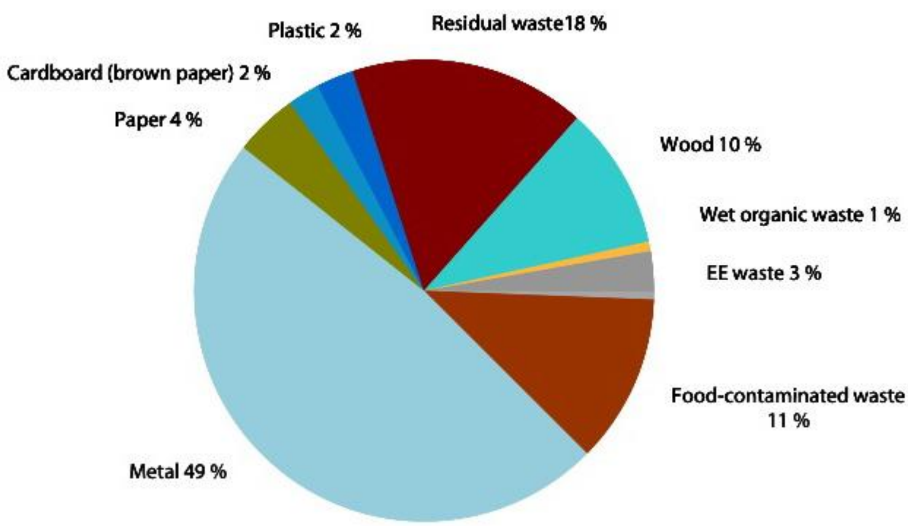


Figure 11: Distribution of non-hazardous waste from the offshore activities in 2009 (OLF 2010)

For hazardous waste the picture looks a bit different (see figure 12). Almost 99% (152

000 tonnes) of all waste created arises from drilling and can be classified as cuttings with entrained chemicals. The remaining 1% can be divided into chemical waste mix and oily waste.

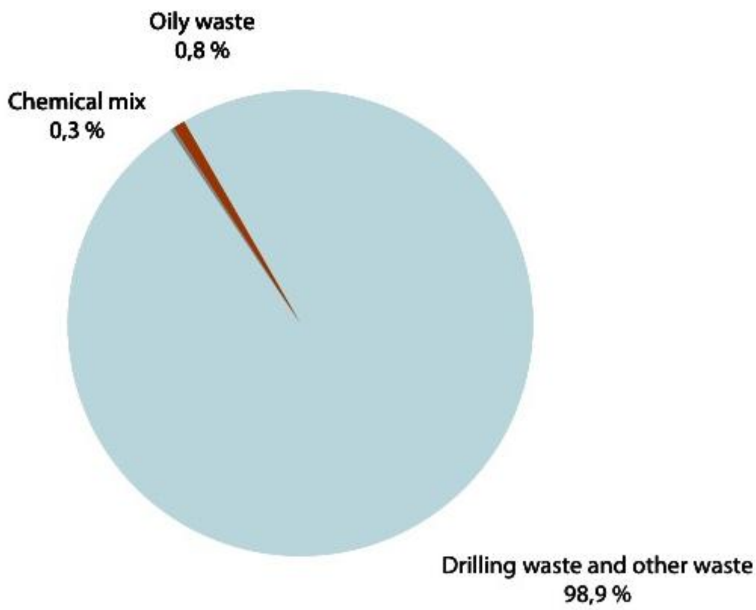


Figure 12: Distribution of hazardous waste from the offshore activities in 2009 (OLF 2010)

The low-level radioactive waste that is relevant for this thesis represents a small percentage within the category of “Drilling and other waste”.

Its handling has to be done according to requirements and guidelines published by the Norwegian Protection Regulations (NPR) and from the Norwegian Radiation Protection Authority (Statens Strålevern). Waste that exceeds activity levels of 10 Bq/g is sent to the repository facility that is located in Gulen. The remaining waste is processed with all the other hazardous waste according to the just mentioned guidelines.

The regulations are being revised and updated regularly with regard to e.g. limit value requirements concerning the definition of “radioactive waste”.

4.4.3 Waste sources on the NCS and discharges to sea

The following are the four main sources for operational discharges to sea originated from the oil and gas industry and their activities:

1. drilling and well operations,

2. chemicals used during production,
3. produced water and
4. oil itself.

During drilling operations there are two types of waste being produced: used drilling fluids and drill cuttings that are consisting out of rock material. Drilling fluid provides different functions: it transports the drill cuttings up to the platform, it serves as lubricant and cooler for the drilling bit during drilling, it prevents that the borehole collapses and it keeps the well pressure under control. Due to that, drill cuttings always contain a specific percentage of drilling fluids. Three types of drilling fluids are used throughout the industry: oil-based, synthetic and water-based drilling fluids. Synthetic drilling fluids are based on ether, ester or olefin; in 2009 Norway has not made use of this fluid. The discharge of neither oil-based nor synthetic drilling fluids or cuttings that contain a specific amount of those fluids is allowed (See appendix I).

There are two disposal options for used drilling fluids and drill cuttings: they are either taken to shore for appropriate handling or they are re-injected into the seabed. In 2009, almost 50 000 tonnes of oil-based cuttings were injected and about 70 000 were send to land for further treatment.

Water-based drilling fluids contain a number of natural components like clay and/ or salts. The components of drilling fluids are classified as “green” in line with the Climate and Pollution Agency’s classification system, which was developed, based on OSPAR’s chemical classification requirements. Once a fluid is classified as “green”, it means that the chemicals it includes are assumed to have little or no impact to the marine environment when they are discharged (OSPAR’s PLONOR list – Pose Little Or NO Risk). The discharge of used water-based drilling fluids and cuttings is permitted by the authorities upon application. Some Norwegian drilling sites managed to reclaim and reuse water-based fluids. In total, the discharge of these fluids has increased from 2008 to 2009 though, due to an increase in the number of wells drilled on the NCS in the same period (OLF 2010).

The amount of produced water discharged on the Norwegian Shelf in 2009 was 134 million cubic meters. This represents for the second year in the row, a reduction of 10% compared with the previous year. The reason for this is the reduced production on the NCS. It is likely that the discharges of produced water into the sea will decrease in the years to come due to the ratio relation between oil production and gas production and the change in the Norwegian market that is increasing gas production while reducing the oil production.

4.4.4 Specific NORM level concentrations in Norway

Diverse studies have been made in the NCS that measure concentration levels of NORM from various sources. As mentioned before, levels of NORM will vary depending on the rock formation, depth, temperature, pressure and acidity. These factors affect the output result of NORM levels measured. A list of findings from the NCS is presented in table 12 below.

Table 12: NORM level concentrations in the NCS (F. Bou-Rabee et al. 2009)

Sample type	Ra-226	Ra-228
Formation Water	0.3 – 10.4 (Bq/dm^3)	
Produced Water	3.3 (Bq/dm^3)	2.8 (Bq/dm^3)
Produced Water	0.5 – 16 (Bq/dm^3)	0.5 – 21 (Bq/dm^3)
Scale	300 – 32,300 (Bq/kg)	300 – 33,500 (Bq/kg)
Sludge	100 – 4,700 (Bq/kg)	100 – 4,600 (Bq/kg)

The next figure displays the amount of releases of the main NORM radionuclides Ra-226 and Ra-228 to the NCS from 2003 to 2009.

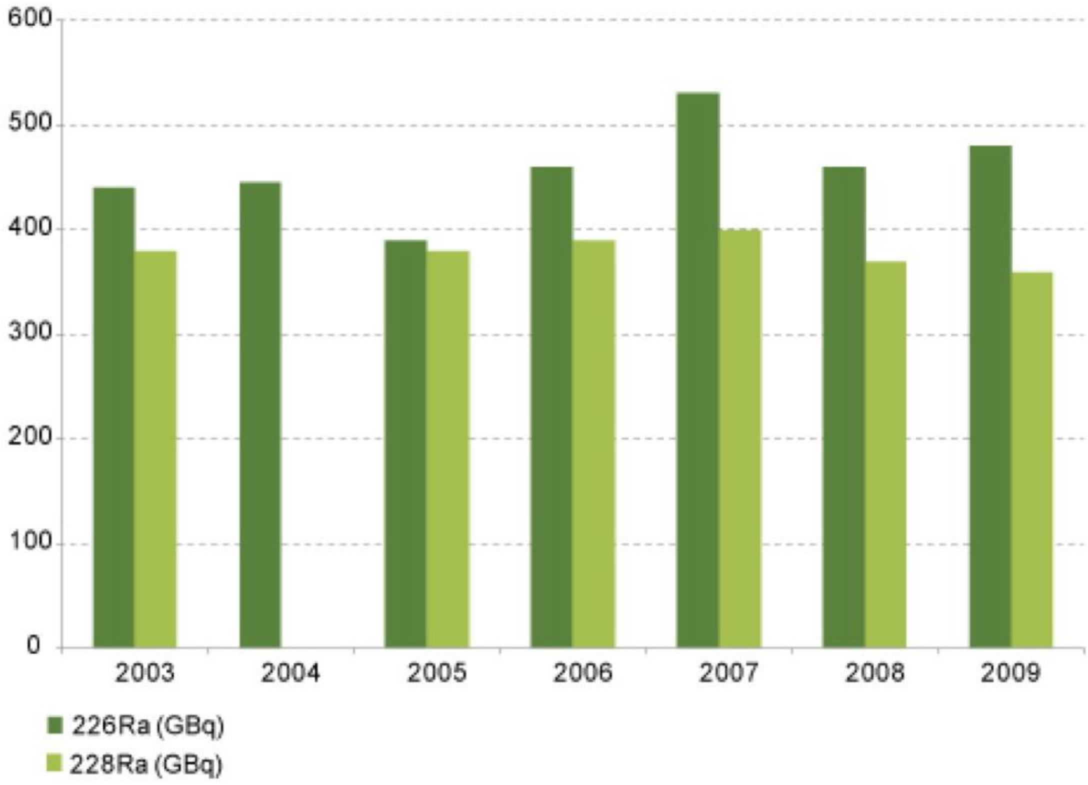


Figure 13: Releases of radioactive substances from Norwegian oil and gas activities in GBq (NRPA 2011)

It is likely that the discharges of produced water into the sea will decrease in the years to come due to the ratio relation between oil production and gas production and the change in the Norwegian market that is increasing gas production while reducing the oil production.

5 Comparative analysis of practices in Norway

Regarding operations associated with the management of NORM/ LRA in the NCS, the following sections of this paper will present actual practices involving the actors from the NORM waste management disposal process.

5.1 *Clearance levels for low radioactive waste*

Since 1997, Norwegian authorities have been using the exemption levels recommended by IAEA as clearance levels in the oil and gas industry. The present clearance levels for NORM in Norway are (Strand 1999):

- 10 Bq/g for Ra-226, Ra-228 and Pb-210
- 1 Bq/g for Th-228

5.2 *Operational Responsibilities*

Before performing any kind of operations a structure that assigns responsibilities should be established. The next table is based on BP structure of responsibilities within the operations regarding NORM operations. The following table briefly describes personnel from different segments and their duties.

Table 13: Personnel responsibilities and duties regarding NORM operations: (own table)

Responsible person	Duty
Offshore installation manager	Handling, use, logging, transportation and storage of LSA is carried out safe and in accordance with regulations
HSE safety officer	Handling, use, logging, transportation and storage of LSA is carried out safe and in accordance with regulations
Area Authority	Keep overview of radioactive sources Ensure that the personnel working with NORM are trained for the work Ensure that all fractions from production, including re-injected NORM are documented
Job Officer	Ensure protective equipment and packaging/containers for storage are available Planning safe treatment for any hazardous waste when planning or performing work operations
Contractor / Operator	Handling, use, logging, transportation and storage of LSA is carried out safe and in accordance with regulations Ensure that performing personnel have the knowledge to work with NORM
BP Drilling supervisor	Keep documentation of all NORM from well operation that is re-

	injected
Authority Coordinator	To be in contact with the National radiation Protection Authority Coordinate work/applications with National Radiation Protection Authority
Performing personnel	Handling and collecting any hazardous waste on completion of the job following instructions and recommendations
Storage supervisor	Storing, packaging, labelling, declaring and sending hazardous waste to the supply base following the regulation Ensure protective equipment and packaging/containers for storage are available Planning safe treatment for any hazardous waste when planning
Supply Base	Receiving and checking all NORM wastes from the different installations Sending NORM waste to the hazardous waste contractor
Hazardous waste contractor	Handling NORM received in accordance to the regulations Forward the wastes to a repository
Health adviser	Manage (store, give, collect) personal dosimeters to/from qualified workers to perform measurements. Write the result of the measurements in the Registration exposure form and send it to the HSE department

5.3 General requirements for NORM in the offshore facilities

- Areas with potential radiation contamination should be checked with dosimeters previous work.
- Non-compacted NORM waste should be measured according to the Beta radiation measurements.
- External measurement of NORM located in pipes must be performed according to the Low specific activity scale (LSA) measurements regulations. (Detailed information about how to perform radiation measures are given in appendix J)
- All work with LSA requires a work permit level 1 and a work procedure.

(BP 2011)

5.4 Area classification

- Non controlled area: These are areas where radioactive doses rates are *lower* than 7.5 µSv/h or under 0.5 µSv/h. Non-controlled areas should be monitored and subjected to constant inspection of NORM levels.
- Controlled areas: Areas where radioactive dose rates are *higher* than 7.5µSv/h or over 0.5 µSv/h. The controlled area should at least include the areas one meter away from

where the measure was taken.

(BP 2011)

5.5 General safety measurements to work with NORM (BP 2011)

- The personnel should be familiar with the procedures, risk and safety precautions to work with NORM.
- Central Control Room (CCR) or area technician should coordinate the work.
- NORM contaminated material should be moist to prevent inhalation of airborne material.
- All openings of equipment containing NORM should be sealed. If the equipment is stored, the seal should be checked constantly until the equipment is shipped.
- After completion of the work, the personnel should carefully wash themselves before eating and drinking.
- The working area should be indicated with proper signs indicating radiation hazard or sealed off if necessary. The information about the area has been qualified as controlled area and a restricted access while NORM work is ongoing should be given.
- The personnel performing work with NORM presence should be equipped with disposable dust masks, disposable coverall, chemical gloves, chemical glasses, boots, etc.
- No other work should be allowed in controlled areas.

5.6 When the job is completed (BP 2011):

- All material that exceeds the dose rates of normal background value should be packed safely and placed in a container to be stored in approved areas.
- When NORM material is going to be transported to the supply base, the supervisor must inform the store supervisor (material coordinator) and safety officer about the volume and status of NORM.
- Personnel should be checked for radiation.
- Controlled area and equipment should be cleaned and checked for radioactive levels. The area and equipment can be cleared only when the dose rates are not over the background levels.

- After use, all of disposable equipment should be treated as NORM waste. Only equipment that does not exceed normal background levels can be used again.

All NORM waste should be send ashore to a firm that has the approval from the authorities to handle, store, clean NORM wastes and equipment containing NORM with documentation that include the readings of NORM levels.

If NORM wastes happened to be stored in the platform, this waste must be sealed with plastic and placed in a proper container labelled with radiation signs. The area one meter around the container should be restricted and marked. Levels in the surroundings should be lower than 0.75 µSv/h or 0.5 µSv/h if the area is a permanent work area.

5.7 Disposal options

As mentioned previously and shown in figures, the Norwegian oil and gas industry produces huge amounts of material containing NORM. The disposal options for this material containing NORM are numerous. Many of these disposal options that are in accordance with the regulatory scheme for the NCS do not represent a viable option for the Norwegian oil and gas companies who show a very high environmental profile. Regarding the dumping or release of NORM, Norwegian policies and regulations are very strict.

Based on the internal information obtained from Norwegian oil and gas companies, the current and most common disposal options are:

Re-injection: This disposal method can be divided into

- Well injection/ re-injection into the reservoir
- Well injection by hydraulic fracturing

Basically, the re-injection process consists of bringing back the waste to where it comes from by injecting cuttings, drilling muds and produced water into the reservoir or fractures created in the seabed. From a radioactive point of view, these options are very safe. The chances for radioactivity to contaminate the seabed and seawater are almost zero as studies have proven (Strand 1999).

As stated in the BP handbook (2011):

- *All cuttings and production fractions to be reinjected require a special discharge permit issued by the Norwegian Climate and Pollution Control Authority (KLIF) for the installation concerned.*
- *Chemicals which are part of the drilling fluids for cementing and slurrification shall be covered by the fields frame permit for discharge.*
- *Re-injection of produced water and/or seawater for pressure support is also covered by the frame permit for discharge.*

As mention in chapter 4.4.3, production wastes containing NORM are also transported to shore. These are handled, treated and disposed depending of the physical characteristics of the waste and the level of NORM concentration.

According to primary data and using a waste management perspective, the NORM wastes arising offshore can be divided in two types; the first one are the loose sludges and scrapings that arrive in skips and tanks, where upon arrival, vacuum trucks are needed to suck the mixtures and empty the skips/ tanks. The second type arrives in solid form. Mostly it will be scale found in pipes and valves where decontamination processes with high pressure jetting are needed to remove the scale from the metal internal surfaces. In both cases, the low radioactive waste is being collected and packed in special drums for further storage and handling.

Since 2011 there are two classifications for the LRW

- LRA with specific activity above 10 Bq/g
- LRA with a specific activity between 1 - 10 Bq/g

These classifications affect the disposal methods for the wastes as shown in the figure 14.

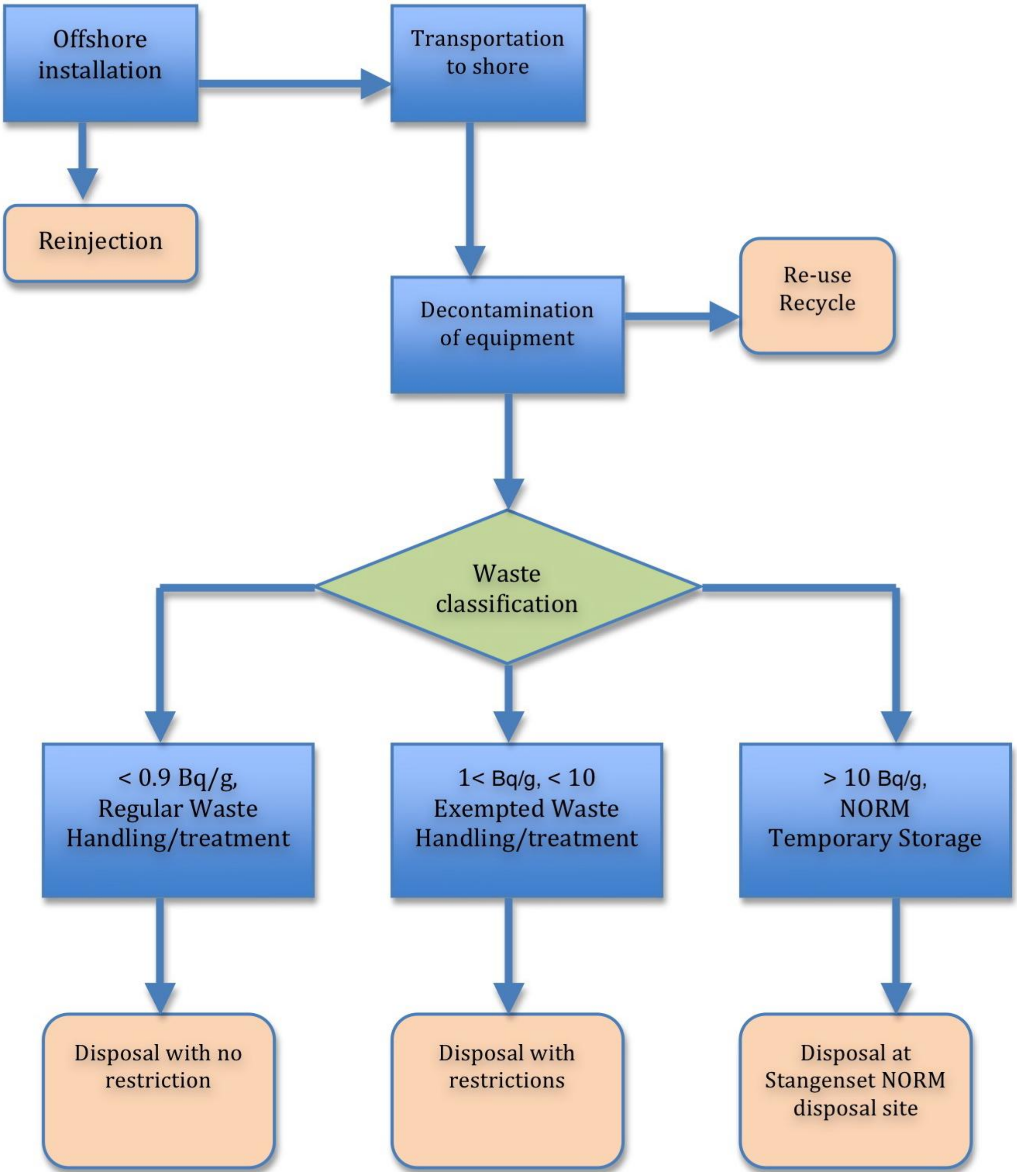
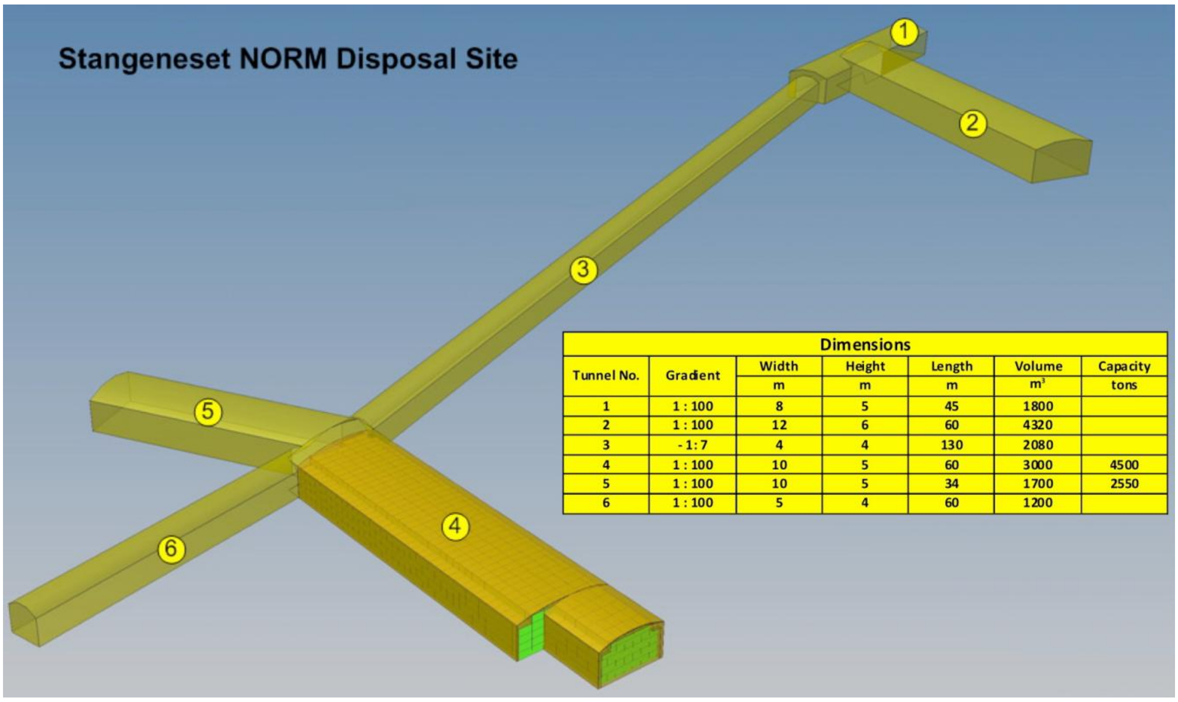


Figure 14: Disposal methods for LRA waste after the 2011 classification (own figure)

The LRA > 10 Bq/g have a depository requirement connected to it. It is being disposed in concrete inside a cavern (see figure 15). This disposal method is one of the most expensive, but at the same time a much safer choice for the public and environment. Disposal with restriction is the waste containing very low radioactive characteristics (under 10 Bq/g) that can be treated in different ways e.g. cuttings/drilling mud and fluids send to Langøya island in Oslo for treatment that stabilize the hazardous components. Thermal disruption and water treatment are also practiced.

5.7.1 National depository

In 2008, the Norwegian Radiation Protection Authority (NRPA), after completion of the repository cavern located at Stangeneset Industrial Site in Gulen, Sogn og Fjordane County, authorized the firm Wergeland-Halsvik to manage the repository for a period of 4 years initially. The repository was built to be the final storage for the radioactive waste originated in the oil and gas industry. The NORM is put in drums with special characteristics and located inside the two repository tunnels and grouted into concrete blocks (up to 100 drums per block). The total capacity is 7 000 tons, but the tunnels can be expanded.



Dimensions						
Tunnel No.	Gradient	Width m	Height m	Length m	Volume m^3	Capacity tons
1	1 : 100	8	5	45	1800	
2	1 : 100	12	6	60	4320	
3	- 1 : 7	4	4	130	2080	
4	1 : 100	10	5	60	3000	4500
5	1 : 100	10	5	34	1700	2550
6	1 : 100	5	4	60	1200	

Figure 15: The Stangneset NORM disposal site (Varskog and Kvingedal 2009)

5.8 Transportation

When NORM waste or equipment containing NORM are transported to shore from the supply base, it should be wrapped in plastic and the valves and tubulars should have caps (to avoid leakage). These should be placed preferably in closed containers if not even a proper seal and cover is needed.

All NORM waste transported must be marked following international codes for transport dangerous goods, class 7 radioactive material.

Radioactive sources are to be transported in line with the applicable Norwegian regulations and also INCAO and IMDG rules.

The sender and the supply base shall inform the safety officer and the operator before sending out any radioactive material.

The inspector on the platform will inform the safety officer when:

- radioactive sources have been received on the installation
- radioactive sources have been sent ashore from the installation

IMDG codes (rules for transportation of hazardous goods by sea)

ADR codes (rules for transportation of hazardous goods by road)

All hazardous waste transported by sea should be followed by a transport document, sent together with the manifest and proper information should be given to the captain of the supply vessel.

(BP 2011)

5.9 Documentation

Based on observations, having the proper documentation (for transportation) and declaration form in order, is very important. Properly filled in declaration forms (see appendix K for new declaration form) for hazardous waste (includes LRA) is a very delicate task because the form will indicate the type of waste and other several categories upon chemical and physical characteristics that requires to fill out the form with the right codes. If the form is filled out incorrectly, could cause deviation. Besides the economic penalties associated with deviation, it could cause that material/ waste containing NORM is handled/ transported as non-radioactive waste creating hazard for the workers and environment.

Declaration forms for final treatment of all types of waste are to be kept for a minimum period of three years. This can serve as a proof for the disposal option if needed for future audit purposes. This could be e.g. to prove that the company X is choosing or has chosen the most efficient/ optimal environmental disposal solutions in the previous years. Documentation is kept in the supply base by the oil company or the waste management provider. The invoice documentation is kept for 10 years to comply with the Norwegian accounting legislation. Documentation regarding transportation (where the waste comes from and where it is going for treatment) is necessary to ensure waste traceability.

5.10 Training and Awareness

As mentioned before in the literature review, training and awareness is one the most important aspects for carrying out a proper waste management for NORM. Training is of particular importance for the workers who handle NORM contaminated material, especially during cleaning/ decontamination operations as the radiological and toxic hazards are higher.

Documentation about training and operational knowledge necessary to perform activities is diverse and quite extend. There is also numerous of “know how” instructions accessible 24/7 to workers at the platforms and supply bases. For example, Statoil ASA use a electronic platform called APOS where the worker can find the procedures and requirements necessaries to perform any operations. The use of paper manuals that describe operations is also well used in the Norwegian oil and gas industry. To set a credible argument, here is an example from BP.

“Required qualifications

All users of portable radioactive sources shall have the competence specified in the authorization from the NRPA. In order to obtain the competency required, normally a three-day-course is sufficient.

Personnel repairing or performing maintenance on equipment where there is a danger of exposure to radioactive radiation shall be certified by the Norwegian Radiation Protection Authority or an accredited personnel certification institute for radiation protection.

The person offshore responsible for radioactive sources shall hold a valid certificate issued by a accreditation company. The person shall also be able to guide workers on how radioactive sources shall be handled and what is the proper PPE and measure equipment.

BPN’s person responsible for radioactive sources must hold the following competencies:

- *Measurement and classification of low-radiation scale, (LRA), 3 day course and* *certificate*

- *In addition a 3-day course covering industrial radiography, sources for control and logging and other use of sources.*

The categories and levels of training are diverse. The author participated a work shop/ training for personnel working in the Åsgard B. platform for Statoil. The training had the intention to introduce a new documentation format for declaring hazardous materials (that include NORM waste) produced in the platform. (Appendix K presents the new declaration form for Hazardous waste in Norway that is to be used from 2011).

The information presented in this chapter is based on internal information from the Norwegian oil and gas industry. This information is fundamental for the discussion conclusion and recommendation in the next chapter. Little summary or outlook on the next chapter

6 Reflections and conclusions

Norwegian NORM waste manage processes vs. international guidelines

Regarding the research question A, this investigation has not found significant differences within the operational practices between Norway and the international guidelines for best practices regarding the management of NORM waste. Norway presents a clear structure for management of NORM wastes, establishing norms, functions, procedures and responsibilities for the different echelons in the Waste Management SC.

The control procedures to work with and/ or around NORM are elaborated in a very detailed manner. Activities requiring working in controlled areas and handling NORM contaminated materials present a high degree of safety precautions, e.g. high quality of protective equipment, safety standards to perform activities and emergency response plans aligned to the corresponding activity.

The areas for storage of NORM in the offshore facilities as well as in the supply bases meet the international recommendations for a safety of workers, public and environment.

Decontamination and transportation of NORM operations in Norway are accomplished with a very high degree of security. This is not only because what is mentioned earlier, or the workers abilities, but mainly because of the high quality of the infrastructure. This is regarding also the modern and well conditioned equipments as e.g. supply vessels, tanks and containers, cranes and forklifts specifically assigned for the handling and transportation of NORM. The decontamination operations are also well benefited from these, e.g. automation process for (HPWJ). The rich infrastructure in this part of the SC reduces the probabilities for both accidents and radiation exposures.

Another area where Norway stands out is in the disposal methods for low radioactive waste. Norwegian practices for disposal of NORM wastes offer minimum radioactive exposures to both population and environment since well and fracture re-injections in the offshore areas and different methods on shore are highly depending on the radioactive levels.

Regarding training and awareness, the Norwegian oil companies established minimum requirements for the personnel working with NORM (commonly three to six days of training). These requirements will vary depending on the degree of participation and responsibility of the worker involved in the NORM operations. The National Radioactive Protection Authority demands minimum training sessions and offers different certifications for the workers participating in those.

The documentation regarding the storage and movement of NORM contaminated material in Norway is abundant (required for transporting, delivering, receiving, cleaning, storing, disposal) and it is also very detailed (physical and chemical characteristics). Documentation is fundamental for traceability and accounting.

This thesis found that the operational practices from the NORM waste management in Norway are in line with the best managerial practices recommended for the oil and gas industry. How Norway got to implement best practices (from an HSE perspective), is not part of the argument in this research question, but the author can infer that the high regulatory system in Norway with a strong focus on HSE and solid financial power of the oil and gas industry contribute to achieve great oil and gas waste management practices, that in other countries, it would be consider inefficient by due to the cost structure.

Regarding the question B; *How does the regulatory framework affect the waste management operations?,* this paper have found several observations.

Better environmental performance equals more waste produced:

When it comes to evaluating the results from the regulations and normative approaches taken by the Norwegian regime that manage the oil and gas industry towards the protection of the environment and human health, it can be described as successful. Emissions to the environment from hazardous chemicals have been reduced by more than 99% since 1997 and the use of synthetic drilling fluids in the NCS is practically eradicated. In addition, every year more of drilling fluids (oil and water based) are transported to shore. These are a just a few examples to be named from many others.

As the environmentally friendly trend towards transporting the used drilling fluids to treat and/ or dispose them on shore continues, the waste management operation will increase at the same time. In addition to this, the market figures for the last three years indicate thatt drilling operations have increased, i.e. more drilling fluids are produced. This trend will continue for a few years due to the increased number of the new discoveries (small in size) in the NCS.

Regarding this, it is important to take the number of increasing operations, their location in the NCS and volumes of waste produced by the offshore facilities into consideration because it will influence the number of operations in the specific supply bases. These supply bases might need to expand their personnel, equipment and geographical area to cope with new supply operations (e.g. new areas for equipment for the platforms) and the increase of waste management operations such as area for storage of hazardous, non-hazardous and NORM wastes.

Regulatory regime creates voluntary sustainability initiatives.

It is clear that most of the pro-environmental practices from the oil and gas industry are a reaction to the external pressures, especially to the oil and gas regulations, meaning that they are not voluntary, but they are coercive, and they are a response to negative economic results e.g. (different kind of penalties, damage of company image). However, there are also pro-environmental practices that are voluntary such as actions that outperformed the environmental demands significantly. Whether they have environmental ("help the nature") or economic (improve corporate image, gain more clients, etc) fundaments would be nice to know, but it is out of question, as long as it is voluntary. Statoil ASA offer economic incentives to outperform the demands for the waste segregation at the offshore platforms. If segregation is good and deviation is at a minimum throughout a year, the economic incentives will be awarded to the offshore facility and distributed between the employees. Moreover, the management creates sustainable initiatives at the intrafirm level, e.g. segregation trash bins all over corporate offices.

TCA perspective for regulatory regime

Most of the regulatory basis set by the central authorities regarding the waste management to be implemented in the oil and gas industry is aimed to improve the HSE conditions. Commonly, there is a period of time given to the industry so it can adopt the new regulations. These regulations might influence the transaction cost between the members of the SC e.g. if companies need to adopt new technologies (decontamination or recycling) could lead to bargaining about new prices for services between the members and thus a new service cost. Another example is if the offshore platform needs to improve environmental performance, e.g. “zero emissions from top side of the platform to the ocean”, for which more monitoring is needed in order to reduce information asymmetries and the risk of monetary sanctions (if the offshore platform is emitting waste from the top). Regulations might also affect the purchasing practices for the oil companies e.g. chemicals that become prohibited, buy “green/biodegradable” products etc.

Radon Doses

Based on several researches, international and national legislation have established limits for the doses rates for the workers in the oil and gas industry in Norway. These maximum levels do not present a health hazard to the workers. These limits are documented and only account the exposure during operations while working. Norway as other Scandinavian countries possesses geographical areas where the levels of *natural* radon exposure are 100 times higher than the recommended for the public (Norwegian Ministries 2010). So far I have found no evidence that the radon exposures “out of the job” for the workers in the oil and gas industry has been taken into consideration when determining their yearly exposures. Thus, I strongly assume that the sum of both exposures i.e. while working and out the work could exceed the yearly limits significantly and moreover could increase the possibilities to develop a form of cancer.

A side of the obvious regulatory influences such it detailed instructions of "*how to*" or "*when to*" perform certain activities, the findings presented above show that the Norwegian regulatory regime has a strong influence over the oil and gas industry and how this pressures make the companies improve their environmental practices.

7 Limitations and further research

General Limitations

Time, scope and information availability:

The information for this thesis was recollected in a four month period which limited the opportunity to gather more information. During the collection of internal data I faced obstacles related to companies privacy. In addition the internal data collected is from a small number of companies and is not representative of the whole industry.

Further research

Training and awareness

This thesis evaluates the training and awareness based on documentation and little personal experience. It would be interesting to have a concrete evaluation of the workers knowledge's regarding NORM contamination throughout conducting surveys.

Technologies for better radioactive segregation

One way to improve the waste management operations is through better segregation. Radioactive contaminated waste is reduced if the radioactive particles are segregated in a better way. Implementing innovative operations, using and finding new techniques for decontamination and segregation is possible. This is achievable if the economical resources are available and the approaches for implementing new procedures are based on risk and environmental assessments.

Reasons why companies outperform environmental obligations

As mentioned in chapter six, it would be interesting to find out why companies adopt voluntary environmental initiatives. Additionally, companies and regulatory institutions are managed by persons who have a specific attitude towards environmental practices. Regarding this, an interesting question that remains to be investigated is in which degree these initiatives are influenced by the human resources of a company.

Outsource enforcement

In Norway there is the peculiar characteristic that there is only one waste management operator for radioactive waste in each supply base. This is licensed by the Norwegian authorities. The reason why this is done like this is unknown, but based on risk assessment it makes sense because it reduces the chances for radiation exposure (less companies involved with movement of contaminated material, less personnel used, less transportation, probabilities of accident reduced etc). However, from a transaction cost and SCM perspective it would be interesting to know the implications of "compulsory outsourcing".

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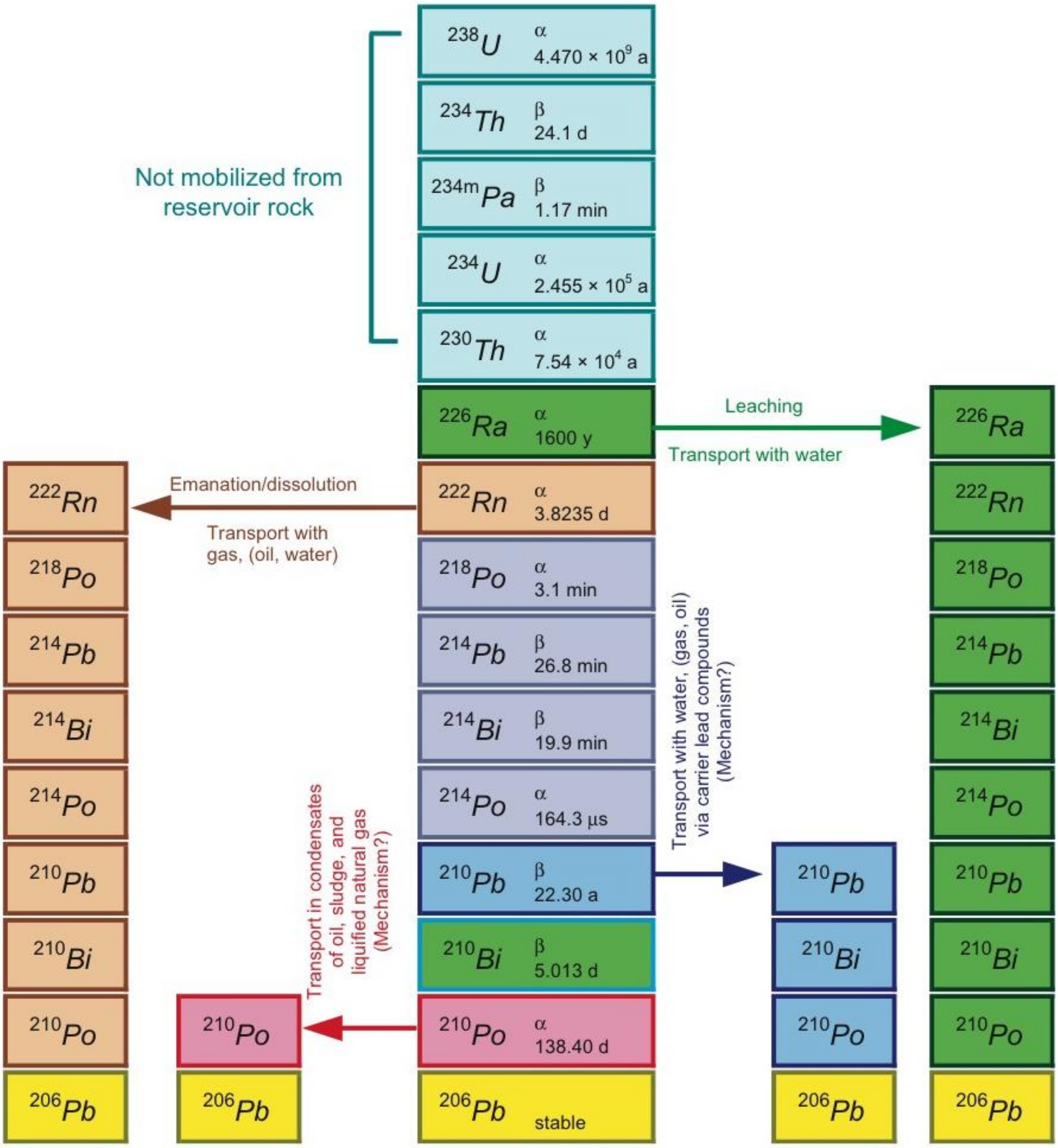
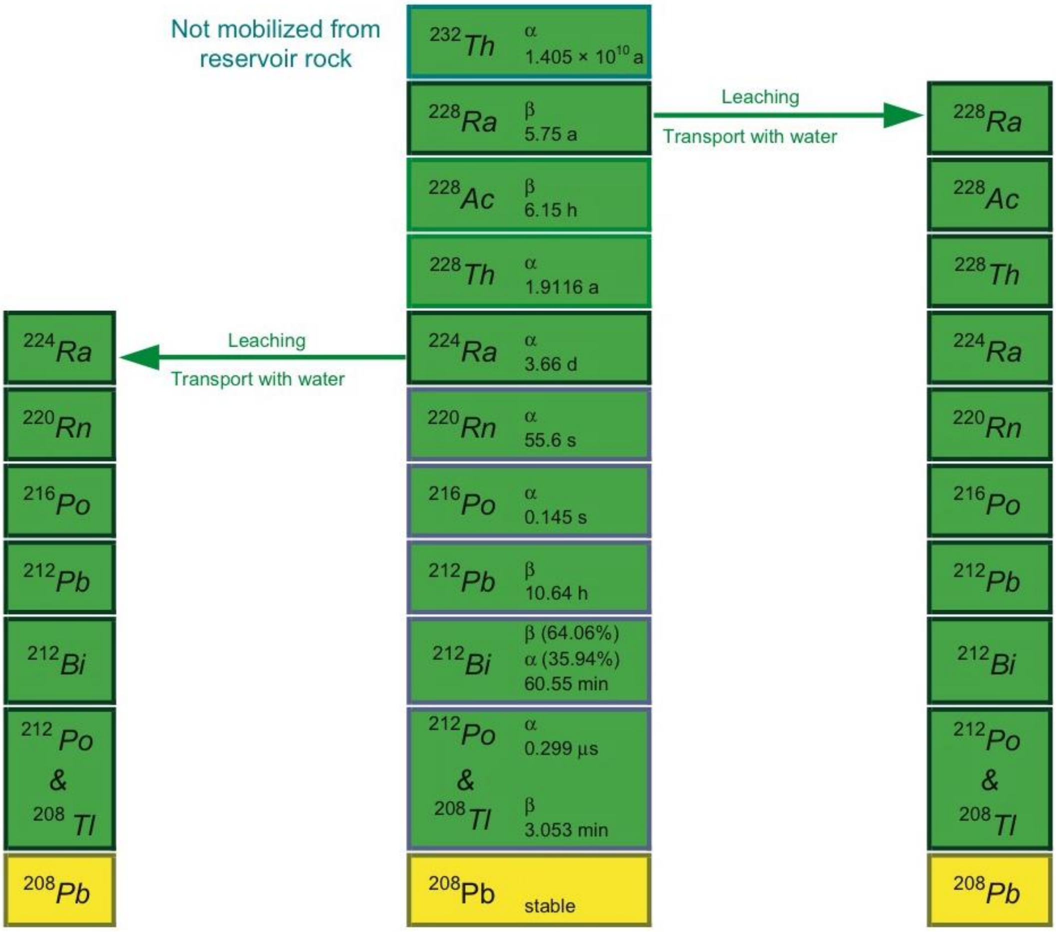
Appendix

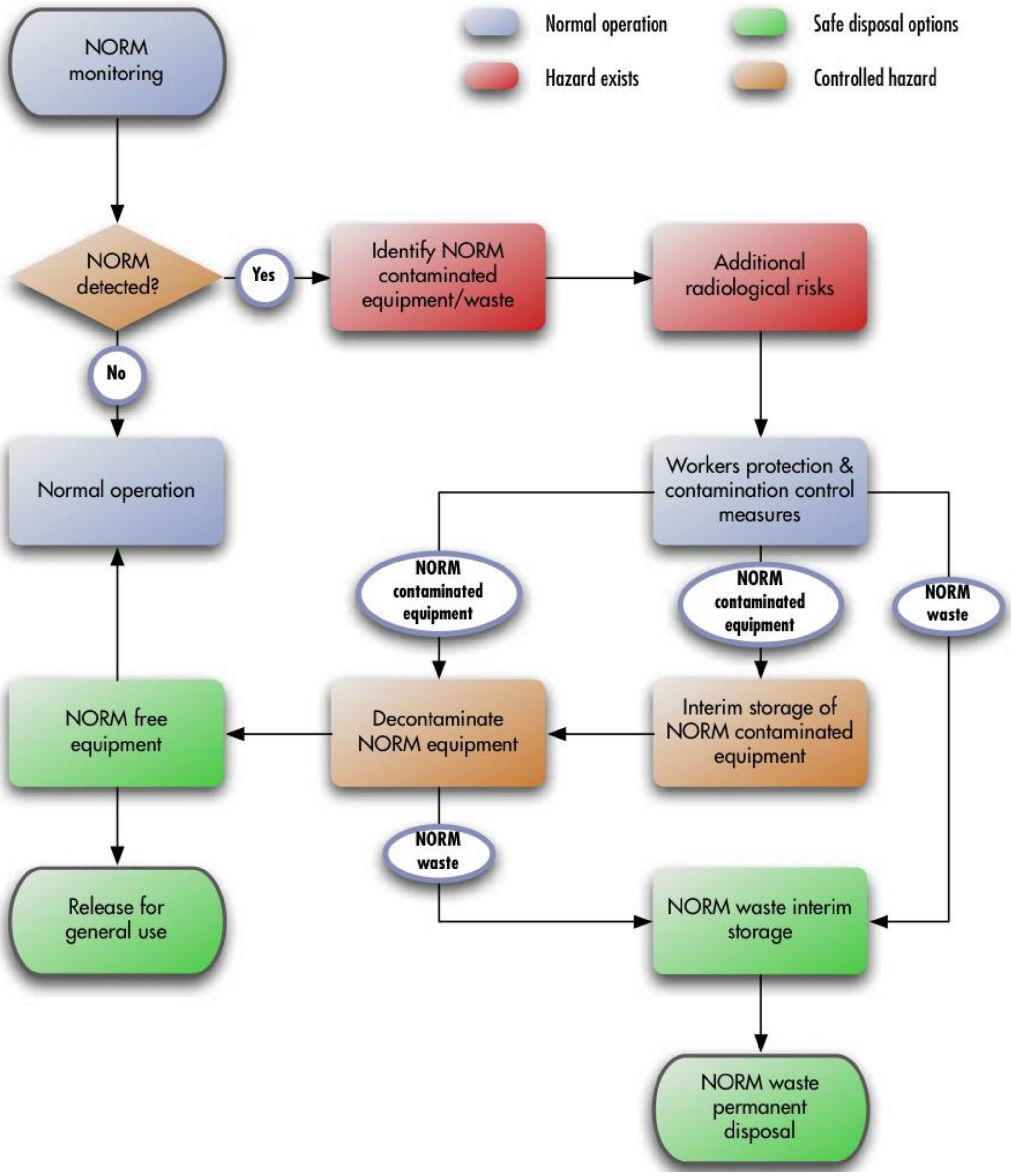
Appendix A: Uranium ^{238} *decay series (IAEA 2003)*



Appendix B: Thorium decay series (IAEA 2003)



Appendix C: Process cycle of NORM Management (OGP 2008)

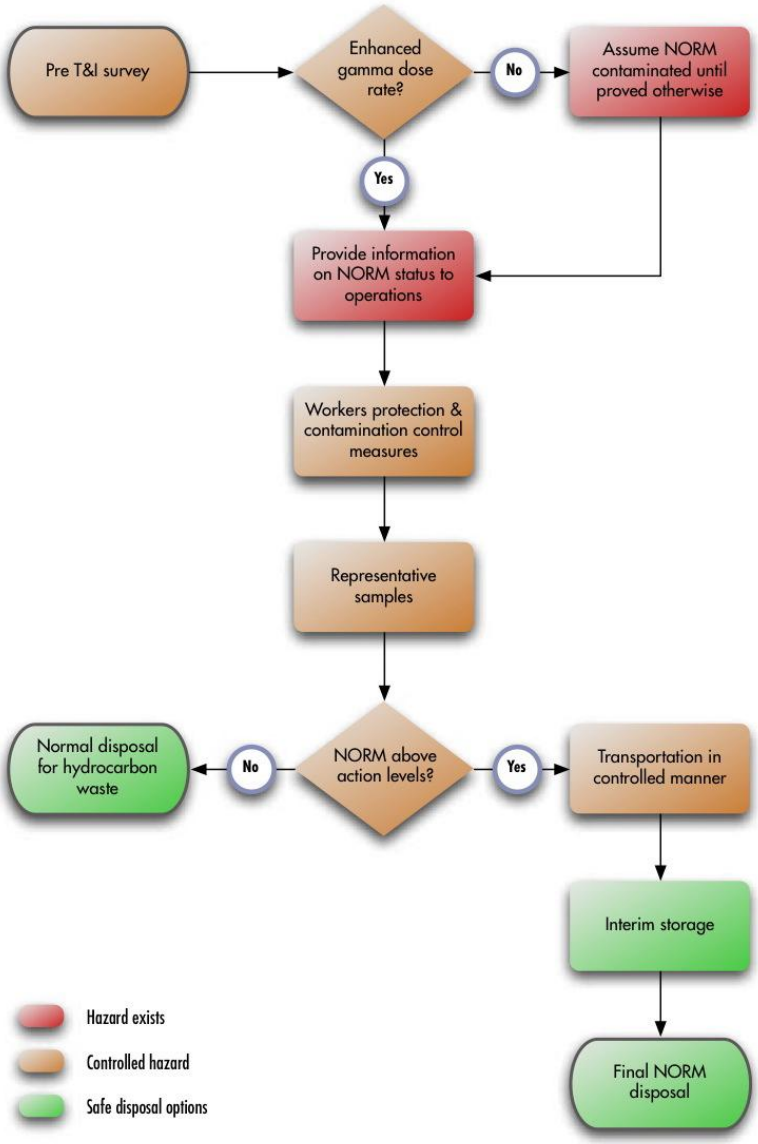


Appendix D: Container requirements for transportation of NORM waste (OGP 2008)

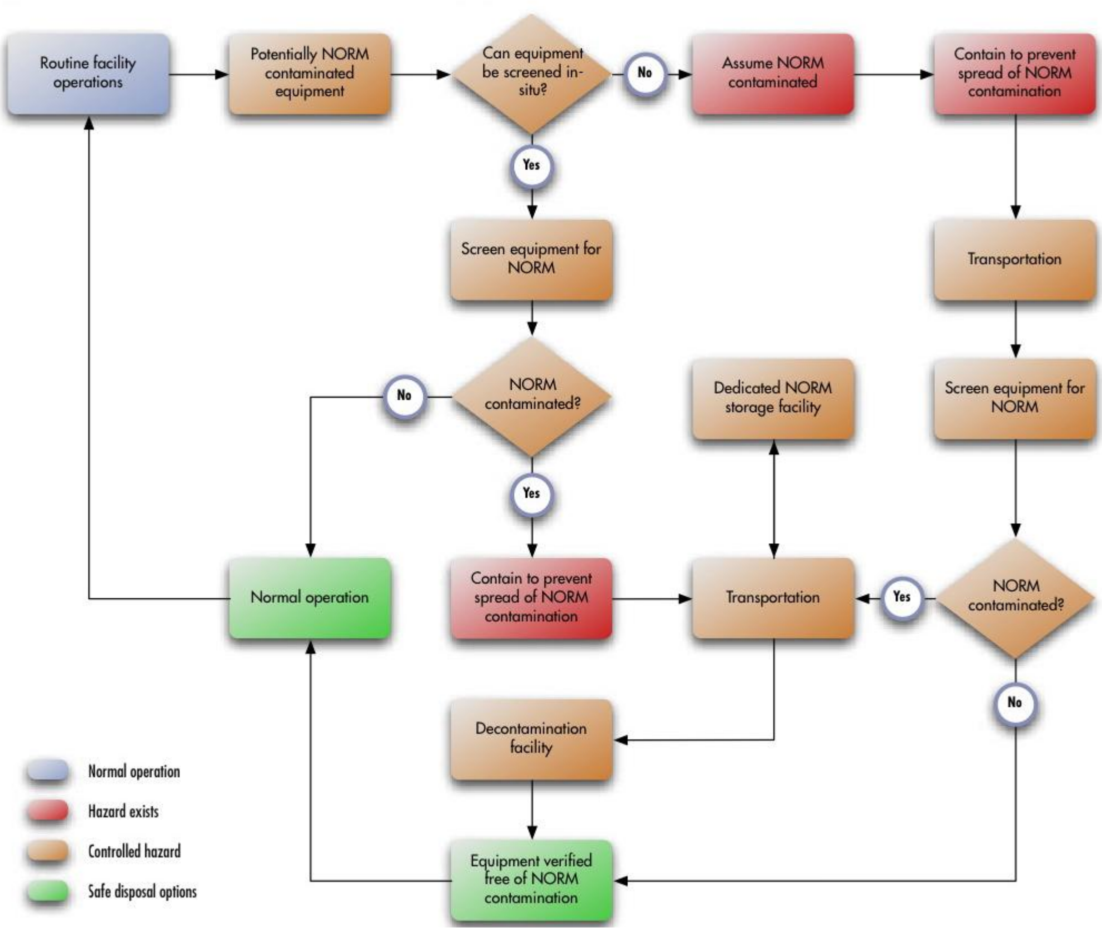
The container requirements:

- Should be in good condition with no visible indications of internal or external corrosion, and be made of a durable material such that it provides adequate containment of the NORM waste during the storage period.
- Should be made of or lined with materials that will not react with or be incompatible with the NORM waste so that the ability of the container is not impaired or compromised.
- Should be resistant to degradation by Ultra Violet radiation.
- Should be closed and sealed during storage, and practical to open and re-seal when it is necessary to add or remove waste.
- Should not be opened, handled, or stored in a manner that may rupture the container or cause it to leak.
- Should bear the radiation symbol and a label clearly indicating that it contains NORM contaminated waste.
- Should pay due regard to any other materials which may be present in the NORM waste matrix (i.e. oils, grease or chemicals etc)
- Should be resistant to normally expected range of temperature in storage environment.
- Should be resistant to water ingress.
- Should be stored in a dry environment to prevent corrosion.
- Should be physically robust to prevent damage during transport.
- The storage location should be hard surfaced and bonded to prevent contamination of ground/ surface waters and the creation of contaminated land from any potential leaks/spills as a result of incidents during storage period.
- Areas where containers of NORM waste are stored should be inspected regularly.
- Containers should be inspected for signs of leakage, overall deterioration and proper labelling. Records of these inspections should be documented and properly maintained.

Appendix E: Control of NORM waste during shutdown operations (OGP 2008)



Appendix F: Control of NORM contaminated equipment (OGP 2008)



Appendix G: Worker protection requirements

Workers entering NORM-contaminated vessels or conducting intrusive work on NORM-contaminated equipment should adhere to the following guidelines (OGP 2008):

- Personnel required to work with NORM should be trained in the associated hazards.
- All NORM operations shall be covered by a safe system of work which should identify the hazards and highlight the precautions to be taken.
- Any item or area with detectable levels of loose NORM contamination should be subject to radiological controls.
- Appropriate PPE should be worn (which may include but not be restricted to):
    - 'Tyvek' style coveralls
    - Neoprene, PVC, or NBR gloves
    - Half-face respirators with HEPA cartridges; these should be tested for fit
    - Quarter-face HEPA disposable respirators.
- Eating, drinking, smoking and chewing are not allowed in work areas where there is potential NORM contamination.
- Only essential personnel should be allowed in the work areas of potential NORM contamination.
- Personnel should wash up thoroughly with copious quantities of soap and water, after working with contaminated equipment, and before eating, drinking, or smoking, and at the end of the workday.
- Use systems of work that minimise the generation of waste PPE (i.e. use PPE that can be cleaned, inspected and re-used).

Appendix H: Petroleum delivery from the NCS in million sm^3 oil equivalents (OLF 2010)

Reporting year	Gas	Condensate	NGL	Oil
1987	28,151	0,055	4,117	56,960
1988	28,330	0,047	4,846	64,720
1989	28,738	0,053	4,898	85,980
1990	25,479	0,048	5,011	94,540
1991	25,027	0,057	4,897	108,510
1992	25,834	0,054	4,959	124,000
1993	24,804	0,554	5,518	131,840
1994	26,842	2,830	7,122	146,280
1995	27,814	3,726	7,942	156,780
1996	37,407	4,442	8,232	175,420
1997	42,950	6,401	8,074	175,910
1998	44,190	5,999	7,390	168,740
1999	48,479	6,497	6,992	168,690
2000	49,748	6,277	7,225	181,180
2001	53,895	6,561	10,924	180,880
2002	65,501	8,020	11,798	173,650
2003	73,124	11,060	12,878	165,480
2004	78,465	9,142	13,621	162,777
2005	84,901	8,422	15,735	148,137
2006	87,613	7,989	16,672	136,580
2007	89,662	3,474	16,577	128,277
2008	99,231	4,180	16,022	122,668
2009	103,464	4,421	16,048	115,443

Appendix I: Overview of drilling fluid types used in Norway 2004-2009 (OLF 2010)

TABLE 3: DRILLING WITH OIL-BASED DRILLING FLUIDS, TONNES

Reporting year	Consumption of drilling fluids	Discharge of drilling fluids - volume	Injected drilling fluids	Drilling fluids transported to land	Base fluids left in hole or lost to formation
2004	132 062	0	60 087	23 422	48 414
2005	217 852	0	64 486	44 699	52 020
2006	183 702	0	58 205	38 989	48 343
2007	182 364	0	53 301	42 660	50 837
2008	183 225	0	51 819	50 051	50 356
2009	220 394	0	45 728	71 567	54 270

TABLE 4: DRILLING WITH SYNTHETIC DRILLING FLUIDS, TONNES

Reporting year	Consumtion of drilling fluids	Discharge of drilling fluids - volume	Injected drilling fluids	Drilling fluids transported to land	Base fluids left in hole or lost to formation
2004	2 298	826	0	439	1 030
2005	5 303	0	0	4 039	1 263
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	968	0	0	630	338
2009	0	0	0	0	0

TABLE 5: DRILLING WITH WATER-BASED DRILLING FLUIDS, TONNES

Reporting year	Consumption of drilling fluids	Discharge of drilling fluids - volume	Injected drilling fluids	Drilling fluids - transported to land	Base fluids left in hole or lost to formation
2004	239 889	199 429	15 684	2 940	20 329
2005	219 126	153 352	21 879	17 082	20 804
2006	267 310	196 680	22 139	9 956	23 634
2007	265 754	199 281	27 243	9 439	16 982
2008	265 668	169 442	33 151	20 590	25 516
2009	419 440	285 662	20 320	24 717	31 417

Appendix J: Measurement of Low Specific Activity Scale (LSA) (BP 2011)

Application area

- Measurement of LSA radiation is used for the measurement of:
  - components with LSA
  - loose materials
  - lead deposits
- The measurements can be carried out directly on the component or on a sample taken from the component

Calibration of instruments

1. Use the standards where the ratio between the nuclides ^{226}Ra and ^{228}Ra is 3:1. These containers are labelled with yellow labels on the lids.

2. Measure the background counting rate on site over a period of a few seconds. If the background is significant (> 5 CPS), then the measured counting rate must be adjusted accordingly.

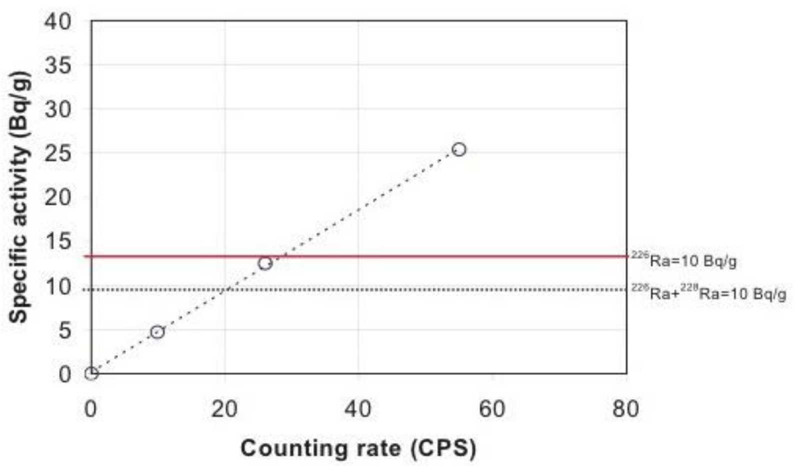
3. The lid is screwed off the container before calibration. Specific activity of ^{226}Ra + specific activity of ^{228}Ra in units of Bq/g are indicated on the label on the bottom of the container. Note this.

4. Place the probe in direct contact with the surface of the deposit and start measuring. It is recommended to measure the average counting rate over a period of few seconds.

5. Repeat this procedure for the two other standards in this series.

The result can be illustrated graphically by displaying the specific activity in Bq/g as a function of the counting rate in CPS, as illustrated in the example below. A straight line is drawn in the best possible way through the three measurement points. A horizontal line is then drawn in on the graph denoting the LLW limit for classification as free, which will correspond to 10 Bq/g, since we measure the specific activity of the sum of the two radium isotopes and the ratio between them is 3:1.

Counting rate - specific activity



Measurement directly on the component

1. Before taking a measurement. Turn the instrument on first and check the battery voltage.

2. Then check the counting rate against a known radiation source. One of the standards in the LLW standard set is suitable for this purpose.

3. To prevent the measuring probe from getting dirty, it is advisable to cover it with thin cling film. If cling film are used, you shall also use cling film when calibrating.

4. Measure the background counting rate on site. If it is low (< 5 CPS) you can ignore it.

5. The measurement is performed by holding the measuring probe in close proximity to the internal surface of the component. Measurements should be taken at a number of different points on the component. The measurement points should be chosen based on where it is most likely deposits will be found.

6. The measurement result in CPS shall be entered in the measurement report.

7. Specific activity in Bq/g can be determined based on the instrument's calibration curve. The value shall be entered in the measurement report.

Measurement of deposit or loose material samples

1. Extract a suitable amount of material (100-200g) from the component and place it in a container similar to the calibration containers.

2. Take the container to a site where there is no explosion risk and there are no other radiation sources nearby.

3. A functional check of the instrument shall be performed before taking a measurement. Turn the instrument on first and check the battery voltage.

4. Then check the counting rate against a known radiation source. One or the standards in the LLW standard set is suitable for this purpose.

5. To prevent the measuring probe from getting dirty, it is advisable to cover it with thin cling film.

6. Measure the background counting rate on site. If it is low (< 5 CPS you can ignore it.

7. The measurement is performed by holding the measuring probe in close proximity to the sample. Find the average reading. The measurement result in CPS shall be entered in the measuremen report.

8. Specific activity in Bq/g can be determined based on the instrument's calibration curve. The value shall be entered in the measurement report.

MEASUREMENT OF γ-(GAMMA) RADIATION

Area of application

- The metering of γ-radiation on the exterior of pipes or components is used when measurement directly on coating or scale (see Appendix 5) is not possible, or when, for some reason, the presence of low level radioactive scale (LRA) is to be determined. One possible area of application could be metering on the exterior of the separator tank for determination of deposits of LRA in the produced sand

- The metering is to be conducted with g–sensitive instruments, for example a dose meter. The unit displayed by the instrument is not important: the concluding result will be obtained

Method limitations

- The method is qualitative, meaning that it only determines if LRA is present or not
- The method has a high determination limit, meaning that it will give a positive result only when large quantities of LRA are present
- The method can not be used to demonstrate potential deposits of radioactive lead (^{210}Pb)
- The method is sensitive to other possible nearby deposits of LRA

Metering procedures

1. Clean the instrument before metering, to ensure that the instrument is not contaminated from earlier measurements.

2. Test battery function.

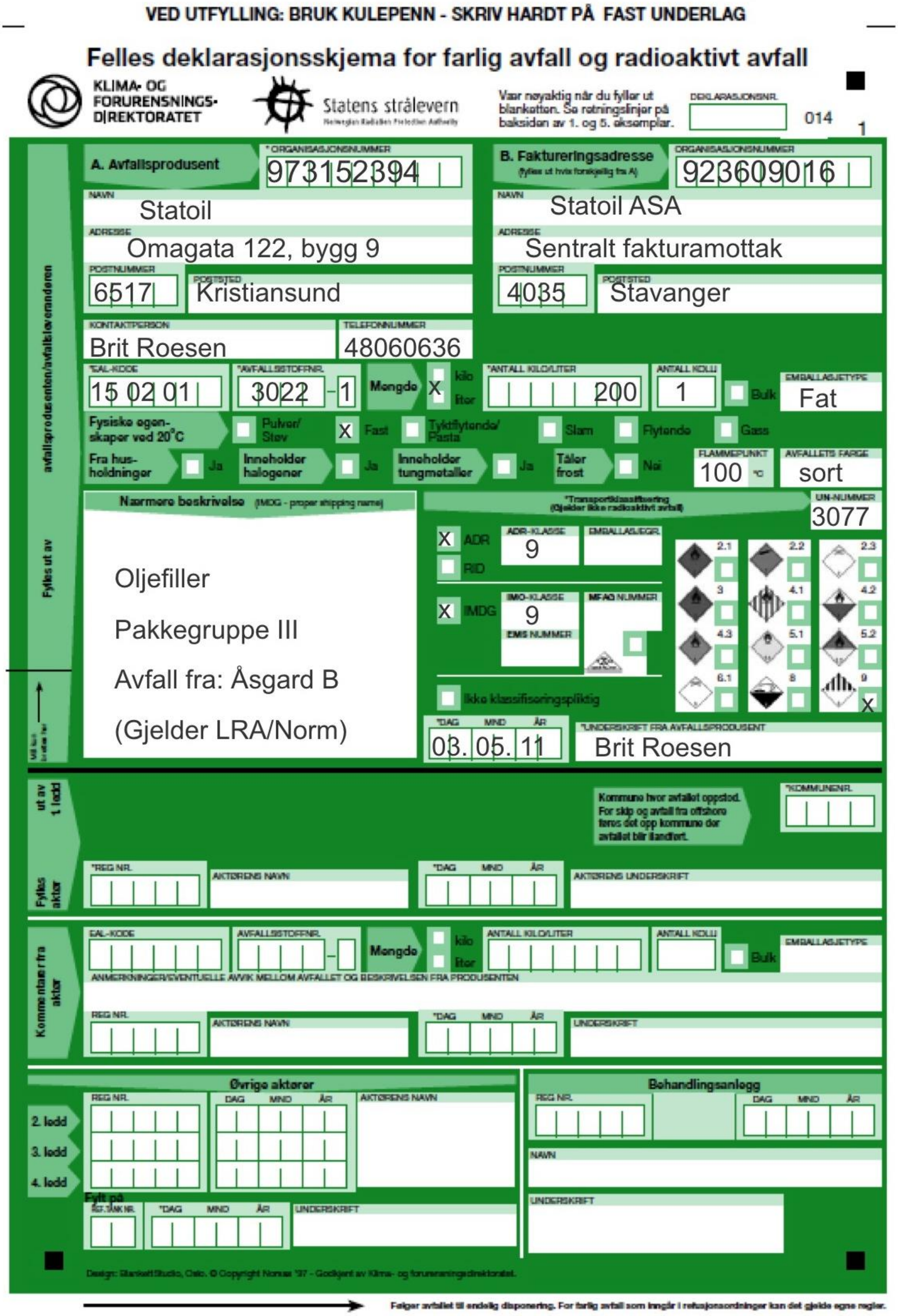
3. Survey the background spectrum by metering the area surrounding the pipe/component to be metered. This is done to find possible other deposits of LRA that could affect the measurement.

4. Measure the background spectrum about 30 cm from where the metering is to take place towards the area where the background spectrum (see point 3) is the strongest. Record the result as ***Background***.

5. With the instrument in contact with the surface of the pipe or component, commence metering. Record the result as ***Measurement***.

6. If ***Measurement*** is considered to be definitely larger than Background, the presence of LRA is proven. *(Comment: it is practically impossible to define more specific criteria than the above. The correct use of the method depends on the users experience and good judgment.)*

Appendix K: New declaration form for NORM waste in Norway (Statoil 2011)



VED UTFYLLING: BRUK KULEPENN - SKRIV HARDT PÅ FAST UNDERLAG

Felles deklarasjonsskjema for farlig avfall og radioaktivt avfall

KLIMA- OG FORURENSNINGS- DIREKTORATET

Statens strålevern

Vær nøyaktig når du fyller ut blanketten. Se retningslinjer på baksiden av 1. og 5. eksemplar.

DEKLARASJONSNR. 014 1

A. Avfallsprodusent — ORGANISASJONSNUMMER: 973152394

NAVN: Statoil

ADRESSE: Omagata 122, bygg 9

POSTNUMMER: 6517 POSTSTED: Kristiansund

KONTAKTPERSON: Brit Roesen TELEFONNUMMER: 48060636

B. Faktureringsadresse (fylles ut hvis forskjellig fra A) — ORGANISASJONSNUMMER: 923609016

NAVN: Statoil ASA

ADRESSE: Sentralt fakturamottak

POSTNUMMER: 4035 POSTSTED: Stavanger

EAL-KODE: 15 02 01 AVFALLSSTOFFNR.: 3022 - 1 Mengde: X kilo / liter ANTALL KILO/LITER: 200 ANTALL KOLLI: 1 Bulk EMBALLASJETYPE: Fat

Fysiske egenskaper ved 20°C: Pulver/Støv; X Fast; Tyktflytende/Pasta; Slam; Flytende; Gass

Fra husholdninger: Ja; Inneholder halogener: Ja; Inneholder tungmetaller: Ja; Tåler frost: Nei; FLAMMEPUNKT: 100 °C; AVFALLETS FARGE: sort

Nærmere beskrivelse (IMDG - proper shipping name):

Oljefiller

Pakkegruppe III

Avfall fra: Åsgard B

(Gjelder LRA/Norm)

Transportklassifisering (Gjelder ikke radioaktivt avfall) — UN-NUMMER: 3077

X ADR — ADR-KLASSE: 9 — EMBALLASJEGR.

RID

X IMDG — IMO-KLASSE: 9 — MFAG NUMMER — EMS NUMMER

2.1 2.2 2.3 3 4.1 4.2 4.3 5.1 5.2 6.1 8 9 X

Ikke klassifiseringspliktig

DAG MND ÅR: 03. 05. 11 — UNDERSKRIFT FRA AVFALLSPRODUSENT: Brit Roesen

Fylles ut av avfallsprodusenten/avfallsleverandøren

Fylles ut av 1. ledd — Kommune hvor avfallet oppstod. For skip og avfall fra offshore føres det opp kommune der avfallet blir ilandført. KOMMUNENR.

Fylles ut av aktør — REG NR. — AKTØRENS NAVN — DAG MND ÅR — AKTØRENS UNDERSKRIFT

Kommentarer fra aktør — EAL-KODE — AVFALLSSTOFFNR. — Mengde kilo / liter — ANTALL KILO/LITER — ANTALL KOLLI — Bulk — EMBALLASJETYPE

ANMERKNINGER/EVENTUELLE AVVIK MELLOM AVFALLET OG BESKRIVELSEN FRA PRODUSENTEN

REG NR. — AKTØRENS NAVN — DAG MND ÅR — UNDERSKRIFT

Øvrige aktører — REG NR. — DAG MND ÅR — AKTØRENS NAVN — 2. ledd — 3. ledd — 4. ledd

Fylt på — REF. TANK NR. — DAG MND ÅR — UNDERSKRIFT

Behandlingsanlegg — REG NR. — DAG MND ÅR — NAVN — UNDERSKRIFT

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Følger avfallet til endelig disponering. For farlig avfall som inngår i refusjonsordninger kan det gjelde egne regler.

Glossary

The glossary contain technical information and definitions extracted from the articles cited ; (OGP 2008;IAEA 2003)

Alpha radiation: Radioactive decay by the emission of a high-energy charged particle consisting of 2 protons and 2 neutrons (nucleus of helium atom)

Beta radiation: Radioactive decay by emission of a negatively charged particle from the nucleus of an unstable atom (a beta particle has the same mass and charge as an electron)

Carbonate: A compound containing the acid radical of the carbonic acid (CO3 group). Bases react with carbonic acid to form carbonates, e.g. CaCO3 calcium carbonate.

Controlled area: A defined area in which specific protection measures and safety provisions are or could be required for controlling normal exposures or for preventing the spread of contamination during normal working conditions, and preventing or limiting the extent of potential exposures.

Decay series: A succession of radionuclides each of which is transformed by radioactive decay into the next member until a stable nuclide is reached. The first member is known as the parent and the subsequent nuclides are the progeny or daughters.

Exposure: The act or condition of being subject to irradiation.

Gamma radiation: High energy, penetrating electromagnetic radiation (photons) emitted by unstable nuclei.

Half-life: For a radionuclide, the time required for the activity to decrease, by a radioactive decay process, by half.

NORM: Naturally Occurring Radioactive Material, relating to the material which is enhanced by technological intervention to concentrations above those usually found in nature. It is sometimes referred to as TENORM (Technologically Enhanced Naturally Occurring Radioactive Material).

Silicates: The largest group of minerals, of widely different and in some cases, extremely complex composition, but all composed of silicon, oxygen, and one or more metals, with or without hydrogen.

Sulphates: Salts of sulphuric acid produced when the acid acts on certain metals, metallic oxides, hydroxides and carbonates. The acid is dibasic forming two salts; sulphates and bisulphate.

Well: A hole drilled in rock from the surface to the reservoir in order to explore for, or extract, oil or gas.

Radiation units

Becquerel (Bq): The SI unit of radioactivity. One Bq is equal to one nuclear disintegration per second. Bq is used as a measure of surface contamination, Bq cm-2; as a measure of air activity concentration, Bq m-3; and as a specific activity per unit mass, Bq g-1 or Bq kg-1.

Curie (Ci): The old unit of radioactivity, has been replaced by the Becquerel (Bq). One Ci is equal to 3.7×1010Bq. One Bq is equal to 27 pCi.

REM (r): The old unit of radiation dose equivalent. 100 r is equal to 1 Sv.

Sievert (Sv): The SI unit of radiation dose equivalent. Occupational radiation dose limits are specified in units of milliSievert (i.e. the whole body radiation dose limit for a radiation worker is 20mSv). In NORM measurements, it is usual to measure in the microSievert or nanoSievert range. All measurements of radiation dose-rate are provided as a rate per hour, e.g. 10 microSieverts per hour (10µSv/hr)

Gray (Gy): SI unit for the absorbed (energy) dose. One Gray equals 1 J/kg.

Rad: The old unit of radiation dose absorbed (rad). The SI unit is the Gray (Gy), which is equal to 0.01 rad.

Unit conversions

Activity

Curie (Ci)	Becquerel (Bq)
27 pCi	1 Bq
1 nCi	37 Bq
27 nCi	1 kBq
1 μCi	37 kBq
27 μCi	1 MBq
1 mCi	37 MBq
27 mCi	1 GBq
1 Ci	37 GBq
27 Ci	1 TBq
1 kCi	37 TBq

Equivalent dose

Rem (r)	Sievert
100 μr	1 μSv
1 mr	10 μSv
10 mr	100 μSv
100 mr	1 mSv
1 r	10 mSv
5 r	50 mSv
100 r	1 Sv

Unit prefixes

Fractions			Multiples		
10^{-3}	milli	m	10^{3}	kilo	k
10^{-6}	micro	μ	10^{6}	Mega	M
10^{-9}	nano	n	10^{9}	Giga	G
10^{-12}	pico	p	10^{12}	Tera	T
10^{-15}	femto	f	10^{15}	Peta	P
10^{-18}	atto	a	10^{18}	Exa	E