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Occupational Protection against Exposure to Radioactive Sources and Electromagnetic Fields in the Offshore Petroleum Industry

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Safety, Health and Environment
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Master´s thesis

NTNU
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Faculty of Social Science and Technology Management
Department of Industrial Economy and Technology Management

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NTNU
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MASTERKONTRAKT
- uttak av masteroppgave

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Purpose:
The objective of this thesis is to map the radioactive sources and electromagnetic fields on offshore installations on the Norwegian continental shelf, as well as how they are transported, handled, applied and stored, their potential health effects and appropriate physical and organisational barriers against exposure.

Main contents:
1. Literature research on radioactive sources and electromagnetic fields on offshore installations, their health effects and potential barriers against exposure to radiation sources.

2. Data collection through expert interviews to identify radioactive sources and electromagnetic fields on offshore installations on the Norwegian continental shelf; existing barriers and practical experiences related to the protection of workers against exposure.

3. A discussion of the results in order to identify the most important radioactive sources and electromagnetic fields, as well as efficient physical and organizational barriers against radiation exposure.

4. Propose further work and studies.

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4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

Trondheim, 6.05.2014
Sted og dato

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Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

Occupational Protection against Exposure to Radioactive Sources and Electromagnetic Fields in the Offshore Petroleum Industry

PREFACE

This report is the product of my Master Thesis, written during the final semester of the Master's Degree Programme in Health, Safety and Environment, at the Department of Industrial Economics and Technology Management, at NTNU.

First of all I want to thank my supervisor Rikke Bramming Jørgensen at the Norwegian University of Science and Technology for valuable guidance and motivation throughout the entire work process.

I owe special gratitude to all the informants who gave me the information needed to make this project possible.

I would also like to thank to Siri Andersen and Petter Trædal in DNV GL for the interesting discussions we had during this spring and for initiating the Master Thesis.

Due to the increasingly numerous applications of radiation sources within the offshore petroleum industry, there is an ongoing need for best available information about radiation protection, in order to maintain a minimal level of harm. This thesis has been an excellent opportunity for me to gain professional experience and at the same time try to provide an overview of: the radiation sources found on petroleum installations on the Norwegian Continental Shelf, their hazards, and of radiation protection concepts and efficient barriers against overexposure. I hope the readers will find the thesis interesting and specialists will feel encouraged to continue the work, and possibly develop an online interactive database, of radiation sources used in the petroleum industry, and for exchange of experiences.

Stud. Maria Flavia Mogos

Trondheim, 10 June 2014

SUMMARY

The objective of the Master Thesis has been to provide an overview of the radioactive sources and Electromagnetic fields (EMF), existing on offshore petroleum installations from the Norwegian continental shelf (NCS). It has also been of interest to describe how offshore workers handle these radiation sources, which are the associated health hazards and which are the most efficient protection measures against exposure.

The report contains a literature research of the most recent national and international publications relevant for the topic; a collection of interesting data from the literature study, from the interviews of various experts within Health, Safety and Environment, and from a workshop where the participants have shared their personal experiences with radiation protection offshore. Moreover, the literature research also provides an overview of important radiation concepts, of measuring units used in the assessment of exposure, of statutory requirements and means of identifying and prioritising protection measures.

The thesis is accompanied by two digital databases that have been created in conjunction with the data collection realised. One of the databases provides the mapping of radioactive sources used in the offshore petroleum industry, while the other one includes a similar mapping for the EMF. Both of the databases contain significant information from the literature study and from the workshop attended about: the properties of almost 40 mapped radiation sources, efficient protection measures and interesting practical experiences. Moreover, the databases have been sent to experts for quality assurance and new inputs.

Furthermore, the results from the data collection have been thoroughly discussed in order to highlight the most critical radiation sources on the NCS and efficient barriers against exposure.

The results show that among the most hazardous radioactive sources on the NCS there are: industrial radiography, well logging by use of neutron and gamma radiation, installed gauges, ‘intelligent pigs’, radiotracers, as well as the natural occurring radioactive material (NORM) formed in gas and oil equipment.

EMF are divided into: Static magnetic fields (SMF), Extremely low frequency electric and magnetic fields (ELF) and Radiofrequency electromagnetic fields (RF). Among the most important sources of ELF, there are: generators, low and high voltage transformers, low-voltage switch gear room, the drive space, as well as power supply cables to or from the shore. RF sources highlighted in the studied literature and by experts are: the X-band and S-band maritime radars and the Radio Link communication antennas, while strong SMF are generated by powerful electric motors.

Protection measures against exposure to radioactive sources are based on restricting as much as possible the total dose people receive throughout their lives and thus, the likelihood of developing cancer and genetic damages. Most of the barriers are related to radiation protection principles like: maximising the distance from the radiation source (radiation doses decrease rapidly with the square of the distance), minimising the exposure time and shielding the source. Moreover it is particularly important to avoid inhaling or ingesting radioactive material, such as NORM dust.

Barriers against exposure to ELF are mainly based on avoiding acute biological effects, such as the excitation of muscle and nerve cells, with possible but nevertheless, uncertain impact on e.g. the development of Alzheimer's. Protection measures are also aimed at avoiding health effects such as the increased risk for leukaemia caused by long term exposures to high magnetic fields. A possible long term biological effect of strong SMF, is their impact on the expression of certain genes, primarily in mammalian cells. Most of the barriers against exposure to ELF and SMF are based on the radiation protection principles of maximising the distance from the source and minimising the exposure time, since the level of exposure to EMF decrease also with the square of the distance. Strong magnetic fields are normally difficult to shield.

Protection measures against exposure to RF are related to biological effects such as tissue damages after a temperature increase in the body of 1-2 °C, caused by extremely high exposure levels. There are several hypotheses about the RF's exact short term and long term health effects but none of them is well established. Thus, most of the barriers are based on a precautionary strategy, and they are primarily related to the principle of minimising the exposure time to avoid tissue heating, maximising the distance from the source, and to design solutions such as directing the transmission of antennas away from manned areas.

Radiation protection is a wide subject, thus, there are many possible recommendations one could give with respect to efficient protective measures. One strategy that applies for both radioactive sources and for EMF is: to use radiation sources only if they are justified and to restrict the exposure levels as much as reasonably achievable. Apart from keeping in mind these three factors: distance, time and shielding against the radiation source, one should always make sure that workers have adequate training and that there is maintained a good level of communication, experience exchange and risk awareness within the organisation and across the industry. Moreover, priority should be given to design and organisational barriers at the source and the use of personal protective equipment must be always considered as a last resort.

SAMMENDRAG

Formålet med masteroppgaven har vært å gi en oversikt over eksisterende radioaktive kilder og Elektromagnetiske felt (EMF) ved oljeinstallasjoner på den norske kontinentalsokkelen (NKS). Det har også vært av interesse å beskrive hvordan offshorearbeidere håndterer disse strålekilder, hvilke helsefarer som er forbundet med kildene, og hvilke vernetiltak mot eksponering som er mest effektive.

Rapporten inneholder en litteraturstudie av de nyeste nasjonale og internasjonale publikasjoner som er relevante for temaet; en samling av interessante data fra litteraturstudiet, fra intervjuer med ulike eksperter innen helse, miljø og sikkerhet, samt fra en workshop hvor deltakerne har delt sine personlige erfaringer med strålevern offshore. Dessuten gir litteraturgjennomgangen også en oversikt over: viktige strålebegreper, måleenheter som brukes i vurdering av eksponeringsnivå, lovkrav, og metoder for identifisering og prioritering av vernetiltak.

Vedlagt avhandlingen er to digitale databaser, som er opprettet i forbindelse med datainnsamlingen. En av databasene inkluderer en kartlegging av radioaktive kilder som brukes i petroleumsindustrien, mens den andre inneholder en tilsvarende kartlegging for EMF. Begge databasene inneholder vesentlig informasjon fra litteraturstudiet og fra workshop om strålevern offshore om: egenskapene til nesten 40 kartlagte strålekilder, effektive vernetiltak og praktiske erfaringer. Databasene har blitt sendt til eksperter for kvalitetssikring og innspill.

Videre har resultatene fra datainnsamlingen vært grundig drøftet for å fremheve de mest kritiske strålekilder på norsk sokkel og effektive barrierer mot eksponering. Resultatene viser at blant de mest farlige radioaktive kilder på NKS er: industriell radiografi, brønnlogging ved bruk av nøytron- og gammastråling, industrielle kontrollkilder, 'intelligent pigs', sporstoffer, samt lav radioaktive avleiringer (LRA) dannet i gass- og oljeutstyr.

EMF er delt inn i: Statiske magnetfelt (SMF), Ekstremt lavfrekvente elektriske og magnetiske felt (ELF) og Radiofrekvente elektromagnetiske felt (RF). Noen av de viktigste ELF kilder er: generatorer, lav- og høyspente traforom, lavspente tavlerom, frekvens omformer rom, samt strømkabler inn og ut fra plattformer. RF- kilder fremhevet i litteraturstudien og av ekspertene er X-band og S-band marine radarer og link- samband antenner, mens sterke SMF genereres av kraftige elektromotorer.

Vernetiltakene mot eksponering for radioaktive kilder er basert på å begrense så mye som mulig livstidsdosen mennesker mottar i løpet av livet og dermed sannsynligheten for å utvikle kreft og genetiske skader. Mesteparten av barrierene er relatert til strålevernsprinsipper som: å øke mest mulig avstanden fra strålingskilden (stråledoser

reduseres raskt med kvadratet av avstanden), å redusere mest mulig eksponeringstiden og å skjerme mot stråling fra kilden. Videre er det spesielt viktig å unngå innånding eller inntak av radioaktivt materiale, slik som LRA støv.

Barrierer mot eksponering for ELF er hovedsakelig basert på å unngå akutte biologiske virkninger, slik som eksitasjon av muskel- og nerveceller, med mulig men likevel usikker effekt på f. eks. utviklingen av Alzheimers. Vernetiltak er også rettet mot å unngå helseplager, som økt risiko for leukemi forårsaket av langsiktig eksponering for høye magnetiske felt. En mulig langvarig biologisk effekt av sterke SMF, er deres effekt på ekspresjonen av visse gener, særlig i pattedyrceller. De fleste av barrierene mot eksponering for ELF og SMF bygger på strålevernprinsippene om å maksimere avstanden fra kilden og å redusere mest mulig eksponeringstiden, ettersom eksponeringsnivåene for EMF reduseres også meget raskt med kvadratet av avstanden. Sterke magnetiske felt er normalt vanskelige å skjerme.

Vernetiltak mot eksponering for RF er knyttet til biologiske effekter, som vev skader etter en temperaturøkning i kroppen på 1-2° C, forårsaket av ekstremt høye eksponeringsnivåer. Det finns flere hypoteser om eksakte kortsiktige og langsiktige helseeffekter av RF, men ingen av dem er godt etablert. Dermed er de fleste barrierene basert på et føre-var-strategi, og de er i hovedsak knyttet til prinsippene: om å redusere mest mulig eksponeringstiden for å unngå vev oppvarming, om å øke mest mulig avstanden fra kilden og om å skjerme stråling fra antenner i den retning hvor det kan være personell.

Strålevern er et bredt fagfelt, og dermed er det mange mulige anbefalinger som man kunne gi med hensyn til effektive vernetiltak. En strategi som gjelder for både radioaktive kilder og EMF er: strålekildene skal brukes bare hvis dette er berettiget og eksponeringsnivåene skal begrenses så mye som praktisk mulig. Bortsett fra å alltid huske disse tre faktorene: avstand, tid og skjerming mot strålekilden, bør man sørge for at arbeidstakerne har tilstrekkelig opplæring og at det er opprettholdt et godt nivå av kommunikasjon, erfaringsoverføring og risikobevissthet, både innen organisasjonen og på tvers av industrien.

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LIST OF ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
BAT	Best Available Technology
ELF	Extremely Low Frequency Electric and Magnetic Fields
EMF	Electromagnetic Fields
HEPA	High Efficiency Particulate Air
IAEA	The International Atomic Energy Agency
ICNIRP	International Commission on Non-ionizing Radiation Protection
ICRP	International Commission on Radiation Protection
NCS	Norwegian Continental Shelf
NDT	Non Destructive Testing
NEK	Norwegian Electrotechnical Committee
NIEHS	National Institute of Environmental Health Sciences
NORM	Naturally Occurring Radioactive Material
NRPA	The Norwegian Radiation Protection Authority
OLF	The Norwegian Oil Industry Association
OGP	The International Association of Oil and Gas Producers
PPE	Personal Protective Equipment
RF	Radio Frequency Fields
RPE	Respiratory Protective Equipment
SCENIHR	The Scientific Committee on Emerging and Newly Identified Health Risks
SJA	Safe Job Analysis
SMF	Static Magnetic Fields
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

1. INTRODUCTION

1.1. Background

Oil and gas industry makes extensive use of sealed and unsealed radioactive sources that are potentially hazardous to human health if not handled properly. In addition, petroleum workers may be exposed to electromagnetic fields (EMF) from increasingly numerous high-voltage, communication and navigation technologies. Safe management of radiation sources is particularly important on remote and demanding locations such as the offshore installations from the Norwegian continental shelf (NCS). Furthermore, especially on older installations, there may be accumulated considerable amounts of naturally occurring radioactive materials (NORM), originating from the reservoir rocks. Thus, safe working routines are required.

The existence of these potential hazards results in the need to gain more knowledge about the applications of ionising radiation and EMF, as well as about appropriate protection measures, in order to control and mitigate workers' exposure. A common understanding of the radiation hazards and protection principles within the petroleum industry would lead to efficient and increasingly safer operations. This is the background for the Master Thesis proposal, which DNV GL, a global HSE consultancy provider, has made. Moreover, upon assessing the work environment on offshore installations from the NCS, DNV GL must relate to requirements from the standard NORSOK S-002 that also demands maintaining a good control over hazardous radiation sources, with the aim of ensuring workers' health and wellbeing.

1.2. Objective

The objective of this thesis is to map the radioactive sources and EMF on offshore installations on the NCS, as well as how they are transported, handled, applied and stored, their potential health effects and appropriate physical and organisational barriers against exposure.

1.2. Main topics and tasks

1. Literature research on radioactive sources and electromagnetic fields on offshore installations, their health effects and on potential barriers against exposure to radiation sources
2. Data collection through expert interviews to identify radioactive sources and EMF on offshore installations on the NCS; existing barriers and practical experiences related to the protection of workers against exposure
3. A discussion of the results in order to identify the most important radioactive sources and EMF and efficient physical and organizational barriers against radiation exposure
4. Propose further work and studies

1.3. Scope Limitation

NORSOK S-002 from 2004 is the starting point for this thesis and sets the boundaries for its objectives. Thus, the focus lies on gaining an overview of: the sources of ionising radiation and of powerful EMF existing on offshore installations from the NCS, their applications, radiation levels, exposure limits, and suitable protection measures introduced by NORSOK S-002, and detailed in the national and international regulations this standard refers to. The mapping of EMF sources regards: static magnetic fields (SMF), extremely low frequency electric and magnetic fields (ELF) from high voltage equipment, and sources of radiofrequency fields (RF). This classification is based on NORSOK S-002, the Norwegian Radiation Protection Regulations, and the applicable Guidelines on limited exposure to NON-Ionizing Radiation from the International Commission on Non-ionizing Radiation Protection (ICNIRP).

Furthermore, information about transport, handling and storage of radiation sources is exclusively related to the work environment conditions within offshore installations from NCS, but it regards both employees and service suppliers performing work activities on the platforms. Moreover, for the purpose of this thesis the generic concept of 'occupational protection against exposure' used in the title refers to all of the workers present on the installation.

The measurement of radiation doses is out of this thesis' purpose, thus less attention is given to issues related to dosimetry.

During the literature research process, it has been found practical to create two databases comprising relevant mapping information from the studied publications. These databases are a new input to the initial assignment. However, the Master thesis has been written during a limited interval of time, of five months, thus, these databases need to be further developed. More detailed recommendations about this issue are given in Ch. 13.

1.4. Method

Data collection for the thesis has been realised through: personal and telephone interviewing of experts, electronic correspondence with specialists, and by attending to a one day workshop about radiation protection on Norwegian offshore installations. There have been interviewed nine experts representing: two field operators, one corporate health service company, one employee trade union, and several consulting firms (Table 1). In addition, relevant data was collected by carefully noting down two of the participants observations at the attended workshop (two offshore workers).

No.	Occupation	Type of company
1	Radiation Coordinator	Oil and gas field operator 1
2	Work Environment Specialist	Oil and gas field operator 1
3	Security Officer on an offshore platform	Oil and gas field operator 1

4	Operations and Maintenance Manager on an offshore platform	Oil and gas field operator 2
5	Senior Engineer HSEQ	Consultancy company
6	Occupational Hygienist	Consultancy company
7	HSE consultant	Consultancy company
8	Certified Occupational Hygienist	Corporate Health Service Company
9	Certified Occupational Hygienist	Employee Trade Union

Table 1: Overview of the occupations and the type of companies the informants represent

Because of limited access to expertise and publications about the topic, there has been decided to anonymise the collected data, in order to encourage the informants to share as much useful information as possible.

The interview technique has been that of a semi-structured interview based on an interview guide comprising three main research topics: current radioactive sources and EMF on Norwegian installations, efficient barriers against exposure implemented on the NCS, and practical experiences regarding the radiation protection of offshore workers. A more detailed list of questions is included in the Interview guide from Appendix A.

As previously mentioned, in connection with the data collection process, there have been created two databases by use of Excel: one for ionising sources and another one for sources of EMF (see attached DVD). The databases include mapping information about possibly relevant radiation sources on offshore installations on the NCS, both from the literature research and from one brief mapping received at the workshop attended in the beginning of the study period. This brief mapping comprised one of the expert's own collected data, after many years of experience within radiation protection offshore. Data from the received mapping has been attributed the reference, 'Ref. 1', in the database of ionising sources.

Furthermore, these databases have been sent by electronic mail to the informants, together with the three main research topics from the interview guide and the description of the thesis (se Appendix A). Telephone or personal interviews have been carried out a short while after sending the mail.

Some of the radiation sources from the literature research have been neither confirmed nor unconfirmed by informants while others have been confirmed by several informants. This will be reflected by the data collection results and in the discussion. Unclear information has been clarified at the end of the interviews by asking 'interpreting' questions (e.g. "Do I understand correctly?"). There is a generally good level of compliance between the sources the informants have confirmed and the information from the literature research, however, some of the sources and their properties are unknown to the informants, thus further research is needed to increase the validity of the results.

1.5. Structure

This Master Thesis consists of the following sections:

- Literature research
- Results from the literature research, from a workshop and expert interviews
- Discussion of the results
- Recap of the main findings
- Proposal of further studies

Mapping information from the literature research and the workshop has been the input to the two earlier mentioned databases- found on the attached DVD. The database for ionising sources includes 7 attachments in addition to the main mapping:

- 4 attachments about efficient barriers against exposure to: Gamma radiography, Nuclear gauges, Radiotracers, and generally against Ionising radiation
- 1 table containing radiation properties for a range of radionuclides
- 1 overview of types of monitors (similar to Appendix C)
- 1 overview of types of personal protective equipment (PPE) (similar to Appendix B)

The database for EMF includes also one additional attachment about barriers against exposure to ELF. Furthermore, these databases have been sent to informants, in order to quality assure their content and collect new information. Results from this process and from the telephone and personal interviews are presented in the tables from Ch. 10, and they are thoroughly discussed in Ch. 11 and 12.

2. THE OFFSHORE PETROLEUM INDUSTRY ON THE NCS

This chapter describes briefly the structure of the offshore petroleum industry on the NCS, the operations where radiation sources and especially radioactive sources are used or they are generated, as well as related terminology. Subchapter 2.1 gives an overview of the standard NORSOK S-002, developed by the Norwegian petroleum industry to: fulfil requirements about a safe work environment from the national safety framework, to supplement or complement international standards and to harmonize the oil companies' own specifications (Norsk Standard, 2014).

The Norwegian oil and gas industry is organisationally complex, including several investment companies, the operators that manage the development and production of the fields and a network of suppliers employed by operators. The use of radioactive sources and apparatus generating ionising radiation is usually related to some of the operations suppliers perform on the installations. When oil or gas is discovered, a production platform or a floater is placed over the well. The platforms are made out of a columnar support, known as the 'jacket', usually cemented to the seabed, and of several living and production modules constructed on the top of the jacket. The same topside plant may serve several satellite fields. Flows from the wells containing oil, gas, water and solids are separated and processed on the topside plant. (IAEA, 2010)

Most wells are formed by rotary drilling techniques. The main components of a drilling system are illustrated in Figure 1. The mast or derrick supports a drill string that includes a large hook-like device called the swivel, a rectangular pipe called the 'kelly', a drill pipe (D), a thick-walled and heavy drill pipe called the drill collar (C), and the drill bit (B). During drilling, a pump (P) presses the 'mud' down the drill string to the bit and back to the surface together with the rock cuttings. At the surface, the cuttings are removed by the shale shaker (S) and the mud is processed and returned to the mud pits or tanks (T) for reuse. Radiation sources may be used in the control of the density and consistency of the mud. (IAEA, 2003)

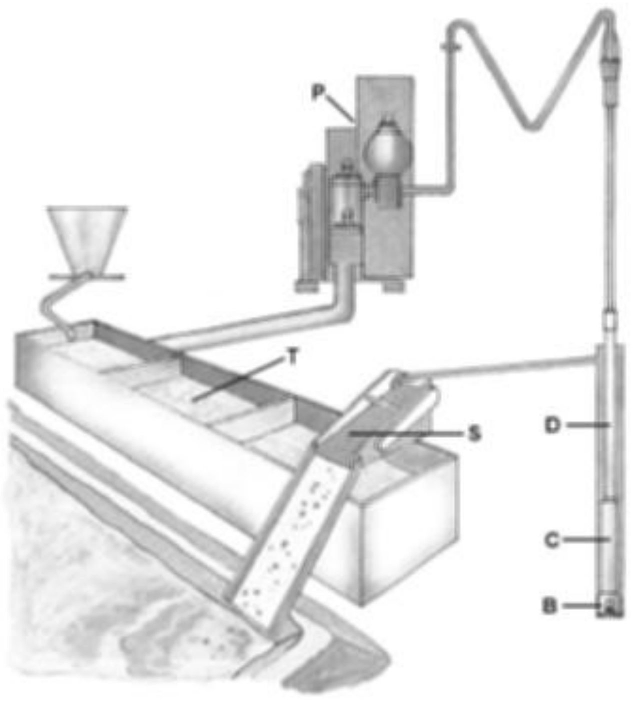

Figure 1: Oil well drilling system (IAEA, 2003)

After drilling for a while, the hole is 'cased' by lowering into it a casing string. The string needs to be fitted with certain devices, such as the centralizers or collars that may also imply the installation of certain radiation sources. There has to be performed investigations such as well loggings, to find out whether the well is commercial or not, and some of these operations will imply the use of powerful radioactive sources. When a well is completed its bottom needs to be cemented and then perforated in the 'pay zone' to allow the oil or gas flow to come to the surface through the production tubing. Sometimes radioactive materials are mixed with the cement in order to detect if the operation was successful or not. The production tubing and its umbilical cables are suspended from a structure containing a range of flow controlling valves, called the 'Christmas tree'. If geological formations have a low permeability in the 'pay zone', there will be carried out several operations in order to stimulate the production flow and radioactive materials may be used to monitor their results. For instance, proppants such as aluminium pellets or sand can be mixed with the fracturing fluid to keep open the fractures. The proppants are sometimes labelled with radioactive substances. Radiation sources may also be necessary in positioning measurements taken while drilling lateral wells, or 'sidetracks'. (IAEA, 2003)

At the topside plant, from the 'Christmas tree' productions fluids are directed into a collector, called the manifold, and then through several vessels where water, oil and gas are separated into different streams. Crude oil needs to be sent for further refining. By using various sources of ionising radiation both separation and complex processes such as oil refining can be efficiently controlled without interrupting the production or opening pressurised systems. On some of the installations, NORM may be deposited in the well tubulars, in the topside plant, as well as in storage, transport and treatment systems. Deposits in the crude oil and gas pipelines are removed regularly by releasing solid plastic or rubber plugs, called 'pigs' down the pipeline. Pigs fitted with radioactive sources are also used to investigate the pipelines. (IAEA, 2010)

Moreover, the Norwegian oil and gas industry implies increasingly numerous high-voltage, navigation and communication technologies. There are for instance used transformers to convert high voltage energy down to consumer voltage, powerful electricity generators and a high number of cables supplying energy to the installations from the shore. Offshore, there is always an implicit need for communication and navigation systems such as maritime radars, i.a. radars associated to helicopter traffic. All these radiation sources are further described in chapter 7 and subchapter 3.2.

2.1. NORSOK S-002 Working Environment

As already stated, the currently applicable NORSOK S-002 from 2004 has been developed by the Norwegian petroleum industry to fulfil requirements about safe work environment from the national safety framework and to harmonize the Norwegian petroleum industries own specifications (Norsk Standard, 2014). The design of any installation shall ensure a safe working environment during the entire operational phase (NORSOK S-002 , 2004).

Furthermore, NORSOK S-002 defines the work environment as the "totality of all physical, chemical, biological and physiological factors at work that may affect the employees' health and wellbeing through acute trauma or lasting exposure". Two of the factors the standard treats are the electromagnetic fields and radioactive sources on installations. The exact guidelines are presented in Table 1. The guidelines state for instance, that certain high voltage equipment should be kept away from manned area and that the undertaking should maintain an inventory of the radioactive sources. The requirements are based on applicable national legislation, i.a. the Radiation Protection Regulations, and NORSOK refers to these for further specifications. Both requirements in NORSOK and in related legislation form the basis for this thesis.

5	**Working environment requirements**
5.9	**Electromagnetic fields**
5.9.0-1	The location of high voltage equipment (> 690 V) adjacent to permanently manned work areas and accommodation areas should be avoided.
5.9.0-2	Worker exposure to electromagnetic fields shall conform to the limits stated.
5.10	**Radioactive sources - Ionising radiation**
5.10.0-1	For protection against radiation from radioactive sources, reference is made to the national legislation.
5.10.0-2	As a general rule, all occupational exposure to ionising radiation shall be kept as low as reasonably achievable.
5.10.0-3	The use of radioactive sources on an installation shall be minimised.
5.10.0-4	A separate list of all radioactive sources on the installation shall be prepared. This list shall provide information on location, type of equipment and radioactive source, radiation levels, and required
5.10.0-5	The radioactive sources shall be adequately marked at the location.
5.10.0-6	The design shall ensure that radioactive sources can be safely transported, handled, applied and stored
5.10.0-7	Storage lockers for radioactive sources shall be made from non-combustible material, and be lockable.
5.10.0-8	The sources shall not be stored together with explosives or combustible materials.

Table 2: Requirements about radioactive sources and EMF, quoted from NORSOK S-002 (NORSOK S-002 , 2004)

3. IONISING RADIATION AND ELECTROMAGNETIC FIELDS

As a result of the technological development and the increased use of artificial radiation sources, humans have become more and more exposed to radiation in recent decades. However, people have been exposed to radiation as long as the universe has existed (WHO , 2014). *Radiation* can be defined as the energy transfer from one radiation source to a medium that absorbs the radiation energy, e.g. the human body (Fandrem, 2010a). '*Radiation source*' is a general term for the device or substance where the radiation is generated and emitted, e.g. a X-ray apparatus, a radioactive substance, the radar antenna, the sun etc. (Saxebøl, 2003)

There are two main categories of radiation types, depending on the effects they have on the human body: ionising and non-ionising radiation. *Ionizing radiation* has high enough energy to knock out electrons from the orbit around the nucleus and break chemical bonds in the body (WHO , 2014). If essential molecules such as certain enzymes or the DNA are damaged, mutations in the cell may later lead to the development of cancer. Only X-rays and the radiation from radioactive sources are considered to be ionising radiation. (NRPA, 2005)

All the other known types of radiation are included in the category of *non-ionising radiation*, such as: visible light; infrared radiation; radiation from cell phones, from wireless networks, microwave ovens, radio transmitters or radars, and EMF from high voltage power lines and all the other AC cables (se also Figure 2) (WHO , 2014). These radiation types have less energy, and one beam alone does not have high enough energy to break chemical bonds in the body. However, when many rays interact with each other they may produce adverse effects in the body. (Fandrem, 2010a)

3.1. Ionising Radiation

Ionising radiation is usually divided into nuclear or radioactive radiation and the X-ray radiation, which is artificially generated. In the following subchapters, there are explained specific characteristics of this type of radiation as well as radiation dose concepts and their applicability.

3.1.1. Nuclear and X-ray radiation

All the radiation from *radioactive sources* originates from the nucleus and it is usually generically called *'nuclear radiation'*. Nuclear radiation occurs when there is an imbalance between the number of protons and the number of neutrons in the nucleus, or when the protons and neutrons are organized in an energetically unfavourable manner relative to each other. These radioactive atomic nuclei stabilise by emitting energy either in the form of high speed particles, such as *alpha, beta or neutron radiation*, or in the form of electromagnetic radiation- the *gamma radiation*. α, β and γ-radiation are emitted spontaneously. Neutron radiation usually needs to be generated by use of special apparatus. (Fandrem, 2010a)

A chemical element and its atomic number, is determined by the number of protons in its nucleus. The number of neutrons can vary. In a nuclide both the number of protons and the number of neutrons are determined. Unstable nuclides are also known as *radionuclides* while nuclides of the same element are called *isotopes.* 91 of the elements known today are natural elements. All the elements in the periodic table starting with polonium (^{84}Po) and finishing with uranium (^{92}U) are only found in nature as radionuclides. ^{92}U and ^{90}Th generates series of core processes with the transmission of α, β and γ rays. Both of them end up as radon (Rn) and in the end as stable lead. (IAEA, 2010)

X-ray, also called *Roentgen radiation* is electromagnetic radiation that occurs when high energetic electrons are decelerated in a material or when orbital electrons jump to an energy level closer to the atomic nucleus. X-rays and γ-rays are basically identical rays with the same energy. The only thing that differentiates these radiation types is their origin: γ-radiation always comes from the nuclei while X-rays always comes from electrons. Unlike radioactive sources that can never be turned off, the X-ray radiation is generated only when current flows through the X-ray apparatus. By adjusting the amperage one can adjust the amount of X-ray produced, and the voltage determines how high energy the rays can have. (Fandrem, 2010a)

3.1.2. The characteristics of the radiation source

Radioactive sources and the artificially generated X rays occur in different manners, are considered to lead to different health effects (see Ch. 5 and 8), and the units used to describe exposure are different. (NRPA, 2005)

A radioactive source is characterized by the properties of the radionuclides it contains, as well as the amount and concentration of these radionuclides.

The range of a radionuclide and its damage potential depend on the *type(s) of radiation* emitted (α, β and/or γ), as well as on *the energy* of these rays. The radionuclide's energy is measured in electron volt (eV). Moreover, each radionuclide has a *specific half-life* that may last from milliseconds to billions of years. The specific half-life represents the time it takes until half of the radioactive nuclei in a radioactive source has decayed. The amount of ray transmissions or nuclear reactions a source has within one second represents *the activity*, which in Norway it is measured in Becquerel (Bq). In some countries, including USA there will be used Curie (Ci) instead (1 Ci = 37 GBq). After the specific half-life has been reached the Bq value will be also halved. The concentration of a radionuclide is measured in, i.a. Bq/g or Bq/m^3 and it is called *specific activity*. (Saxebøl, 2003)

In any material, even in the air, there are molecules that absorb the energy of the rays and thus slow down the radiation. How deep rays penetrate a material depends on the density and size of the nuclei in this material, as well as the type of radiation and the energy of the rays. α- radiation has a short range, from a few mm to 2-3 cm in the air, and β radiation ranges from a few cm to a few meters in the air (Fandrem, 2010a). Both α and β radiation can be completely stopped by certain materials. γ- radiation and X-rays can never be stopped 100%, but sufficiently thick materials with large nuclei and high density will nevertheless shield effectively against this radiation. Further details about different types of shielding materials are presented in Ch. 6. (IAEA, 2010)

X rays are generated by an electrical apparatus, the X-ray tube. The intensity of their energy is described by the voltage across the X-ray tube, measured in kV, while the amount of radiation energy is characterised by the current (mA). (Saxebøl, 2003)

3.1.3. Radiation doses and dosimetry for radioactive sources

While the specific activity and the unit Becquerel are linked to the radiation source and to the transmission of energy, the *radiation dose* is related to the human body, or another object and the energy absorption. The radiation dose is the basic physical dimension for transmitted energy from the source to an object, and it is measured in Gray (Gy) (Saxebøl, 2003). Rays that pass through the body without changing their direction give no radiation dose. However, because of the differences between α, β, γ and neutron radiation, the radiation dose alone will not characterise the radiation hazard well enough (Fandrem, 2010a). It is estimated for example, that α-and neutron energy are more dangerous than β and γ-energy. α is 20 times more dangerous than β and γ-energy. Another concept, the *equivalent dose* takes into account this difference by multiplying the absorbed dose by a quality factor (Q). Equivalent dose is measured in the unit Sievert (Sv), where: Sv=Q*Gy. The relations are as follows (Henriksen, 1995):

$$Q_\beta = Q_\gamma = 1 \qquad (3.1)$$
$$Q_\alpha = 20 \qquad (3.2)$$
$$Q_n = 2\text{-}15 \qquad (3.3)$$

Different body organs will also have different sensitivity to radiation. The most sensitive organs are sex glands (gonads), blood-forming cells (red bone marrow) and organs with cells with high turnover, such as the cells in the stomach, colon and lungs. The *effective dose* considers both the absorbed energy, type of radiation and type of organ irradiated. The equivalent daily dose is multiplied by a weighting factor for the irradiated organ (Table 1), and it is also measured in the unit Sv. When *assessing the radiation hazard*, it is always the effective dose one needs to know. (Henriksen, 1995)

Tissue / Organ	W_f	Tissue / Organ	W_f	Tissue / Organ	W_f
Gonads	0.20	Stomach	0.12	Bone surface	0.01
Red bone marrow	0.12	Urinary Bladder	0.05	Skin	0.01

Colon	0.12	Chest	0.05	Remainder of organs	0.05
Lungs	0.12	Oesophagus	0.05		
Total = 1.00					

Table 3: Weighting Factors (W_f) for different body organs (Henriksen, 1995)

Moreover, the effective dose will be proportional to the specific activity, meaning that if the activity of the radiation source is doubled, the effective dose will be doubled. However, since radiation is emitted equally in all directions in the three dimensional plane, by reducing the distance (a) from the source to half, the effective dose will actually be quadrupled (3.4). This relation is also known as the *Square Low.* Shielding materials found between the exposed person and the source, also need to be considered when calculating the effective dose. Air, for instance will have an additional protective effect against α and β radiation. This concept together with the Square Low and the relation between the effective dose and specific activity, are essential radiation protection concepts. (Fandrem, 2010a)

$$D_{eff} \sim (1/a)^2 \quad (3.4)$$

While effective dose needs to be calculated, another unit, the *dose rate* can be easily measured by help of a simple hand-held measuring device and it indicates how fast a person would get doses if she/he needs to spend time at a certain place, the monitored one. The dose rate represents the equivalent dose per unit time and it is measured in Sv/h. Subunits like µSv/h or mSv/year are commonly used. However, if one needs to get an accurate measure of the health risk the exposure implies or to compare the health risk from different exposure situations, calculating the effective dose would be a better option. (Saxebøl, 2003).

When a large group of people is exposed, there is utilized the concept of *collective dose*, which is the sum of effective doses for all the persons exposed, e.g. the entire population. Collective dose is measured in mansievert (man Sv). (Saxebøl, 2003).

There are two possible ways to get radiation doses: either from a radiation source present outside the body, or from a radiation source that is inside the body, i.e. external or internal irradiation. An example of external radiation source is the radiography by use of the X-ray apparatus. (Saxebøl, 2003)

When contaminated particles are inhaled, ingested or are absorbed through the skin (e.g. through wounds) an additional main contributor to the radiation dose needs to be considered, the *internal radiation dose*. α and 'soft' β-radiation sources will usually only give doses if they are inside the body, but their doses will be much higher than from comparable γ sources. γ, neutron and 'hard' β external sources do give doses to internal organs. Because of the small distance between exposed organs and the internal radiation sources, doses will actually be much higher than from a comparable external source. However, assessing the internal radiation dose is a complex process. There can be used tabular values of dose coefficients for various radionuclides with given activities and uptake mechanisms, but it will be challenging to calculate the exact amount of radioactive material assimilated by the body. (Fandrem, 2010a). Figure 2 summarises different characteristics, dose concepts and units related to the radioactive source, the human body and to artificially generated and controlled radiation such as the X-rays, emitted by an X-ray tube. Dose rates, as already mentioned are related to the monitored location. A small fraction of the emitted radiation from the X-ray generator will always be reflected and can give doses.

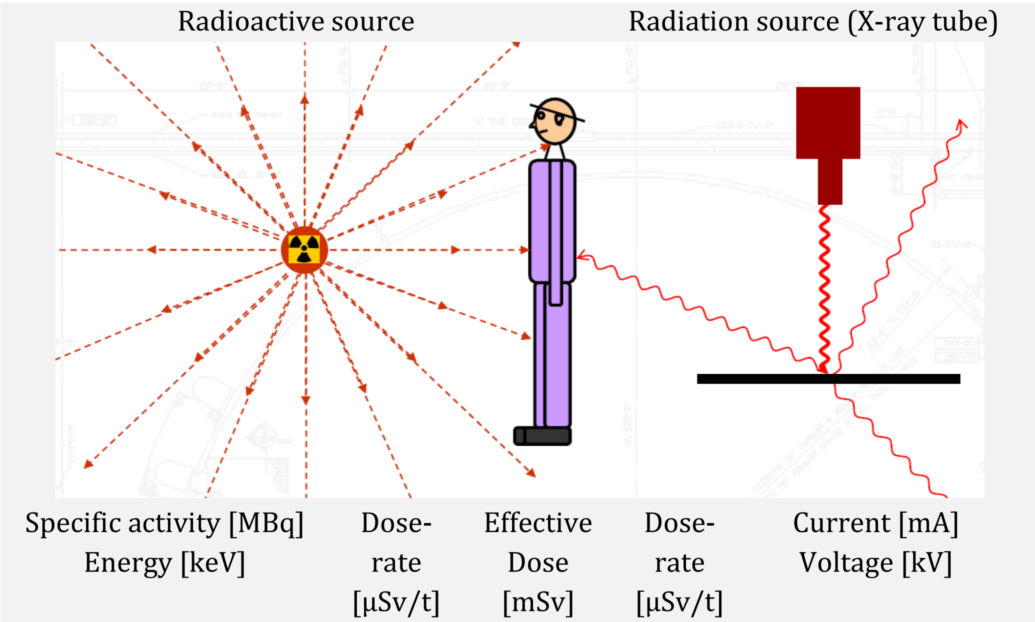

Figure 2: Characteristics, dose concepts and units related to (from left to right): the radioactive source, location, human body and the primary radiation beam from a radiation generator (Fandrem, 2013)

3.2. Electromagnetic Radiation. Electromagnetic fields (EMF)

The *electromagnetic radiation* can be described as the wave motion of an electric and magnetic field. There are several categories of electromagnetic radiation depending on, i.a. frequency, wavelength and energy. It includes both sources of ionising and *non-ionising radiation.* Gamma radiation from radioactive substances and X-ray devices are the two types of ionising radiation sources that produce electromagnetic waves. The other radiation types with a frequency below 10^{16} Hz, belong to the non-ionising area of the frequency spectrum. This area is usually divided into optical radiation and electromagnetic fields. Some examples of EMF sources are: base stations for wireless network and radars (for higher EMF frequencies) as well as high voltage equipment and power cables (for lower frequencies) and electric motors (for SMF) (Figure 3). (NRPA, 2005)

Radiation with long wavelength and low frequency has less energy and thus shorter range than radiation with short wavelength. Non-ionizing radiation has longer wavelength than X-rays and gamma radiation, and therefore less energy. When non-ionising radiation strikes a material, instead of breaking chemical bonds, the energy will go over to heating. (Tynes, 2003)

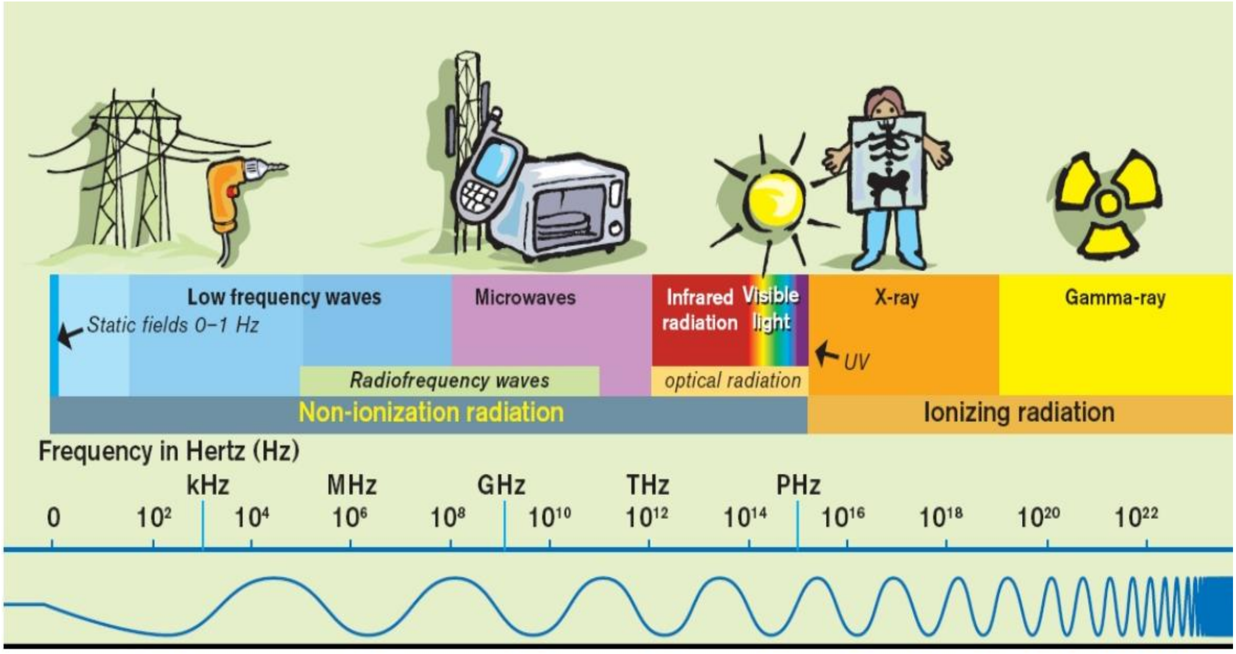

Figure 3: The frequency spectrum of electromagnetic waves (EMF-NET/European Commision, 2008)

Electric fields arise at places where there are electric charged particles, or where there are objects with different voltage. Between electric charges there are always electrical forces (E). The concept of electric field is used to describe the force that will operate on an electrical charge coming into the field. An electrical device connected to the electrical grid will be surrounded by an electric field even when it is off and there is no current flowing (Figure 4). The strength of the electrical field increases as the voltage increases. (NRPA , 2000)

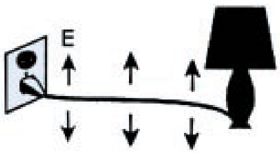

Figure 4: Electric field around a lamp wire when the lamp is plugged (NRPA , 2000)

Magnetic fields occur when electric charges are in motion, i.e. when current is flowing. The magnetic field strength is determined by the flux density (B). To form a magnetic field the device must not only be connected, but also turned on so that current is flowing (Figure 5). The magnetic field increases as the current flow increases. (NRPA , 2000)

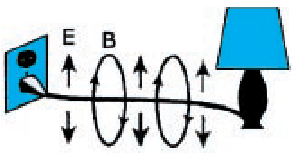

Figure 5: Electric and magnetic fields around a lamp wire when the lamp is plugged and turned on (NRPA , 2000)

The term *Electromagnetic fields* is, i.a. used by NORSOK S-002. According to ICNIRP and NRPA, EMF can be divided into SMF (0-1 Hz) and 'Time- varying electric, magnetic and electromagnetic fields' (ICNIRP, 2014). Unlike SMF, for the latter ones fields change their direction at the same time (with the same frequency) as the current. SMF are produced by the direct current, e.g. the DC from battery powered appliances, while the time-varying fields are produced by the alternative current, e.g. the AC from electrical powered appliances. (WHO, 2014b)

Furthermore, the Time varying electric, magnetic and electromagnetic fields' can be subdivided into: 'Low frequent electric and magnetic fields' (1-100kHz) and RF (300Hz-300GHz). Some of the low frequency fields are also considered radio frequency waves, as presented in subchapter 3.2.2. 'Low frequent electric and magnetic fields' include, i.a. ELF (1-300Hz). (NRPA, 2005)

3.2.1. Extremely low frequency electric and magnetic fields and Static magnetic fields. ELF and SMF sources

At work and in the daily life, people are exposed to electric and magnetic fields from man-made installations. Most of them are caused by objects that are connected to the electricity grid where voltage and current fluctuates 50 times per second or at a frequency of 50Hz. The 50Hz frequency is typical for the electrical grid in Norway and many other European countries. At such low frequency electric and magnetic fields are generated at the same time but they behave independently, i.e. they have to be assessed independently. (Tynes, 2003)

Substations are an example of high voltage equipment that is considered to generate relatively strong magnetic fields. They are used to adjust the voltage from the high voltage network to consumer voltage. Assuming equal electrical power at the consumer, the current times voltage will always be approximately constant. This means that a higher voltage (load) and implicitly higher electric field gives a lower power and lower magnetic field (NRPA , 2000). Figure 6 illustrates how the transfer from the producer to the consumer occurs. A typical transmission voltage in Norway is 132 kV, typical distribution voltages are 47, 33, 22 and 11 kV, while the consumer voltage is often 230 or 400 V. (Tynes, 2003)

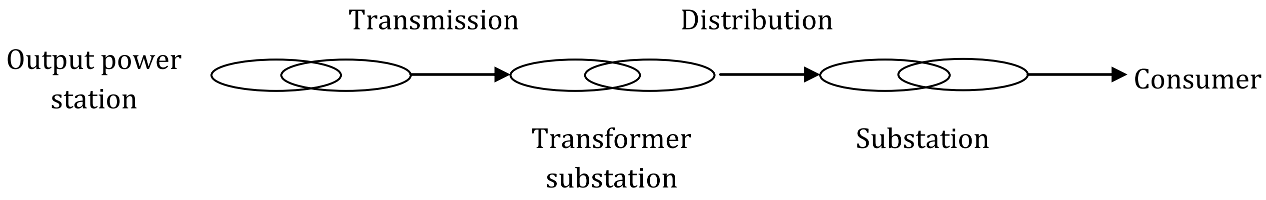

Figure 6: Power transmission from the producer to the consumer (Tynes, 2003)

For the electric and magnetic fields from low-frequency and static EMF, the most common assessment units are the already mentioned, electric field strength (E), measured in V/m and the magnetic flux density (B), measured in tesla (T), μT or mT (for the SMF). (NRPA, 2005)

Substations are actually estimated to have relatively modest magnetic fields at distances of about 5 meters from the equipment: usually 0.5 μT, depending on the load. However, the magnetic fields increase very fast as the distance decreases. The components that are most often dominant field sources are the transformer, the switchboard and the power transmission between the transformer and the switchboard. (NRPA , 2000)

One example of occupation where magnetic fields can be strong is welding. The voltage is low, so there are weak electric fields, but the SMF are estimated to get as high as 10 mT, while the time varying ones can reach up to 500 μT. Only body parts that come in contact with components, such as the power cable will be exposed to these field levels. (Tynes, 2003)

Other sources of magnetic fields are considered to be the handheld electric tools. B fields can reach several hundreds of μT, and as such they do not exceed exposure limits. However, the reason why these sources should be assessed is the average exposure time that usually is quite long and nerve excitation may occur. (SCENIHR , 2013)

Printers, copy machines or other electrical office machines can be surrounded by magnetic fields, especially when they are most active (during heating, printing and copying)- typically up to 0.5- 2 μT for the body part that comes closest to the machine. However, fields normally fall drastically when the equipment is in stand-by. (Bedriftshelsetjenesten, 2003)

3.2.2. Radio frequency fields. RF sources

Radio-frequency fields are fields with the frequency between 300 Hz and 300 GHz. They are divided into two categories: radio-waves with frequencies of up to 30 MHz and microwaves, with frequencies between 300 MHz and 300 GHz. Each of these categories can be divided into several other subcategories depending on the frequency. (NRPA, 2005)

For RFs, the area that covers 1- 10 wavelengths from the source is often defined as the near field (e.g. a few centimetres from the radar). Here, the electric and magnetic fields must be determined and assessed separately. In the far field it is sufficient to determine the irradiance strength (also called power density) that is a function of the electric and magnetic field strength (W/m^2). This also applies for frequencies above 10 GHz where the penetration depth of the field into the body is very low. (EMF-NET/European Commision, 2008).

Different types of radio and microwave frequencies and a few typical applications are listed on Table 4. Low frequency EMF between 300 Hz and 100 kHz, which are also considered radio frequency waves, are also included in the table. They are covered by the VLF and LF frequencies. Right after the table follows a short description of some frequency ranges that may be relevant offshore. Further details about overexposure for these frequency intervals can be found, i.a. in a report published by NRPA in 2005 about occupational exposure from ionising and non-ionising radiation sources. (NRPA, 2005)

Frequency	Abbreviation	Frequency range	Ex. of applications
Radio-waves:			
Very low frequency	VLF	3-30 kHz	Monitors
Low frequency LF	LF	30-300 kHz	Radio navigation
Medium frequency	MF	300-3000 kHz	Loran navigation transmitters, AM radio
High frequency	HF	3-30 MHz	Radio (short waves)
Microwaves:			
Very high frequency	VHF	30-300 MHz	FM radio , radio navigation, air traffic control
Ultrahigh frequency	UHF	300-3000 MHz	Mobile phone, aviation radar
Super high frequency	SHF	3-30 GHz	Satellite stations, police radar
Extra high frequency	EHF	30-300 GHz	Radio astronomy

Table 4: Some typical applications of RF and microwave radiation at different frequencies (NRPA, 2005)

LFs (30-300 kHz) are sometimes used for a civilian radar navigation system employing a pulsed signal of around 100 kHz, called Loran. Measurements of the field strength have shown that exposure levels in the near field can exceed the exposure limits, but at a distance of 3-4 meters fields are expected to be below exposure limits. (NRPA, 2005)

MFs (300-3000 kHz) are common in AM broadcasting. AM broadcasting is transmitted on frequencies between 0.5 and 1.6 MH and the effect typically varies from 1 kW to 1.5 MW. Working, spending time very close to the most powerful antennas can involve exposure above stated limits. (NRPA, 2005)

HFs (3-30 MHz) are used for instance, in military radio communications. Short periods of overexposure can occur, upon working close to the antennas or servicing the transmitter units. (NRPA, 2005)

VHFs (30-300 MHz) are specific to FM radio and to the VHF TV Transmitters.

Measurements in FM radio transmission towers (88-108 MHz) and on VHF TV Transmitters (54-88 MHz and 174-216 MHz) showed electric field strength up to a few hundred V/m and magnetic fields up to a few A/m. When service personnel need to work up in the transmission tower, they may walk by in front of antennas and through the transmission and they can be briefly exposed to such fields. If there are workers in front of the antennas when the effect is very high, they might get considerable doses. Field strength on the ground under such antennas are usually far below the exposure limits. (NRPA, 2005)

UHFs (300 MHz - 3 GHz) can be used by UHF TV Transmitters operating at frequencies of 470-806 MHz. They usually have an effect of up to 5 MW. The exposure situation is similar to the VHF TV transmitters mentioned above. Wireless communication devices (e.g. WLAN and landlines) also function at the UHF level (of around 2400 MHz). Their maximum effect is normally 0.1 W. Exposure over the stated limits is not expected to occur, but some may experience discomfort. Air traffic control radars usually operate at UHF frequencies of a few GHz. Pulsing and antenna rotation leads to significant differences between the average level of the field strength and the peak level (typically 10^5 higher). Upon assessing exposure situations, both average power and pulse power must be considered. The antennas are normally placed high so that the radar beam sweeps over people heads when they are close by and overexposure cannot occur. Service personnel working with the radar antennas and their transmitters can get overexposed when the antennas are in operation. (NRPA, 2005)

One application of the SHFs (3 to 30 GHz) is the weather radar used on planes, functioning at a frequency of 9.4 GHz. The radar transmits pulses, and right in front of it there have been measured peak levels that were far above the exposure limits. The average field strength may also exceed the recommended limits at a distance of 10 cm in front of the radar. The levels are much lower after 10 meters. (NRPA, 2005)

In Norway, radiofrequency fields are regulated and monitored by the Post and Telecommunications Authority ('Post og teletilsynet'). Norwegian Post and Telecommunications Authority together with the Radiation Protection Authority conducted in 2010 a study of the exposure levels to RF fields in the environment, both inside buildings and outdoors. The study included i.a. the exposure to wireless internet (WLAN). Wireless networks were among the weakest RF sources, well below exposure limits. In office environments, WLAN was the dominant source, but the overall exposure to RF fields was still low. (Folkehelseinstituttet, 2012) Further details about exposure and exposure limits are presented in Chapter 9.

4. RADIOACTIVE SOURCES ON OFFSHORE INSTALLATIONS

A *radiation source* can be defined as the starting point for the radiation filed. This could be a capsule containing a radioactive substance, meaning that the radiation source is sealed, or an unsealed radioactive substance, also known as an open radiation source. Devices incorporating radioactive substances are also treated as radiation sources. (Radiation Protection Regulations, 2011)

The most common sealed radioactive sources on offshore installations are: the industrial radiography, well logging, installed gauges, as well as mobile gauging equipment and articles. Among the unsealed ones there are the radiotracers and NORM.

4.1. Sealed Radioactive Sources

Sealed radioactive sources are contained in capsules but they are often also enclosed in additional lead containers with a window, directing the radiation in a focused direction. This type of radiation is termed 'primary radiation'. The window is closed when the source is not in use. When equally emitted radiation is needed, sealed sources can also be used without an extra shielding container. (Fandrem, 2010)

4.1.1. Industrial radiography

There are carried out almost 1 million industrial radiography measurements annually in Norway, mostly in the oil and gas production. (NRPA, 2014)

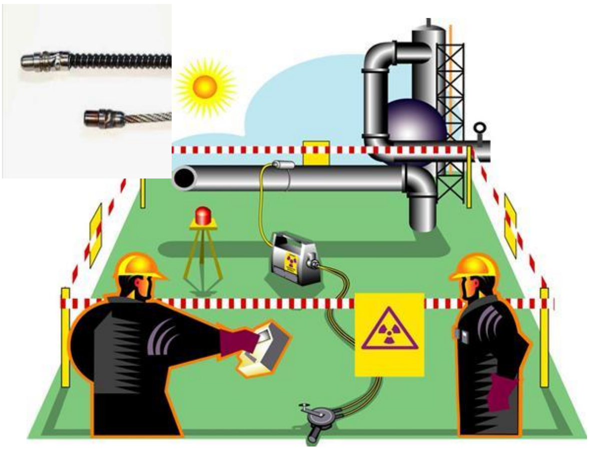

Figure 7: Gamma radiography (NRPA, 2014)

Industrial radiography is a form of non-destructive testing of components and connections in the plant and equipment by help of powerful radiation sources. It is also known as NDT ('Non-destructive Testing'). The radiography technique is mainly used for the control of the welds and detection of cracks. Its main purpose is to verify the quality of components and connections, supposed to withstand extremely high physical forces (i.a. high hydrostatic pressures). (NRPA, 2014)

There are used γ-radiation sources, such as ^{60}Co, ^{192}Ir and to a lesser extent X-ray sources. The benefit of sealed radioactive sources is that they do not require electric power and they are explosion proof. (Fandrem, 2010.c)

Figure 7 illustrates how gamma radiography is performed. A radioactive source, similar to the one in the small picture, is removed from the shielding container and laid over a weld joint. The source radiates through the tube onto a film. If there are e.g. cracks in the material, more radiation will go through the object and the film will be more blackened. The area where the operation is carried out is cordoned off and marked with warning signs and warning light. The NCS petroleum industry contracts out industrial radiography almost exclusively. (NRPA, 2014).

On pipe laying barges there can be used X-ray and gamma pipeline crawlers so as to examine underwater installations. Either the radiography company or the operator engages the services of a specialist diving company, meaning that a good co-operation between the three separate companies will be essential. (IAEA, 2010)

4.1.2. Well logging and additional sources

In well logging, the radiation sources are mounted in a wire or in the drill string near the drill bit, and gauges are installed close to the radiation sources. Measurement data gives useful information about the bedrock and the well, indicating whether the discovery is commercial or not, i.a. information about: hydrocarbon content, density, temperature, pressure, porosity and viscosity. (NRPA, 2014)

Figure 8: Well logging tool string suspended by a derrick above an oil well (IAEA, 2010)

There is used both γ and neutron radiation from encapsulated but unshielded sources. Gamma radiation provides information on the density of the rock around the wellbore, while neutrons offer information about hydrocarbon content. Neutron radiation is generated under the actual recording by using Be together with ^{241}Am. Be emits neutron radiation when bombarded with γ-rays from ^{241}Am. (Fandrem, 2010b)

There are various logging techniques (IAEA , 2010):

- The neutron–neutron or compensated neutron logging where a radioactive source of up to several hundred GBq of ^{241}Am–Be or sometimes Pu–Be will emit 4–5 MeV neutrons. The neutrons will aid indicating how porous the rock is and whether it is likely to contain hydrocarbons or water
- The gamma-gamma or density logging where the tool contains two detectors and a ^{137}Cs source, usually of up to 75 GBq. The density log together with the porosity log provides valuable information about the presence of gas in the well
- The neutron–gamma logging with a tool containing an accelerator with up to several hundred GBq of tritium (^{3}H), a soft β-particle emitter. Tritium generates high energy neutrons (14-15 MeV) when high voltage electricity is applied to the device. The neutrons will bombard the rocks and some of the nuclides in the rocks will become radioactive and will emit γ radiation. The purpose of this technique is the identification of the content of chlorine or salt water in the rocks

While running the casing, there are either inserted pellets into threaded holes in the casing collars or malleable metal tags into the screw threads at the casing joint. These sources contain about 50 kBq of ^{60}Co and are aimed at marking the depth in the well while the logging tool is lowered. By inserting the tags into the screw threads one wants to avoid damaging the radioactive sources. (IAEA, 2003)

Figure 9: The radioactive marker sub incorporates one or two pip tags (Schlumberger, 2014)

During well completions, radioactive tags may be attached to the perforating gun to detect if plasma has been fired at the desired depth or weather the casing has been perforated correctly. These tags are also known as PIP tags (Precision Identification Perforation markers) (Figure 9). A logging tool will be used to measure the depth of the contaminated plasma. Due to dilution factors the contamination on the topside plant and equipment is usually very low. (IAEA, 2010)

Figure 10 Gauge for measuring the density of well fluids (IAEA, 2003)

A sewing needle looking tool may be used for the measurement of the fluid density in the well. The small logging tool contains a source with several GBq of ^{241}Am. A shielding sleeve covers the gauge while the tool is not in use (Figure 10). (IAEA, 2010)

4.1.3. Installed gauges

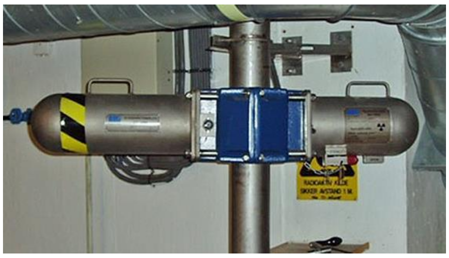

Figure 11: Multiphase counter (Source: NRPA)

Installed gauges, also known as industrial control sources or nuclear sources, are usually mounted on pipelines, tubes or vessels in order to measure a range of parameters. Density gauges are e.g. fitted on pipelines carrying cement for the cementing of the casing string. Level gauges, sometimes called Photon Switches, are installed on tanks and tubes in order to either measure fluid levels or to reveal the interface between fluids of distinct densities, e.g. in separators. The latter are also known as multi-phase counters. Level gauges may be in addition encountered on mud tanks, the flare knockout drum, vent headers of storage tanks and cemented in the jacket legs of the platform. (IAEA, 2010)

Each control source usually comprises one or more radioactive sources and one or more radiation detectors. Gauges are usually mounted with the source on one side and the detectors on another, as shown in Figure 11. The gauge in the picture is used for continuous measurements of the percentage of dry matter in relation to the volume of liquid in a pipe. For density and level gauges there is often used ^{137}Cs with specific activities up to 5 GBq and sometimes up to 100 GBq. For larger vessels or for higher densities one needs to use powerful sources such as ^{60}Co. Examples of radioactive sources used in installed gauges are listed on Table 5. (NRPA, 2014)

Radionuclide	Half life	Radiation type	Utility
^{241} Am	433 years	γ	Density gauge/multi-phase counter
^{133}Ba	10.5 years	γ	Density gauge/multi-phase counter
^{137}Cs	30.2 years	γ	Density/ level gauge
^{60}Co	5.3 years	γ	Density/ level gauge
^{241}Am+Be	433 years	Neutrons	Level meters
^{252}Cf	2.7 years	Neutrons	Level meters

Table 5: Examples of sealed radioactive sources used for industrial purposes (NRPA, 2014)

4.1.4. Mobile gauging equipment and articles with radioactive sources. Pipeline pigs

A range of mobile gauges used in the petroleum industry contain radioactive sources such as e.g. ^{60}Co, ^{137}Cs and ^{241}Am. Usually, these sources do not require approval, but their use must be reported to NRPA (Fandrem, 2010b).

Figure 12: Level gauge used to measure fluid level inside fire extinguishers (IAEA, 2003)

One example of mobile gauging equipment often used by service companies is the hand-held level gauge containing a ^{137}Cs source of several MBq together with a detector to determine the fluid level in fire extinguishers (Figure 12). A similar hand-held gauge containing a neutron generating ^{241}Am -Be source may be used by NDT companies to detect water trapped between the insulation and the surface of pipes or vessels where it could cause corrosion. (IAEA, 2010)

Radioactive sources are also used in articles such as self luminous signs and ionic smoke detectors. In self luminous signs used i.a. to mark escape routes (e.g. 'beta lights') there has to be used either ^{3}H or ^{14}C in order to activate the phosphorous contained by the signs, and all the ionic smoke detectors contain a small radioactive source of ^{241}Am (Fandrem, 2010b). Smoke detectors are only covered by the Radiation Protection Regulations when the specific activity of the source exceeds 40 kBq. (Radiation Protection Regulations, 2011)

Figure 13: Pipeline pig at its arrival at the other end of a pipe (Pipeline Products & Services Association, 2014)

Another type of mobile gauge is the 'pipe wall profiler', a larger equipment containing a ^{137}Cs source of several GBq. The gauge aids checking the uniformity of the steel pipes used in tubing strings. Furthermore, level or multi-phase counters are also encountered in the form of mobile equipment and they can be temporary mounted on remotely operated vehicles to detect water ingress into subsea components. Moreover, for the detection of phase changes of hydrogenous substances in vessels and for monitoring flare stack lines for ice deposits when condensate starts freezing there are used mobile gauges containing ^{241}Am-Be. (IAEA, 2010)

Sometimes, pipeline pigs contain sealed radioactive sources that aid locating them when they encounter a blockage and get stuck inside the lines. Pigs labelled with sealed sources can be also used to detect leakages in umbilical pipelines. The principle is that the pig will lose its driving force in the vicinity of these leaks (IAEA, 2003). Radioactive pigs are usually known as ‘intelligent pigs’.

4.2. Unsealed Radioactive Sources

The unsealed radioactive sources encountered in the oil and gas industry are either materials artificially labelled with radionuclides or the naturally occurring radioactive waste, called NORM. These sources represent both an external and an internal exposure hazard. Internal doses may be received by inhalation, ingestion or skin absorption (Fandrem, 2010b).

4.2.1. Radiotracers

Materials labelled with radionuclides are generally used as tracers, also called radiotracers or markers, to trace chemical molecules of oil, gas or water in the production flows, as well as for mapping the reservoir conditions. They are usually γ and β- emitters with a short half-life, injected into the structure to be examined and then monitored by help of logging tools and detectors (NRPA, 2014). γ- and β-emitting radionuclides such as, ^{46}Sc, ^{140}La, ^{56}Mn, ^{24}Na, ^{124}Sb, ^{192}Ir, ^{99}Tc^{m}, ^{131}I, ^{110}Ag^{m}, ^{41}Ar and ^{133}Xe are commonly used in tracer operations, being easy to detect and identify. (IAEA, 2010) Other radionuclides used as radiotracers may be: ^{82}Br, ^{79}Kr, ^{113m}In, ^{137m}Ba (emitting γ) and He (emitting β). (NRPA, 2014)

Some examples of upstream radiotracers are (IAEA, 2010):

- glass ampoules containing scandium oxide labelled with 750 MBq of ^{46}Sc, discharged into the slurry tank right before cementing and well completion
- plastic pellets coated with about 10 GBq of ^{110}Ag^{m}, added to a proppant during the ‘frac job’
- radiotracer ‘spikes’, containing ^{99}Tc^{m} and ^{131}I solutions released into the wells to determine flow rates
- compounds labelled with up to 1TBq of the soft β- emitters, ^{3}H and ^{14}C injected into the wells to follow water and gas flows
- short -life γ-emitters, such as ^{82}Br used to spike the soft β-emitters in order to make them easier to detect in the event of a spillage

- hard β-emitters like the gaseous ^{85}Kr and γ-emitters in flow rate measurement

4.2.2. Naturally occurring radioactive material

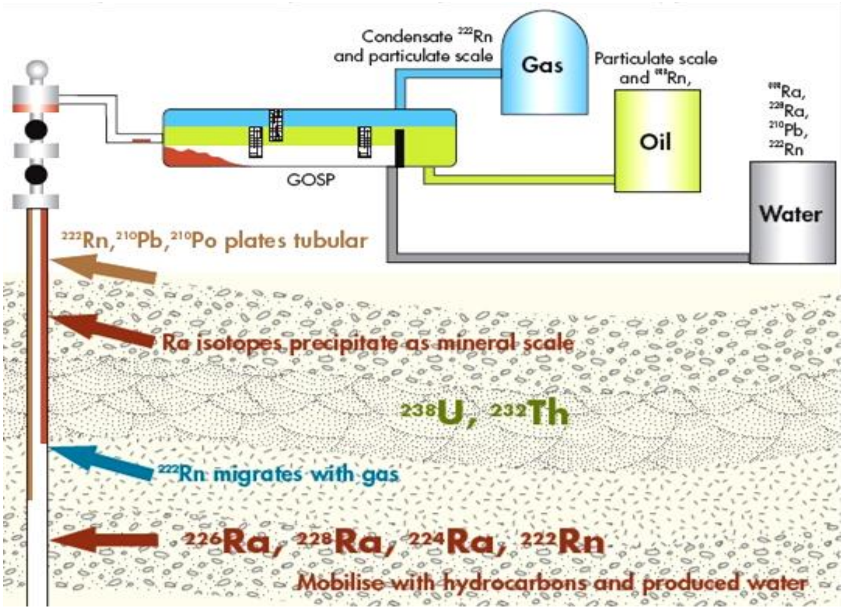

Figure 14: Left: places where NORM may accumulate in the recovery process. (OGP , 2008). Right: NORM scale inside a pipe (NET Waterjet , 2014)

Naturally occurring radioactive material, also known as LSA (Low Specific Activity) material or LRA (in Norway), is formed in the geological environment. Because of the large volumes of accumulated radioactive waste, NORM is primarily an environmental concern, but apart from its low specific activity it also represents a health hazard. It is particularly important to avoid the inhalation of contaminated particles. Repeatedly inhalation would soon lead to considerable internal doses. Personnel can in addition receive significant external doses upon working unprotected inside tanks that contain NORM, as well as where large amounts of NORM waste or contaminated equipment are stored. Cleaning and maintenance personnel are specially exposed to this type of irradiation. (Fandrem, 2010.c)

NORM starts to develop after two natural radionuclides, ^{226}Ra and ^{228}Ra present in the formation water, precipitate as radium sulphate and barium sulphate in the produced water. Radium carbonate may also occur (Fandrem, 2010.c). These salts are laid as scales inside the equipment that has been in contact with the production flow, such as: pipelines, wellheads, valves, pumps and separators. NORM may also appear at Gas/Oil Separation Plants (GOSP) in the form of sludge, and at gas plants in the form of thin films as a result of the Rn gas decay (Figure 14) (OGP , 2008).

The amount of NORM varies widely from field to field, depending on the concentrations of radium and uranium in sedimentary rocks and formation water. Normally, the amount of radioactive deposits will start increasing after sea water injections, mainly because there are added more sulphates, which accelerates the precipitation. (OLF, 1999)

NORM may appear in the oil production, the gas production, and in small amounts in the

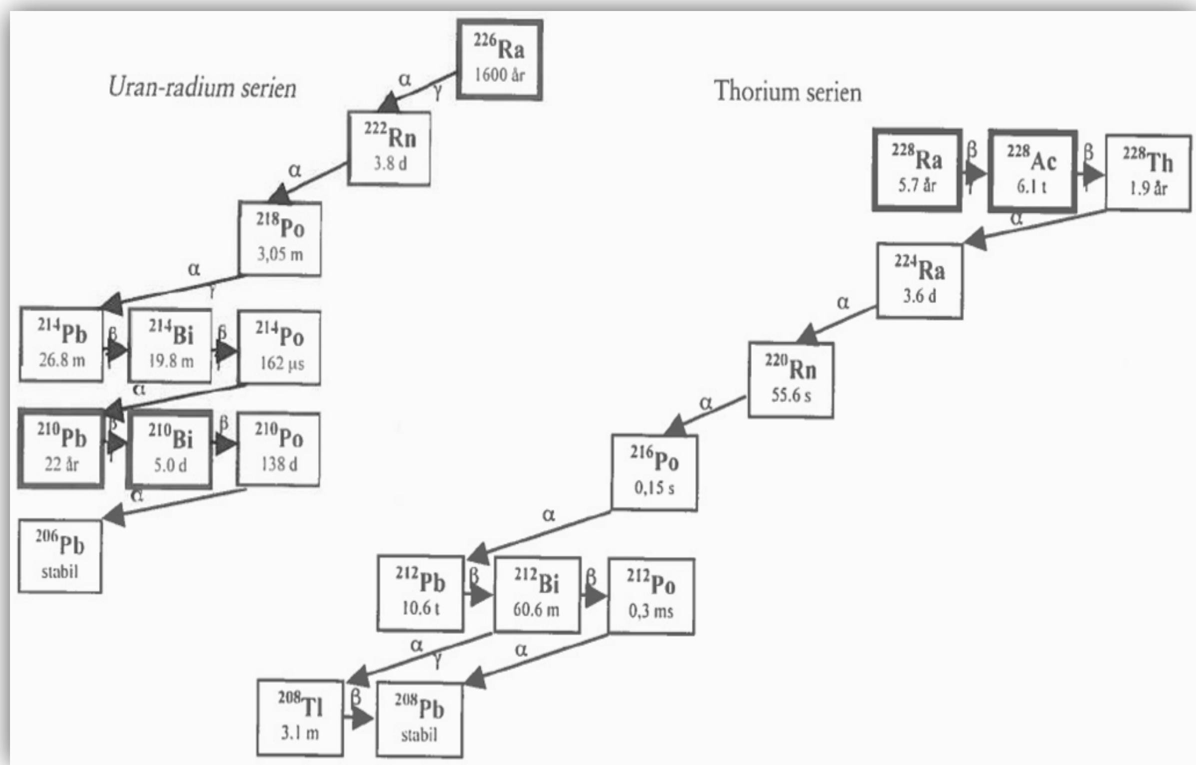

Figure 15: Radionuclides found in NORM from the oil production.
Radium (^{226}Ra and ^{228}Ra) is the parent isotope for NORM in both the Uranium series (left) and the Thorium series (right). Both of the series end up with stable lead (^{206}Pb and ^{208}Pb) (Fandrem, 2010.c)

produced water. According to the 'Regulations on the Pollution Act applicable for radioactive contamination and radioactive waste', material with a concentration of more than 1 Bq/g must be treated as radioactive waste, while material with a concentration exceeding 10Bq/g (or 10KBq/year) must be disposed in NORM landfill (FOR-2010-11-01-1394, 2010). The concentration of radium in NORM from the Norwegian continental shelf is usually below 200 Bq/g. (Fandrem, 2010.c)

NORM from oil production contains primarily ^{226}Ra with a half-life of 1600 years and ^{228}Ra with a half-life of 5.7 years. The radium nuclei decay emits radiation and generates new radioactive 'daughters'. These disintegrate again in series of radionuclides until stable lead is formed. ^{226}Ra is part of the uranium- radium series, while ^{228}Ra is part of the thorium series (IAEA, 2010). NORM contains about all the 19 radionuclides formed between Ra and stable lead in the two series, but their proportion will vary over time (Figure 15). (Fandrem, 2010.c)

NORM from oil production emits α-, β- and γ- radiation and if it is inhaled or ingested it will always give internal doses. How large doses are, depends for instance on how much dust is inhaled and how large concentration of radionuclides is in the inhaled dust. (OLF, 1999)

In gas production, there is primarily the precipitation of metallic ^{210}Pb originating from

^{222}Rn, the radon gas that may be relevant. Stable lead containing ^{210}Pb may be encountered on the inner surfaces of gas production equipment, in the form of very thin radioactive films, as well as in sludge. Even though the quantities of NORM are often much lower here than in the oil production, the concentration can often be much higher. ^{210}Pb may also be encountered in condensates and in some parts of the liquefied natural gas processing plants, together with ^{222}Rn and ^{210}Po. (Gesell, 1975)

There are only three different radionuclides in NORM from gas production. In addition to ^{210}Pb, the radioactive deposits will also contain ^{210}Bi and ^{210}Po. These radionuclides emit α- β-and γ-radiation. Due to a weak γ-radiation, the NORM from gas production will practically never give external doses to workers. However, because of α- radiation inhaled or ingested particles will always give internal doses (IAEA, 2003). The main forms of appearance of NORM in oil and gas production are summarized in Table 6:

Type	Radionuclides	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, skimmer 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
Produced water	Ra-226, Ra-228, Ra-224 and/or Pb-210	More or less saline, large volumes in oil production	Each production facility

Table 6: Main forms of appearance of NORM in oil and gas production (IAEA, 2010)

5. HEALTH EFFECTS FROM EXPOSURE TO RADIOACTIVE SOURCES

Radiation is ubiquitous and sometimes cells and genes are injured but human body is able to repair most of these injuries. The amount of unrepaired damages will however increase with age (Henriksen, 1995). Health effects of radiation vary greatly depending on a range of factors. Apart from the age, other important risk factors for health damages are: the amount of exposure, rate of exposure, area of body that is irradiated, type of radiation and individual biological variability. (IAEA, 2010)

There are both short term (acute) and long term health effects from the exposure to radioactive sources. *Short term health effects* occur only after large radiation doses, and they are manifested through symptoms like: diarrhoea and vomiting, nausea, lassitude, haemorrhaging, emaciation, infection and, ultimately, death. Table 7 presents an overview of doses for certain short term effects, after the acute irradiation of the whole body. (IAEA, 2010)

Effect	Dose (Gy)
No discernible effect	0.25
Blood changes, no illness	1.0
Radiation sickness, no deaths	2.0
Death to 50% of irradiated people (LD 50)	4.5
Death to 100% of irradiated people (LD 100)	10.0

Table 7: Doses for acute health effects (IAEA, 2010)

The major *long term biological effects* from smaller doses received over a longer period of time are the increased risks of cancer and severe hereditary effects in progeny. The utter most important factor for the development of cancer or genetic damages is the *lifetime dose.* The higher the lifetime dose, the higher the likelihood of getting the disease. Other important factors are radiation type and which body parts and organs that are mostly exposed. (IAEA, 2010)

A small dose can cause mutations in a cell and if the cell is not repaired, it can be consequently transformed into a cancer cell. By dividing itself again and again a malignant tumour will be eventually formed (Henriksen, 1995). This takes time and represents the *latent period* that can range between a few months and several years. It is shorter for leukaemia and skin cancer, from 5 to 7 years, and longer for other types of cancers, 10 to 20 years or more. *Dose rate* or how fast dose is given plays also an important role in cancer formation. A radiation dose given over a short time is far more dangerous than an equivalent dose given over a longer time period. Large dose rates produce many injuries at once meaning that the chance for unrepaired, mutagenic cells will be higher. (Henriksen, 1995)

There are many scientific evidences about the biological effects of *radiation doses* above 100 mSv but the smaller the doses are, less accurate the knowledge. According to ICRP and UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), the fatality risk is calculated to be 10 individuals per 100 manSv (collective dose). There has been also calculated that the likelihood for cancer increases by around 0.5% for each 100 mSv received in addition to the *background radiation* (IAEA, 2010). In Norway, the likelihood for cancer was about 26% in 2012. (SSB, 2013)

Below 100 mSv is estimated that there are about five latent cancer fatalities per 100 manSv. For example, if 10 000 people were exposed to a dose of 10 mSv in a short interval, 5 of them may later on die due to a cancer induced by that dose (IAEA, 2010). In what concerns the risk for hereditary effects in progeny, the evidences are weaker, but ICRP has estimated it to be $0.2x10^{-2}$/Sv. (ICRP, 2007)

People are constantly exposed to sources of ionizing radiation that occur naturally in the Universe. This represents the natural *background radiation*. In addition to natural radiation one is also unavoidably exposed to man-made radiation from sources like nuclear testing and nuclear power plants. This is the radioactive pollution, an artificial background radiation. Apart from the background radiation that one cannot avoid, most of the people will get some doses from health examinations, such as X-ray. In Norway, one normally receives an average annual dose from natural and artificial background radiation of 4 mSv. About 74% of the background radiation originates from natural sources, such as: radon, natural external γ radiation from the environment, natural radioactivity inside human body and cosmic radiation. Mean annual doses to the general population from common sources of ionising radiation are shown in Figure 16. Most of the people will also receive doses from flights and some will receive doses because of radiotherapy or at work. These are not accounted for in the figure. (Folkehelseinstituttet, 2013)

Radon, a noble gas originating from the bedrock, represents the main contributor to natural background radiation. The amount of radon gas varies much from place to place, thus background doses will also vary much among different individuals. It is for instance estimated that 10% of the population receives doses of more than 6 mSv/ year from radon gas and that in some places one can receive doses of up to 500 mSv/ year (Fandrem, 2010a). *Offshore*, people will normally not be exposed to radioactive materials from the ground or radon, thus background radiation is lower than on land. The offshore background radiation is estimated to be about 1-2 mSv/ year. (OLF, 1999)

When it comes to *external doses to workers within the Norwegian petroleum industry*, NRPA states that the industrial radiographers who worn personal dosimeters (see Appendix C for more details about personal dosimeters) given by the radiation authority registered a mean of 1.8 mSv/ year in 2012 and about 1.3 mSv in 2011. Industrial radiographers recorded the highest doses among industrial workers. Well logging personnel that worn dosimeters from NRPA, registered about 0.3 mSv in 2012 and there was no recording in

2011. NRPA also specifies that the most exposed offshore workers are those involved in maintenance activities. (NRPA, 2014)

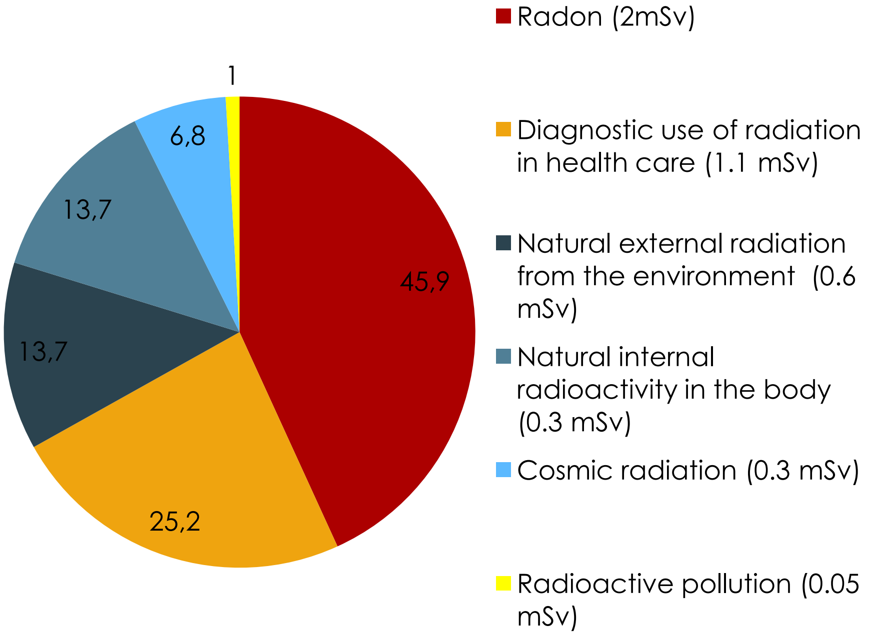

Figure 16: Mean doses (mSv per year) to the population from common sources of ionising radiation (Folkehelseinstituttet, 2013)

Personnel handling NORM receive both external and internal doses from irradiation and respectively, inhalation of contaminated dust (Figure 17). The amount of radiation doses they get depends on the quantities of inhaled dust but also on the concentration of the various radionuclides in the dust. The external doses that NRPA registers are usually low but the internal doses are not recorded, being difficult to collect accurate and complete data. In 1999, there was calculated an average of 0.1 mSv/ year (between 0.01 and 0.7 mSv/ y) from external exposure to NORM. The offshore natural background radiation was not considered. (OLF, 1999)

Table 8 presents some examples of effective doses from 1 gram (1/10 of a teaspoon) NORM dust, with a concentration of 100 Bq/g and different radionuclides in its composition. The expected dose contribution from the radionuclide 'daughters' is considered. They are presented in relation to the average background radiation and to the allowed

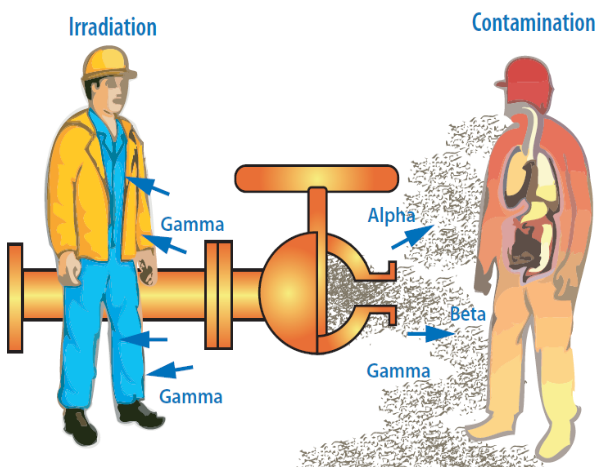

Figure 17: NORM exposure scenarios: irradiation from γ and contamination from α,β and γ (OGP , 2008)

dose limits for occupationally exposed and general population. (Fandrem, 2010.c)

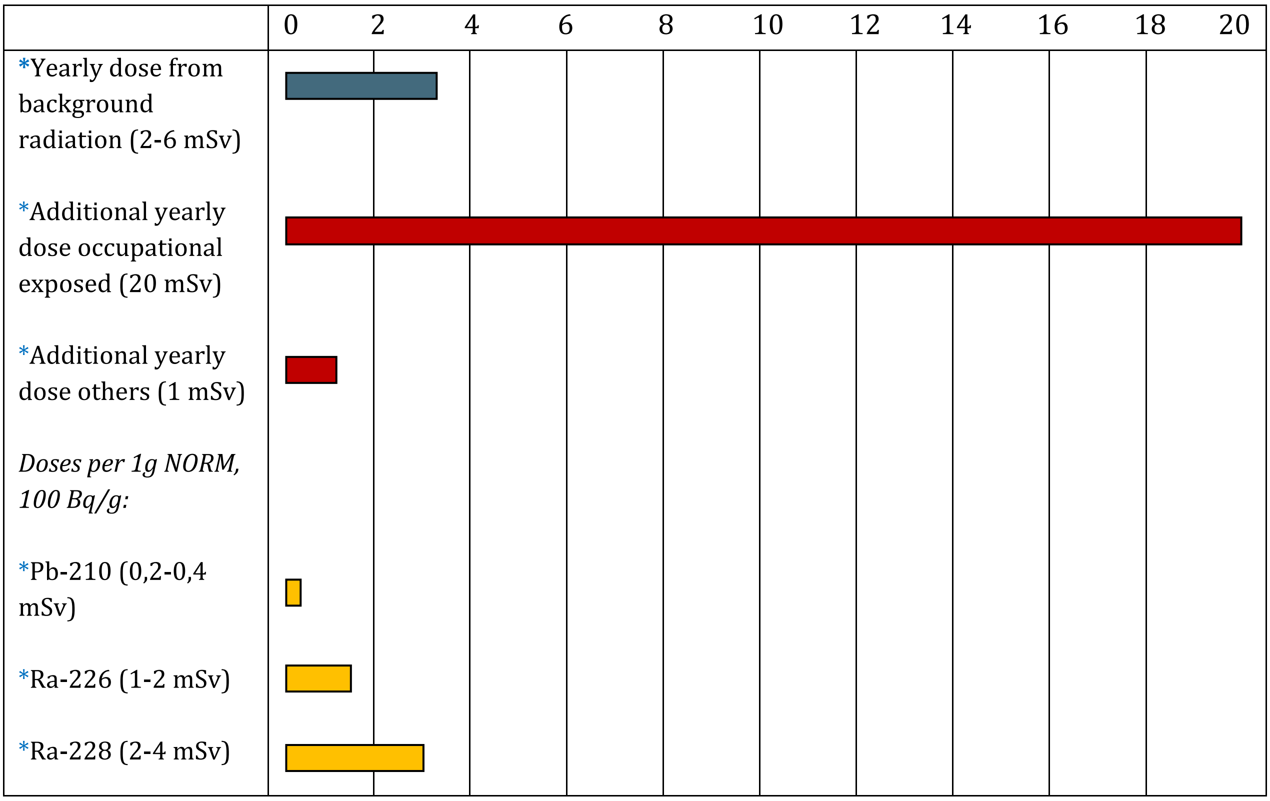

Table 8: Examples of radiation doses. All of the doses (apart from the background radiation) come in addition to the background radiation (Fandrem, 2010.c)**. Given doses of NORM dust for each radionuclide, include also the expected dose contributions from the radionuclide daughters**

6. BARRIERS AGAINST EXPOSURE TO RADIOACTIVE SOURCES

6.1. Radiation protection principles

One of the main purposes of the radiation protection discipline is to ensure the proper use of radiation sources and to prevent the harmful effects of radiation on human health. There are three fundamental principles of radiation protection based on the recommendations from the International Commission on Radiological Protection (ICRP). These principles have been implemented in the national regulations of many countries and form also the basis for both NORSOK S-002 and the Norwegian statutory regulations in this field, the Radiation Protection Regulations. Work involving ionising and non- ionising radiation must fulfil the following principles (Radiation Protection Regulations, 2011):

1. The principle of justification. The benefits of allowing the use of radiation sources have to be greater than the disadvantages
2. The principle of optimization. All doses should be kept as low as reasonably achievable. This is also known as the ALARA principle. If there are reasonably achievable means for further reducing exposure, the undertaking must implement them even if the exposure is low
3. The principle of limitation. There have been established limits for the dose rates NRPA allows in addition to background radiation. These limits are presented in Table 9. These are not considered to be acceptable doses. The ALARA principle shall always apply.

Dose rates to/ around	**Limits**
Non-occupationally exposed workers, general public, risk groups and foetus	1 mSv / year 0.25 mSv / year from one undertaking
Occupationally exposed workers	Effective dose for the whole body or parts of bodies: 20 mSv / year
	Effective dose for skin, hands and feet: 500 mSv / year
	The effective dose for workers with *installed gauges* should not exceed 1 mSv/ year
People outside controlled and supervised area - both public and workers	1mSv/ year
Around source container	On the surface (at a distance of 5 cm): 500 µSv/h for installed gauges At 1 m from the container: 7.5 µSv / h
Storage room / storage space	7.5 µSv/h

Controlled area	6-20 mSv/ year
Supervised area	1-6 mSv/year

Table 9: Dose limits and allowed radiation levels (NRPA, 2012b)

ICRP's philosophy behind the justification, optimisation and limitation principles is mainly to avoid short term heath effects from radiation exposure and to restrict long term health effects to an acceptable level. (IAEA, 2010)

Furthermore, the *'barrier'* concept is going to be mentioned several times throughout this thesis. One appropriate definition for a barrier is: "a physical or nonphysical means with the aim of preventing, controlling or mitigating unwanted events or accidents". (Sklet, 2006). In the radiation protection literature, physical barriers mostly comprise *technological measures* and *personal protective equipment,* while nonphysical barriers are often called *organisational or administrative protection measures*. Administrative barriers are related in this thesis to aspects like: workers competence, procedures and documentation, communication within the organisation and across the industry, monitoring and the workers' participation.

The word 'barrier' is a general term commonly used in relation to health, safety and environment, i.a. to illustrate the positive effects of risk reducing measures ("to prevent, control or mitigate unwanted events or accidents"). It is closely related to one classical accident model with roots in the prevention and treatment of health disorders- often referred to as the 'Energy- Barrier model'. This model is commonly used to identify, prioritise and select protective measures. Barriers are divided into three main categories:

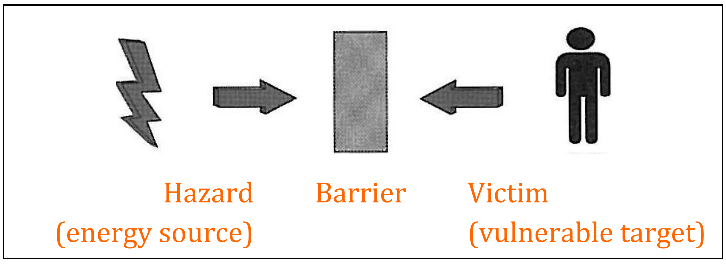

Figure 18: The Energy- Barrier model. Adapted from (Haddon, 1980)

- Preventive barriers related to the energy source (the cause), and to the period prior to an unwanted event
- Barriers aimed at controlling the energy after it has been released, by separating the vulnerable target (e.g.: the workers) from the hazard
- Barriers aimed at mitigating the damages (the consequences) when the control over the source has been lost or an unwanted event has occurred (Figure 18) (Haddon, 1980)

Several radiation protection strategies have similarities to this model, to the barrier concept and the three ICRP principles, as seen in the following paragraphs.

In the context of radiation protection, two of the main purposes of barriers are as already mentioned, to prevent short term health effects and to reduce as much as possible long term consequences. In order to achieve these objectives, there are several essential factors the undertakings should consider, and workers' competence within the field of radiation protection is considered to be one of them. According to the Radiation Protection Regulations, the undertaking shall ensure that all the workers, who may become exposed to radiation, have sufficient competence with regard to the safe handling of radiation sources, radiation monitoring and the use of protective equipment. A radiation protection coordinator shall be able to give guidance to employees, and also to carry out or order measurements and assessments in order to determine the radiation doses. (Radiation Protection Regulations, 2011)

In step with guidelines from the Chemical Regulations one should start the assessment process by finding out if the use of radiation sources can be avoided (The Chemical Regulations, 2001) If no reasonable method exists, then one should follow the principle of radiation protection 'at the source' and find out if the ionising radiation sources or/ and the working methods could be replaced with less dangerous ones. The radiation sources should also be of the type least likely to spill. Working methods where radiation sources can be remotely controlled are to be preferred. If none of these strategies is practicable, the undertaking has to identify measures for minimizing the radiation exposure of the personnel. A thorough planning of the activities is always essential. New activities shall not be initiated before the risk has been assessed in writing and appropriate risk reduction measures have been implemented. (Radiation Protection Regulations, 2011)

The concept of reducing the exposure at the source also implies that the purchase of BAT (Best Available Technology) facilities and equipment should be prioritised and the engineering barriers should be inherent safe by design (IAEA, 2010). Radiation sources shall comply with harmonised standards from the Norwegian Electrotechnical Committee (NEK) and the Norwegian Standards Association (Radiation Protection Regulations, 2011). Furthermore, radiation sources should be designed so that they require minimal need for cleaning and maintenance, and equipment must not lose its shielding properties if exposed to a 'normal' fire (NRPA, 2012b).

Ionizing radiation sources shall be marked with the appropriate symbol: NS 1029 'Symbol of ionizing radiation' (Figure 19). Information that uniquely identifies the radiation source and the activity of the source at a given date shall be specified in the marking. (NRPA, 2012b)

Figure 19: Symbol of ionising radiation (NRPA, 2012b)

The radiation exposure of the personnel will always be minimized by reducing the time they spend in the radiation field and by increasing the distance between personnel and the source (NRPA, 2012b). Storage of open radioactive radiation sources on installations shall be limited to a minimum. Areas where hazardous materials are stored and other hazardous areas such as the wellhead must be properly separated. Moreover, it is particularly important to focus on preventing internal exposure that can occur by inhaling dusts and aerosols or by ingestion. Thus, smoking, eating or drinking with contaminated hands, or working with unprotected wounds, grazes or cuts must be prohibited. Further protection against internal exposure will sometimes be achieved by extraction ventilation with HEPA (high efficiency particulate air) filters, from points where radiation dispersions are likely to occur. Open radiation sources shall be contained whenever possible. (IAEA, 2010)

According to the Radiation Protection Regulations, working areas with annual dose rates between 1-6 mSv must be marked with the radiation trefoil and warning signs (e.g. with 'Access restricted to unauthorised persons'), while areas with dose rates between 6-20 mSv/year must be in addition cordoned off and workers need to undergo regularly health checks (Radiation Protection Regulations, 2011).

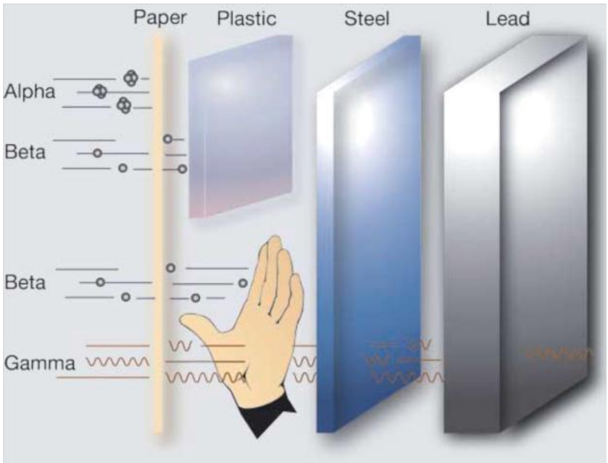

Figure 20: The penetrating capacity of alpha, beta and gamma (IAEA, 2010)

Exposure to personnel will also be reduced by using appropriate shielding material against radiation (NRPA, 2012b). Alpha particles can be stopped by a sheet of paper and they do not penetrate the surface layer of human skin. Beta particles will be stopped by thin layers of metal or plastic. α and β emitting particles are usually considered hazardous to people's health only if they are inhaled or ingested. Gamma rays have a higher penetrating capacity than alpha and beta and they can only be shielded by layers of lead, steel or other dense materials (Figure 20). A few cm of lead will stop efficiently even the most powerful γ - rays. For X-rays and weaker γ - rays the thickness can be below 1 mm. Gamma rays, however cannot be completely stopped and they represent a source of external radiation. (OGP , 2008)

Administrative or organisational controls may be less effective than engineering controls at the source because their effectiveness relies on the cooperation of workers. Workers cooperation is, e.g. needed when access to unqualified personnel and the amount of time qualified personnel can spend inside controlled or supervised areas are restricted (IAEA, 2010).

Similar to the guidelines from the Chemical Regulations the use of personal protective equipment (PPE) should always be the last resort, i.e. when no engineering or administrative protection method is reasonably practicable. It is essential that PPE is correctly selected and maintained. The most common type of respiratory protective equipment (RPE), the filtering face piece respirator helps to keep contaminated gloves away from the mouth area but they do not provide any protection against skin contamination. Facial hair, even growth over the working day, will lift some masks and allow inward leakage of contaminated air. In order to avoid this, RPE such as hoods, visors, blouses or suits should be worn. This type of equipment would also allow users to wear prescription spectacles. For further details about PPE see Appendix B. One should always be aware of the new risk factors the use of PPE might introduce. For example, RPE might impair workers' field of vision, hearing or capacity to communicate. Thus, increased awareness and consideration are needed. (IAEA, 2010)

Workers who can be exposed to more than 1 mSv/year and personnel working with service, maintenance and replacing of sources shall wear personal radiation dosimeters (see Appendix C) (NRPA, 2014), and they shall be informed in writing about dose readings (Radiation Protection Regulations, 2011). The time interval measurements are carried out shall normally be between one and three months. When the dose rate for penetrating radiation cannot be measured, the dosimeter readings should rather indicate the radiation dose behind 10 mm soft tissue, the so-called Hp (10). Then, the dose results can be related to the annual dose limit of 20 mSv (NRPA, 2006). If there are reasons to believe that an employee has exceeded the dose limit, the employer shall immediately carry out an examination to identify the causes thereof, and initiate measures to avoid repeats. (Radiation Protection Regulations, 2011)

The undertakings shall also have good routines after work completion, like the decontamination of the working site and of any equipment used, as well as appropriate waste control. Decontamination should be followed by control measurements of radiation doses. (IAEA, 2010)

The undertaking is responsible for the protection of radioactive radiation sources against theft, sabotage and damage, including fire and water damage. If any accident or abnormal event occurs, the undertaking shall inform the Norwegian Radiation Protection Authority within 3 days at the latest (Radiation Protection Regulations, 2011). There shall be maintained an up-to-date record over all the ionising sources on the installation. A copy of the record should be kept at an onshore location in the event of a serious incident on the platform (IAEA, 2010). As stated in NORSOK S-002, the record shall provide information about location including temporary relocations, type of equipment and radioactive source, radiation levels, as well as required protection (NORSOK S-002 , 2004). An inventory describing all the radiation sources shall also be available at the storage site. Furthermore, the storage site shall be locked and marked with an ionising radiation warning sign (Radiation Protection Regulations, 2011), and one should control that the sources are in place at least once a week (NRPA, 2012a).

Each individual device shall have a technical measurement protocol including results from completion, acceptance testing, periodic checks, as well as maintenance and service reports. A leakage test shall be performed at points where the source encapsulation is often exposed to mechanical or chemical wear and tear, in order to find out if the encapsulation is damaged (Radiation Protection Regulations, 2011).

6.2. Sealed Radioactive Sources and Generators

6.2.1. Industrial Radiography

According to the Radiation Protection Regulations and to the principle of substitution of hazardous radiation sources by less dangerous ones, the undertakings should whenever possible perform radiographies by help of the X-ray equipment (NRPA, 2012b). However, X-ray equipment is not intrinsically safe and this is the reason why gamma radiography is more frequent in the offshore petroleum industry.If the X-ray radiography is not reasonably practicable, then selected source activities should preferably not exceed 400 GBq for ^{60}Co, 1500 GBq for ^{192}Ir and 3000 GBq for ^{75}Se. (NRPA, 2012a)

Undertakings that perform industrial radiography and maintenance of industrial radiography equipment need the approval of Norwegian Radiation Protection Agency (Radiation Protection Regulations, 2011). Two certified operators are required for radiography on open installations. One of them must be able to document competence as a certified supervisor and the other one as a certified operator (NRPA, 2012a).

Radiography containers and associated equipment shall meet the requirements specified in ISO 3999. Maximum leakage radiation from portable radiography containers is set to a dose rate of 500 µSv per hour at a 5 cm distance from the surface of the container and to 20 µSv per hour at 1 m (NRPA, 2012a).

In order to satisfy the requirements related to written instructions and procedures in industrial radiography, one should as a minimum prepare the following: instructions for the radiation protection coordinator, i.e. a description of hers/his responsibilities; instructions for supervisors and operators; safe Working Procedure for the use of radiography devices and special procedures for e.g. access control, warning signs and notification (NRPA, 2012a).

The following protection equipment should accompany the gamma radiography device: remote handling tongs (at least 1 m long); lead blocks or bags of lead shot for source shielding; cordoning equipment such as ropes and warning signs; emergency or cut-container, and an additional monitoring instrument with telescope detector to locate the radiation source. All transfers of unshielded radioactive sources must be made with the greatest possible distance between the source and the body. The distance shall be maintained at minimum 1 m from the body e.g., by using the remote handling tongs. (NRPA, 2012a).

Emergency drills should be held annually. Both the container and the gamma source capsule shall be recorded in the ionising source inventory (NRPA, 2012a).

Where physical barriers would reduce the general safety level, e.g. block emergency exits and where visibility is good, authorized guards can be positioned at the entrance of the restricted area (NRPA, 2012a). Other barriers for minimizing the extent of the controlled areas would be: moving the items to be radiographed as far away from the living areas as possible e.g., to the cellar deck where feasible; placing shielding near the radiation source and carrying out the radiography in the vicinity of storage tanks that provide shielding. Audible and visible warning signals (e.g. a flashing light) will also aid restricting access to controlled areas. (IAEA, 2010)

Everyone working with industrial radiography sources must wear personal dosimeters and the dose reports shall be kept for 60 years (Radiation Protection Regulations, 2011). A direct reading dosimeter (see Appendix C) should be used in addition to the one aimed for measuring gamma radiation. Direct reading dosimeters are designed with an alarm that will immediately indicate a high dose or dose rate in the event of accidental exposure. Workers who accidentally receive high doses may have their work with radioactive sources restricted for the rest of their working life. The position of the radiation source shall always be checked by help of the hand held monitor. By using the hand held monitor, one will have enough time to plan well the rescue work in case of abnormalities like when the source gets stuck in cables or detaches from the wire. (IAEA, 2010).

Dose rates exceeding regulatory limits are possible within industrial radiography, but normally such operations are accomplished with radiation doses below 3- 5 mSv (NRPA, 2012a). The most common radionuclides used in gamma radiography, Ir-192 and Co-60, have specific activities of several hundreds or thousands of GBq. Therefore, if the encapsulation has damages, the consequence can be extremely large internal and external doses to those exposed. Thus, leakage tests should be regularly performed (IAEA, 1998).

6.2.2. Well logging

Logging companies shall have an authorization from the Norwegian Radiation Protection Authority and the operators must use personal dosimeters in order to record radiation doses (Radiation Protection Regulations, 2011). Dosimeters should record both gamma and neutron doses (NRPA, 2014).

Figure 21: Transport container used as a temporary store for well logging sources (IAEA, 2003)

Sealed sources used in well logging need to be transported and stored while they are not in use, in containers designed to provide additional shielding. These containers, also called shields can be surprisingly large, especially for neutron sources, which have a high penetration capacity. There are often used thick- walled boxes of about 1.75 ^{3}m (Figure 21). When sealed sources are transferred from the container to the logging tools this is done by help of a handling rod of about 1.5 m long, in order to maintain a safe distance from the radioactive material. Appropriate shielding placed near the source will reduce the extent of the controlled areas and audible and visible signals will aid restricting the access. Furthermore, the primary radiation of the source must be always directed away from any occupied areas (IAEA, 2010).

There have occurred several incidents where disconnected sources have been lost into the well. If the source falls into the well it could be damaged, contaminate the well, and the logging operators could easily receive considerable radiation doses. Difficult 'fishing' operations can also lead to long exposure periods for the workers. A plate covering the annulus around a well logging tool, or a chain connecting the source to the handling rod while it is being screwed into the logging tool will hinder the source from falling into the well. An appropriate monitoring instrument must be always used in order to detect hazardous contamination from the well. If the source has been disconnected, it could be recovered by help of the handling rod. In the event that the source cannot be recovered and it has to abandoned inside the well, one should cement it in, eventually by use of coloured cement, and the wellhead should be marked with a clear warning notice about the abandoned source. (IAEA, 2010)

6.2.3. Installed gauges

Work with powerful installed gauges, also known as nuclear or nucleonic gauges (often above 10 GBq) should be performed by trained and authorized workers (Fandrem, 2010b). There shall not be possible to disassemble the installed gauges without using special tools or without breaking the seal of the radiation source (Radiation Protection Regulations, 2011).

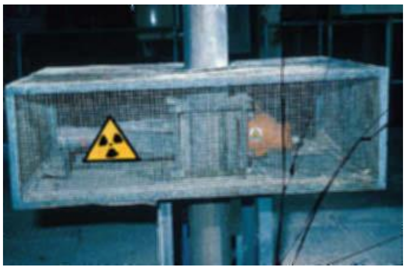

Figure 22: Installed density gauge mounted in housing (IAEA, 2003)

The gauges are usually mounted in steel or lead housings of about 30 cm in diameter, as shown in Figure 22 (IAEA, 2010). The containers should be brightly coloured and labelled with radiation warning signs. When they are mounted on pipelines or vessels there must be no clearance which would allow workers hands or fingers to gain access to hazardous area and especially to the primary beam (IAEA, 2010). All the installed gauges should be regularly monitored by using the dose rate meter, e.g. monthly. One should also make sure that controlled areas are clearly marked by physical barriers. Warning signs shall always be clean and readable, especially on gauges' containers and on access doors (IAEA, 1996b).

The closing mechanism of the equipment shall have clear positions for 'open' and 'closed' and shall be robust (NRPA, 2012a). The equipment must always be closed and locked before allowing workers to entry vessels with installed gauges or before the removal of the container from its installed position (IAEA, 2010).

One should always have the dose rate mater switched on whilst working with nuclear gauges (IAEA, 1996b). If all or parts of workers' body come into the primary beam of the gauges, received radiation doses could quickly exceed the normal levels (Radiation Protection Regulations, 2011). Experience from past events indicates that radiation doses from unwanted incidents implying control sources are usually below 5 mSv per year (NRPA, 2012a).

If the shielding container or the sealed source seems to be damaged, one should measure the dose rates and restrict personnel's access. There should be also performed a leak test to find out whether the source has been severely damaged. Workers suspected to have touched the contaminated surfaces should remain inside the marked area and the supervisor should be noticed (IAEA, 1996b).

6.2.4. Mobile gauging equipment and articles with radioactive sources

A portable gauge should be used only when it is accompanied by all the necessary ancillary equipment such as: handling tools, cordons, warning notices and signals and a dose rate meter. Work with gauges usually implies restricting the access to the place where the operations are carried out. After work completion one should examine the gauges carefully and always use a dose rate meter to check if the shutter has closed the device properly. Mobile gauges and the ancillary equipment require also regular maintenance and leak test. The container should be clean, the markings legible and all the moving parts maintained by help of suitable lubricants (IAEA, 1996b).

Figure 23: The removal of a pipeline pig (Source: http://www.nord-stream.com/press-info/images/arrival-of-the-inline-inspection-tool-in-lubmin-3502/)

The likelihood of loss or damage is greater for mobile gauges (particularly small articles, e.g. beta lights). Thus, equipment should be included in plant and equipment drawings and there must be carried out regular checks on stored gauges e.g. weekly (IAEA, 2010).

Individuals involved in tasks implying the use of neutron sources need to wear dosimeters that will measure both gamma and neutron radiation (IAEA, 2010).

Sealed sources fitted on intelligent pigs contain radionuclides with high energy and specific activities in the range of kBq-MBq. Pigs are sent through pipelines and removed at the opposite end by operators, by help of lifting equipment (Figure 23). It is essential that all the operators are aware about the hazards and that appropriate precautions are taken. They must avoid coming in contact with sealed sources and wear suitable personal protective equipment. Intelligent pigs should always be stored away from an occupied area.

6.3. Unsealed radioactive sources

6.3.1. Radiotracers

The injection company must prepare thoroughly the well site before operations involving unsealed radioactive sources. The preparations should also include a survey of the working site and the delimitation of the controlled area. The company is responsible for bringing appropriate containment for contaminated items, necessary monitors and its personnel should use suitable protective equipment. Moreover, the injection company must have a contingency plan for all possible unwanted events, written instructions and all the necessary equipment available. (IAEA, 2010)

The radiotracers need to fulfil a series of requirements e.g.: they need to have a stable form, they should be easy to detect by monitors and their radiotoxicity should be as low as reasonably achievable. Some of the radionuclides used are volatile. By selecting non-volatile radionuclides one would eliminate the risk of inhaling hazardous particles. For instance, ^{99m}Tc could be a better alternative than^{131}I, a radionuclide with very high energy. (IAEA, 2010)

When radiotracers are being injected into high pressure systems it is essential that valve systems have all the connections tight and that all the precautions are taken in the event of a backward flow of fluids, also called a ‘sand out’. This could contaminate the surface around the wellhead and possibly other areas or equipment. Injection companies have the responsibility of monitoring and if needed, decontaminating the equipment until allowed clearance levels (IAEA, 2003).

Work with radioactive substances that emit very low beta energy, like ^{3}H and ^{14}C requires no personal dosimetry with respect to external radiation (NRPA, 2006). There are used ^{3}H and ^{14}C with specific activities of up to 1TBq, but the activity concentrations at the injection wells are very low. However when it comes to ‘hard’ beta emitters like ^{85}Kr, a fraction of the emitted radiation will be reflected and personnel do need protection against external exposure. ‘Soft’ beta emitters spiked with ^{82}Br require also caution with respect to external radiation. (IAEA, 2003).

6.3.2. NORM

Regular, for example triennially surveys and monitoring should be performed in order to assess whether NORM is present at an installation. Surveys should be carried out even more frequently after e.g. changes in the salinity of produced water (IAEA, 2010). If NORM is traced at an installation one should map the contaminated areas. When measurements show that the specific activity of deposits exceeds 1 Bq/g dust of either ^{226}Ra and ^{228}Ra or ^{210}Pb, the deposits must be classified as radioactive material and appropriate protective measures have to be implemented (Pollution Control Act, 2013). The focus should lie on implementing measures against regular inhalations of NORM dust (Saxebøl, 2003).

A few basic radiation protection principles when working with NORM are: restricting the access to the working site, keeping the material moist, maximising the distance to the source, minimising exposure time and the use of correct personal protective equipment. The PPE should as a minimum include suitable respiratory masks and gloves (OLF, 1999). The following types of PPE are among the recommended ones: waterproof coverall; neoprene, PVC, or nitrile rubber (NBR) gloves and half-face respirators with HEPA cartridges, which are tested for fit. For more details about different types of PPE see Appendix B. Moreover, personnel handling NORM inside working tents should also wear personal dosimeters (see Appendix C). Eating, drinking, smoking and chewing should not be allowed in potentially contaminated work areas, and after working with contaminated equipment personnel should always wash up thoroughly (OGP , 2008).

As a routine, tanks or vessels in gas plants should be ventilated through forced ventilation for at least four hours before cleaning or maintenance operations (especially in propane and methane streams). This would i.a. force out the radon gas accumulated inside. After work completion all personnel and equipment should be examined for contamination with NORM (OGP , 2008).

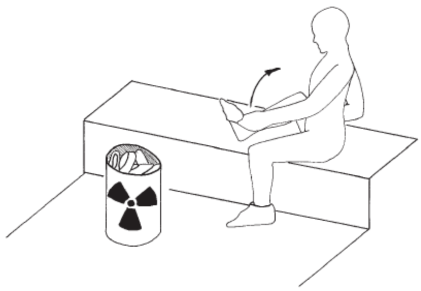

Figure 24: Clear barrier between clean and contaminated area (IAEA, 2010)

According to the International Association of Oil & Gas Producers (OGP), some basic control procedures when handling NORM contaminated objects would be as follows (Figure 24) (OGP , 2008):

- Holding a safety meeting where operators, managers and supervisors participate. Discussed topics should include, i.a.: critical operations, radiation and contamination levels, emergency procedures, PPE
- Delimitating a boundary around the working site
- Placing containers for discarded PPE and contaminated waste at the exit of the working site
- Marking the boundary with warning signs containing the radiation trefoil and a message like: "Caution: NORM Material"

- Segregating the entrance from the exit way to prevent spread of contamination
- Only essential personnel is allowed inside the boundary
- Placing plastic ground covers, drip-trays or catch pans on the ground prior to maintenance of contaminated equipment or prior to opening inspection hatches, sludge traps or pig receivers. The plastic covers should be of an appropriate size and made out of a waterproof and durable material
- Sealing and labelling of openings on contaminated equipment or pipes, by use of e.g. heavy - gauge and UV- stabilised type of plastic. Monitoring results above background levels should be a positive indication of contamination
- Cordoning and labelling of temporary storage places with the warning: "Containing Radioactive Materials"
- Loading contaminated waste from maintenance activities into marked containers. Waste samples should be analysed for radioactivity
- Transporting of contaminated materials and equipment in specially dedicated vehicles
- Workshops are always informed when contaminated equipment is sent for repair or maintenance
- After work completion personnel remove their protective clothing before leaving the contaminated area
- All the surfaces are monitored and cleaned if necessary before the removal of physical barriers

7. EMF ON OFFSHORE INSTALLATIONS

In 2008, there was carried out a pilot project about non-ionising sources on Norwegian offshore platforms, including powerful ELF and RF sources. Some of the main objectives of the pilot project were: assessing the prevalence of non-ionizing radiation sources on Norwegian offshore installations, establishing best practices for systematic monitoring and mapping of non-ionising sources and experience transfer to the rest of the industry. The assessment included also cabins for personnel and offices where low levels were expected, but where exposure time could be relatively long. Workers' exposure was mapped by help of person borne monitors.

The installation chosen for this project was a gas platform, Troll A, at that time, the only one on the NCS operated with electric power from the shore. Two powerful compressors had been installed on the platform for this purpose.

7.1. Sources of ELF and SMF

It was assessed that equipment like the low and high frequency transformer rooms, the switchgear room (Figure 26) and the frequency converter room (or the drive space room) had levels above background level (considered to be 0.1 μT), but below the exposure limits for general population. All of them had the access restricted. There have been also realised measurements of the exposure level in areas close to large power consumers and generators such as the two installed compressors, and the situation was similar. However, exposure levels over the recommended limits were possible within 0.5- 1m from these powerful generators. Thus, it was decided that measures like warning signs, access restriction, as well as better knowledge about radiation protection were necessary. Assessed exposure levels inside personnel cabins were below background level.

Figure 25: Low voltage switch gear room and LV transformer room (in the small picture) (Peikli, 2008)

Despite relatively low levels, there was decided to adopt a precautionary strategy to reduce exposure levels as much as practicable at the source and by help of engineering measures. In line with this strategy, there were established additional exposure limits for the situations when EMF levels were below international exposure limits but reducing measures needed to be assessed. For instance, for magnetic fields above 0.4 μT it was decided that strong ELF sources close to personnel cabins and permanent offices should be avoided. For fields above 10 μT there was in addition recommended to avoid as much as practicable the traffic in the vicinity of the sources. For levels above the international limit for the general population of 100 μT (in 2008), the access to the EMF sources was only allowed for authorised personnel and for as short time as possible. Finally, for magnetic fields above the occupational limit of 500 μT (in 2008) there was in addition required a Safe Job Analysis (SJA) and documented and well implemented protection measures were compulsory. That also implied establishing administrative measures related to working at a safe distance from the source.

Both LV and HV switch gear and transformer rooms had levels above 0.4 μT. The low voltage ones exceeded 10 μT and powerful motors (e.g. of 30 MW) had levels above the occupational limit at 1 m distance (see database for EMF from attached DVD). Moreover, it was assessed that magnetic fields around equipment (e.g. a 7.3-2.9 MW high voltage transformer room) were much higher right after the equipment was switched on but they decreased very quickly as the voltage increased. Exposure decreased also very quickly with the square of the distance. For instance, magnetic fields around powerful supply cables were exceeding general population limits at more than 20 cm from the source, but at only 1 m they were below background level. This also applied for SMF on the surface of powerful motors, although levels were well below exposure limits even at the worst point.

7.2. Sources of Radio frequency fields

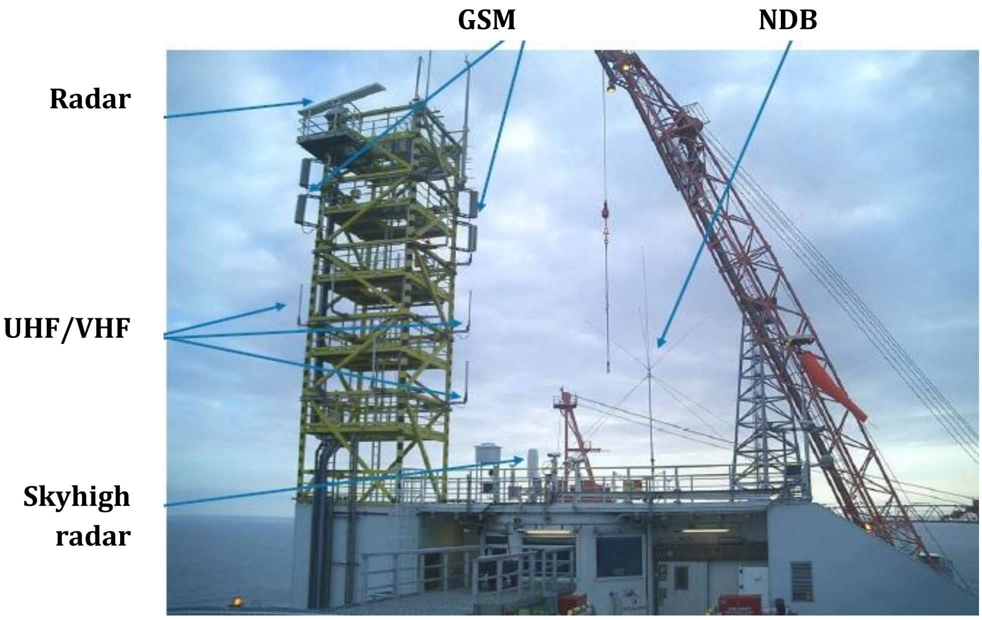

Figure 27: Different RF sources installed on an antenna tower. Adapted after: (Peikli, 2008)

The project's assessment results for typical RF sources on Norwegian offshore platforms are presented in Table 11. Different sources of SHF (e.g., Radio link 1-4), UHF, VHF and MF (NDB for helicopters) are listed in the table, together with their frequency and irradiated effect.

Source	Frequency (MHz)	Irradiated Effect (W)
Radio link 1	7428	1
Radio link 2	7484	1
Radio link 3	7428	2
Radio link 4	7484	2
Radio link 5	814	
UHF base station Helitower	410	2
UHF portables close by	410	1
Portables in general	410	1
VHF marine in Emergency Room	160	3.5
VHF marine in Radio Room	160	3.5
VHF marine in Control Room	160	3
VHF marine in Helitower	160	3.5
VHF marine in Telecom Room	160	3.5
VHF in cranes	160	1/2
VHF aeromobile in Helitower	130	6
VHF aeromobile in Radio Room	130	5
VHF aeromobile Telecom Room	130	10
VHF aeromobile portable	130	1
UHF in cranes	410	2
UHF link to rigs/ ships (Shipcom)	420	5
NDB for helicopters	0.561	100
Maritime Radar S-band (in antenna tower)	3000	30000 for max. pulse
Maritime Radars X-band	9410	25000 for max. pulse
DME for helicopters	1100	100
UHF Pager	420	5
GSM antenna	900	
CCTV Transmitter	2450	0.1

Table 10: Measurement results for typical RF sources offshore (Peikli, 2008)

Measured RF levels from radars and antennas were well below the guideline limits, in areas available for normal traffic. However, in the same way as for ELFs, there was adopted a precautionary strategy and priority was given to engineering measures. The corresponding thresholds for mean power densities were 0.1, 1, 10 and respectively 50 W/m^2, and for mean electric fields strengths they were: 6, 19, 61

Figure 28: Maritime radar X-band (Peikli, 2008)

and 137 V/m. The transmission of the maritime radars with very high irradiated effect was directed away from any traffic (were set on “Sector blanking”). They were also placed away from traffic and marked with warning signs (Figure 29). Some other types of RF sources from Table 11 are illustrated in Figure 28.

8. HEALTH EFFECTS FROM EXPOSURE TO EMF

The exposure to EMF and its possible health risks has received increasingly more attention over the last thirty years and several expert groups have been working with this topic in recent years.

In the same way as for ionising radiation, one must consider both the possibility of short time effects and of long-term effects for any of the non-ionising sources. There are several evidences about the acute effects of the different types of EMF, but when it comes to the long term effects the evidences are unclear. Unlike radioactive exposure, EMFs will not be gradually accumulated in the body up to a lifetime dose and to the outbreak of a certain disease. Similar to e.g. light exposure, the primary effects disappear when the exposure is terminated. One existing hypothesis about the possibility of long-term effects is related to the indirect health effects of EMF. Acute but non-hazardous effects from exposure to EMF could cause a temporary acceleration of an otherwise natural evolution path, e.g.: a temporarily increased growth of already established cancer cells, a temporarily compromised immune system, or the delay or acceleration of growth processes in the foetus. Such secondary effects will always depend on the overall health status of the individual. (NIEHS, 1998)

8.1. Potential health effects from exposure to ELF and SMF

Normally, static and low-frequency field do not cause any permanent biochemical or structural changes unless the exposure is so strong that it leads to tissue damage, e.g. burns. (NIEHS, 1998)

One of the *acute effects* from exposure to powerful ELF is considered to be the induction of electric fields in the body (typically above one fifth of the external field) and the induction of associated currents, with the excitation of nerves or muscles as a consequence. The induction of currents inside the body will depend on the direction of the magnetic fields with respect to the surface and the body height. Below the threshold for nerve and muscle activation, the major short time effect of ELF is the induction of retinal phosphenes that leads to the perception of faint flickering light and disturbs the visual field. Moreover, exposure to ELF can cause electric charge effects on the surface of the body. These three short time effects are the only well established health effects from exposure to ELF and forms the basis for the recommended exposure limits. (ICNIRP, 2010b)

Long-term effects from exposure to ELF are less clear. It has not been found any strong scientific evidence that the ELFs people are exposed to in their daily life or in most of the occupations lead to any particular form of injury or disease. A comprehensive document on the biological effects of exposure to EMF is the report from 2013 of an independent working group established by the European Commission: The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). The conclusions of this report are based on numerous scientific journals and documents from governmental authorities. Neither research results from laboratory studies nor studies on population groups, indicate that ELF radiation is carcinogenic. However, studies have repeatedly suggested an increased risk of childhood leukaemia upon long-term average exposure to magnetic fields above 0.4 μT. Investigations from the last couple of years have also come to similar conclusions regarding the risk of developing chronic leukaemia among occupationally exposed (Tynes, 2003). Recent results do not show any effect of the extremely low frequent magnetic fields exposure on reproductive function in humans but it is still unclear whether exposure to these fields may have an impact on the development or progression of Alzheimer's and neurodegenerative diseases and further studies are required. (SCENIHR , 2013).

When it comes to SMF, the observational studies on population groups have shown that strong SMFs (typically above 2 T) may cause subjective symptoms like vertigo or nausea for people walking or moving in the presence of these fields. Moreover, studies have repeatedly stated that SMFs can affect the expression of certain genes, primarily in mammalian cells, but this depends on the duration and gradient of the fields. Further investigations are required. (SCENIHR , 2013).

8.2. Potential health effects from exposure to RF

Biological effects from exposure to radiofrequency radiation are highly dependent on the frequency and they are usually categorised into thermal and non-thermal effects.

At a high frequency range, above 10 MHz (e.g.: VHF communication, UHF aviation radar), RFs can lead to energy absorption inside the body and *thermal effects*, such as tissue heating. In the frequency range between 100 kHz and 10 MHz (e.g. the frequency of certain navigation transmitters) exposure limits lead to both induced currents (similar to ELF) and energy absorption. It is considered that generally, thermal injuries may occur after a temperature increase in the tissues of 1-2 ^{o}C. The international exposure limits are mostly based on this finding, even though the recommended thresholds are well below the actual damage level, due to a precautionary approach. (ICNIRP, 1998)

There have been performed thorough investigations on a range of potential thermal health effects, but as reported by the International Commission on Non Ionizing Radiation Protection, most of the evidences are unclear and sometimes implausible, especially under the exposure limits. Among the potential health effects that have been studied there are the risk of: cataracts, cancer, reduced semen quality, foetus damage, and the increased permeability of the blood-brain barrier with consequences on the immune system. However, there is still high uncertainty about long term effects of tissue heating and this also applies to *non- thermal effects* and more research is needed. (ICNIRP, 1998)

According to SCENIHR, recent studies have not proven the following hypothesis either: the increased risk of brain tumours or other cancer types of the head and neck region, such as glioma (tumour originating in the brain or spine) and the potentially adverse effects of RFs on the cognitive functions during wake and sleep. The hypothesis of the increased risk of acoustic neuroma (a type of benign brain tumour) from exposure to RFs requires further investigations. (SCENIHR , 2013)

One study from 2007, financed by the Norwegian Department of Defence approaches the issue of the health effects from occupational exposure to powerful military radars. The report was signed by a working group including experts from: NRPA, 'Rikshospitalet - Radiumhospitalet' and the department itself. Assessment conclusions are in line with conclusions from other international studies: one cannot expect thermal effects to those exposed below the exposure limits, overexposure occurs only in special situations (e.g. maintenance and reparations) and non-thermal effects cannot be completely ruled out because of insufficient data and evidences. (Forsvarsdepartamentet et.al. , 2007)

Moreover, another comprehensive study from 2012, commissioned by the Norwegian Health Care Ministry and the Ministry of Transport concluded that there are no adverse effects from weak high- frequent fields such as the ones from wireless network either. (Folkehelseinstituttet, 2012)

8.3. Potential health effects from combined EMF exposure, and from co-exposure of EMF and other stressors

There have been only carried out a few studies on combined exposure to EMFs of different frequency ranges, so even though none of them proves any particular adverse effect, the total EMF level should be maintained below exposure limits, as a precautionary measure. Further studies are necessary especially for combined exposure to low and high frequencies, an increasingly actual issue nowadays, both home and at work. Aspects like gene damage, cancer and the impact of neurological damages on behaviour ('neurobehavior') need more investigation. (SCENIHR , 2013)

Results from the research on combined effects from EMF and other stressors indicate both negative and positive effects of non-ionising radiation on other factors such as certain chemical and physical agents. For instance there have been suggested that exposure to ELF may increase the carcinogenic effects of some agents, while RFs may decrease the harmful effects of radioactive sources. Further laboratory studies are required to clarify the relevance of these results. (SCENIHR , 2013)

9. BARRIERS AGAINST EXPOSURE TO EMF

Directive 2012/11/EU lays down minimum requirements for occupational protection against exposure to EMF, i.e. fields with frequencies between 0 Hz to 300 GHz. This directive applies in Norway and replaces the previously applicable Directive 2004/40/EC. According to the Directive, undertakings shall first and foremost respect the three basic principles of radiation protection. (EU, 2012)

In line with the *optimisation principle*, radiation from EMF sources must be kept as low as reasonably achievable and there shouldn't be used stronger radiation sources than necessary. Both the directive and the Radiation Protection Regulations refer to the exposure limits recommended by the International Commission on Non-ionizing Radiation Protection. ICNIRP has introduced the EMF exposure limits through a set of guidelines that are based on health effects not necessarily hazardous, but nevertheless undesirable in most of the situations (Peikli, 2008). These are mainly the acute effect of muscle and nerve cell simulation from ELFs and the acute thermal effects of the RFs (ICNIRP, 2014). The guidelines are as follows:

- 'Guidelines for limiting exposure to time- varying electric and magnetic fields (1 Hz to 100 kHz)', from 2010; applicable to ELF (ICNIRP, 2010)
- 'Guidelines for limiting exposure to static magnetic fields', from 2009; applicable to Static Magnetic Fields (ICNIRP, 2009)
- 'Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)', from 1998; applicable to ELF, SMF and RF (ICNIRP, 1998)

The most frequently used exposure limits from the guidelines are summarised in Table 12:

Types of EMF	**General Population** *Magnetic Flux Density(B),[μT] or[T]* *Electric Field Strength (E), [kV/m]* *Power Density [W/m²]*	**Occupational Exposed** *Magnetic Flux Density(B), [μT] or[T]* *Electric Field Strength(E), [kV/m]* *Power Density [W/m²]*
ELF	200 μT 5 kV/m	1000 μT 10 kV/m
Static Magnetic Fields	400 mT*	Head, body:2T Arms, legs:8T
RF	10 W/m²	50 W/m²

Table 11: Basic restrictions for exposure to EMF.****0.5 mT for risk groups: e.g. persons with implanted electronic medical devices and implants containing ferromagnetic material***

Furthermore, according to the Directive, the undertaking shall ensure that workers who may become exposed to EMF and their representatives receive any necessary *information and training about*, i.a.: protection measures; safe working practices; exposure limits and their meaning; results from exposure assessments; how to detect adverse health effects caused by exposure to EMF, how to report them and when they have the right to health surveillance. (EU, 2012)

The radiation protection strategies for non-ionising radiation are basically the same as for ionising sources and they also include i.a.: the substitution principle, the radiation protection 'at the source', the principle of maximising the distance from the source and minimising the exposure time, as well as the principle of PPE used only as a last resort. In line with the *substitution principle*, if it is possible to select equipment or working techniques leading to lower EMF fields, the undertaking should prioritise these as long as it is reasonable. The purchase of low emitting equipment is an issue to be addressed in the early design phase of any petroleum installation. If the exposure levels cannot be reduced by selecting other equipment or working procedure, one should follow the principle of *radiation protection 'at the source'*. This could be achieved by engineering controls like the use of interlocking mechanisms and shielding (EU, 2012). *Electric fields* are easily shielded by materials that conduct electricity (e.g. walls) and they penetrate very little through the body. *Magnetic fields* on the other hand, are difficult to shield and they penetrate easily through the body. They are little affected by materials in the environment, apart from strong magnetisable materials such as iron and steel (Saxebøl, 2003). As already mentioned in subchapter 3.2., equipment that is plugged but is not turned on does not generate any magnetic fields and if equipment that is not in use is unplugged, it will not generate electric fields either.

When equipment is switched on, in the same way as for radioactive sources, workers should try to maximise the distance (by e.g. remote control) and minimise the exposure time (Radiation Protection Regulations, 2011). Taking frequent breaks without exposure would also reduce the possibility of any tissue damages arising from thermal effects. Moreover, unshielded radiation will be reduced by the square of the distance (Tynes, 2003). When one decides the layout of the installations, i.e. early in the design phase, it is important that the EMF radiation issues are considered. According to *NORSOK S-002,* the location of high voltage equipment such as the transformer room closed to permanently manned working and living areas should be avoided.

It is also essential to establish and implement an appropriate *maintenance* programme in order to ensure that equipment and its safety barriers function as intended (EU, 2012). A few simple measures would be: checking if all the shielding covers are on and screws are tight, replacing any damaged brass foils used for conducting the current and for grounding, and verifying if the settings where machines are placed are optimal for EMF reduction (EMF-NET/European Commision, 2008).

Engineering controls followed by *administrative controls* should always be the preferred reduction measures. Additionally, *personal protection measures* can be used, but these should be regarded as the last option (e.g. insulating gloves against high-frequency shock and burns). (Tynes, 2003)

Moreover, as stated in the Directive 2012/11/EU when *risk assessments* are carried out, the employer shall always consider the following aspects: the level, frequency spectrum, duration and type of exposure; recommended exposure limits; the health and safety of workers at particular risk; the results from health surveillances, and if there is any interaction with medical equipment and devices such as cardiac pacemakers and other implanted devices. The employer shall also analyse the co- exposure of workers to EMF sources and other stressors as well as their simultaneous exposure to multiple frequency fields. Moreover, in agreement with the Radiation Protection Regulations, undertakings shall keep an updated *inventory* over strong non - ionising sources (likely to exceed stated limits, e.g. radar) in the same way as for radioactive sources.

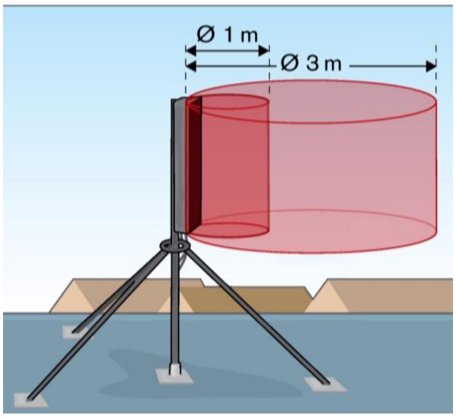

Figure 29: Recommended distance from antennas for occupational exposed (1m) and for other workers (3m) (EMF-NET/European Commision, 2008)

The undertaking should also assess whether there is a need to select *precautionary measures* and if so to which level. This precautionary strategy should be adopted when adverse health effects cannot be proved but there are many reasons to believe that there might be unwanted effects with potentially severe consequences. The exposure hazards would then exceed the benefits. (Folkehelseinstituttet, 2012)

Workers considered to be *at risk* should always receive particular attention. Pregnant women who work in close proximity of unusually *strong electric and/ or magnetic fields* (e.g. while performing welding operations) could be offered the opportunity to temporarily relocate to other work during pregnancy. Their exposure limits should not exceed the ICNIRP limits for the general population (NOU, 1995). Other workers considered at risk are the carriers of peacemakers or other electronic implants. According to ICNIRP, they should not get exposed to SMF above 0.5 mT. (ICNIRP, 2009)

When it comes to *RF fields* from antennas, the main factors that affect exposure are: distance from the antenna, the effect from the transmitter, frequency, the antenna's transmission direction, the location, as well as the number of antennas. (Folkehelseinstituttet, 2012). For instance, antennas with high frequencies and transmission effects (e.g. UHF, SHF) should be mounted high above the ground and away from permanently manned areas (NRPA, 2005). Exposure levels are normally low, but during maintenance and repair it may happen that workers get accidentally exposed to RF fields exceeding the ICNIRP limits. When service personnel need to work or walk by powerful antennas (e.g. a GSM antenna) and through the antennas' transmission, a general rule of thumb says that there should be kept a distance of 1 meter away from antennas, in front of them. For other workers the distance should be augmented to 3 meters (Figure 30). Behind antennas the RF fields are normally below background levels. (EMF-NET/European Commision, 2008)

10. MAPPING RESULTS FOR OFFSHORE RADIATION SOURCES ON THE NCS

In this chapter there are presented results from expert interviews aimed at identifying: relevant sources of ionising radiation and EMF on offshore installations from the NCS, common barriers on the NCS, as well as practical experiences related to the protection of workers against exposure. As earlier mentioned, in order to collect and quality assure data, there have been in addition realised one data base for ionising sources and another one for EMF (see attached DVD). These databases contain information resulting from the literature research (for more details see Ch. 1.5).

Relevant results from these databases and from interviews are summarised in the following tables. Data obtained from experts is presented on a white background while information from the literature research is presented on a light gray background. Given the high amount of details in the information resulting from the literature study, the interview questions have been reduced to the three main objectives of the data collection: the informants' feedback related to relevant sources on the offshore installations from the NCS, their feedback related to existing barriers on the NCS, and their own practical experiences related to workers' protection against radiation exposure.

10.1. Mapping of radioactive sources on offshore installations from the NCS

In the following table there are presented the radioactive sources that informants have confirmed to be common on the NCS, as well as the informants' feedback. Earlier in the research process there was obtained one brief overview of the most common radioactive sources on the NCS and their properties, gathering one of the experts' personal experiences. This data have been included in the database for ionising sources and sent for feedback from other experts. Table 14 presents sources mentioned in investigated publications but unconfirmed by informants.

No	Source	Sealed/ unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from INFORMANTS
	In general	***Practical experiences from informants:*** -Platform workers should have better knowledge about radiation sources, dose concepts and how to protect themselves						

<table>
<tr><th>No</th><th>Source</th><th>Sealed/ unsealed</th><th>Typical nuclides</th><th>Radiation type</th><th>Energy [keV]</th><th>Half life [years]</th><th>Typical activities</th><th>FEEDBACK from INFORMANTS</th></tr>
<tr><td></td><td></td><td colspan="7">against exposure. Many platform workers do not get enough training about radiation protection. The ones who are required to take radiation courses are either specialists considered being occupational exposed or workers who may actually be less exposed than the operators (operation manager etc.). Moreover, most of the workers are not considered to be occupational exposed but still, they may receive doses if they are not aware of the hazards and if there are not enough radiation barriers in place.
-One has to think ALARA all the way: choosing BAT; having well informed and practically trained operators; providing correct PPE and monitors; preparing a thorough contingency plan; implementing good cleaning and surveillance procedures etc.
-Keeping a safe distance from sources is one of the most important radiation protection principles
-Making measurements that are accurate and providing accurate results to those handling equipment is also extremely important (e.g. to service companies repairing NORM contaminated equipment)
- When it comes to access restriction, one should as a precautionary measure, always restrict areas where e.g. contaminated dust could arise. It is not essential to calculate whether the yearly dose rates would really reach the limits for controlled or supervised area because of the dose contribution from the operations to be performed
Existing Barriers:
-Supervised areas must be marked with “Access restricted for unauthorised people” and warning signs. Controlled area must be in addition cordoned off.</td></tr>
<tr><td>1</td><td colspan="8">Industrial radiography Sources offshore on the NCS: Critical operation. Performed by authorised service suppliers</td></tr>
<tr><td>1.1</td><td>Gamma radiography</td><td>Sealed</td><td>^{60}Co
^{75}Se
<b>^{192}Ir</td><td>γ</td><td>1300
260
11050</td><td>5
112
74</td><td>TBq</td><td>Sources offshore on the NCS: Confirmed. Critical operation. ^{60}Co and ^{192}Ir have been confirmed multiple times. They are powerful sources
Existing Barriers: Cordoning off, dose rate measurements.</td></tr>
<tr><td>1.2</td><td>X-ray radiography</td><td>Sealed</td><td></td><td>X-rays</td><td></td><td></td><td></td><td>Practical Experiences: Safer than Gamma radiography. It should have been used more in areas where it does not represent an</td></tr>
</table>

No	Source	Sealed/ unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from INFORMANTS
								explosion hazard. Represents an ex-hazard in the well operations area
2	**Well logging**	***Sources offshore on the NCS:*** Critical operation. Performed by authorised service suppliers ***Existing barriers:*** One of the informants says that the internal rule at his workplace is to stay 30 m away from the place where logging is being performed ***Practical Experiences:*** Crane drivers and especially well operators may get exposed while they are helping wire-line engineers to transport the equipment (e.g. to the well deck) and well operators may also stay too close to the logging area while the operations are being carried out. Their exposure should be also assessed						
2.1	'Neutron-neutron or compensated neutron log'	Sealed	**^{241}Am +Be** and Pu+Be	γ+N and N+N	4-5 MeV	^{241}Am: 433 and Pu: 24-100	**G**Bq	***Sources offshore on the NCS:*** The ^{241}Am+Be source was confirmed multiple times. One activity used is: 592 GBq ***Practical experiences:*** Sources may be lost inside the well leading to high contamination (confirmed multiple times). It has also happened on the NCS. -Neutron radiation is actually the most dangerous. It is relatively easily absorbed by the body and has quite long penetration capability ***Existing barriers:*** The capsules are transported to and from the deck and temporarily stored on the deck in massive containers. The containers (with the capsules inside) are always delivered back to land stations after work completion
2.2	'Neutron-gamma logging'	Sealed	^{3}H	β; generates	N: 14-15 MeV	^{3}H: 12	^{3}H: GBq	***Sources offshore on the NCS:*** Unconfirmed source. Neutron radiation generated by

No	Source	Sealed/ unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from INFORMANTS
				N and γ, by applying ca. 80kV				applying high voltages would not be explosion proof
2.3	Small 'needle' formed logging tool for measuring fluid density in the well	Sealed	^{241}Am	γ	60	433	**G**Bq	***Sources offshore on the NCS:*** Confirmed. Possibly called 'FDR tool' ***Existing barriers***: Cordoning off, The tool is ca. 1m long, so it can be held away from the body
2.4	PIP tags (Precision Identification Perforation markers)	Sealed						***Sources offshore on the NCS:*** Confirmed. Attached to the drill string from place to place. When well-logging equipment is passed through the drill string, there is a detector that indicates the number of sources that have been passed, thus indicating the depth
3	**Installed gauges**	***Practical experiences***: -They may be installed close to walkways. Gauges are marked, but personnel are not always aware of their presence. Measurements have showed that the sources were positioned so that at 1 m distance their dose rate was below the dose limit of 7.5 μSv/ h. It seems that the biggest challenge is that personnel are not aware of the place sources are installed, so they can keep their distance from them! Generally, workers do not have enough knowledge about the significance of the dose concepts and how to protect themselves. - Another informant says that according to the measurements, one can usually only get external radiation doses within 10 cm from the gauge, while an offshore workers (operation manager) mentions that at his workplace, the marking indicates that one should keep a distance of 1 meter from the gauges. - Gauges' primary radiation beams have a focused direction but radiation can be reflected, i.e. one is not entirely safe away from the primary beam. However, reflected radiation is only a small fraction of the radiation from the primary beam.						

No	Source	Sealed/ unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from INFORMANTS
3.1	Level gauge/density gauge	Sealed	**^{60}Co** ^{85}Kr **^{137}Cs** ^{241}Am	γ	1300 514 662 60	5 11 30 433	**k**Bq-**M**Bq	***Sources offshore on the NCS:*** Confirmed sources. ^{137}Cs and ^{60}Co have been confirmed multiple times. One informant says that two of the activities used are: 370 MBq and 3.7 GBq of ^{137}Cs
4	**Mobile gauging equipment**							
4.1	Intelligent pigs	Sealed	^{60}Co ^{137}Cs	γ	1300 662	5 30	**k**Bq-**M**Bq	***Sources offshore on the NCS:*** Confirmed ***Practical experiences:*** Pigs are sent through pipelines and removed at the opposite end by operators, by help of lifting equipment. All the operators should be aware of the hazards. They must avoid coming in contact with the radioactive sources installed in the pigs and wear suitable PPE. Intelligent pigs should always be well marked and stored away from any occupied area. They should be sealed while they are wet
4.2	Hand held lever gauges for detection of fluid level in fire extinguishers	Sealed	^{137}Cs	γ	662	30	**MBq**	***Sources offshore on the NCS:*** Confirmed existence. Unconfirmed properties
4.3	Gauge for	Sealed	^{241}Am+Be		^{241}Am: 60	^{241}Am: 433		***Sources offshore on the NCS:*** Unconfirmed

No	Source	Sealed/ unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from INFORMANTS
	detection of phase changes of hydrogenous substances in vessels, and for monitoring flare stack lines for ice deposits			γ, N				source. Neutron radiation generated by applying high voltages would not be explosion proof
5	**Articles**							
5.1	Smoke detectors	Sealed	^{241}Am	γ	60	433		***Sources offshore on the NCS:*** Confirmed. Typical activity: 40 kBq. Weak γ and low activity means that there is no measurable dose rate outside the detector ***Existing Barriers:*** None
5.2	Self luminous signs	Sealed	^{3}H	β	19	12		***Sources offshore on the NCS***: Confirmed
6	**Radiotracers**							
6.1	Tracers	Unsealed	**^{3}H** **^{14}C**	β	19 157	12 5730	**k**Bq	***Sources offshore on the NCS:*** Confirmed several times. Used sometimes for process diagnose
7	**NORM**	***Sources offshore on the NCS:*** Relevant on some older platforms (the amount increases with the age of the platform). Very critical if contaminated particles are often inhaled or ingested ***Existing Barriers/ Practical Experiences:*** - One should always wear chemical resistant gloves when handling NORM (e.g., nitrile rubber); use filter mask (comb filter with P3) against dust and aerosols, chemical goggles, dust proof and water resistant disposable coveralls (best) or rain							

<table>
<tr><th>No</th><th>Source</th><th>Sealed/ unsealed</th><th>Typical nuclides</th><th>Radiation type</th><th>Energy [keV]</th><th>Half life [years]</th><th>Typical activities</th><th>FEEDBACK from INFORMANTS</th></tr>
<tr><td></td><td></td><td colspan="7">wear, and boots; keep the material moist; seal equipment containing NORM; demarcate the area and mark it with the radiation symbol; avoid contaminating adjoining areas and equipment; clean and inspect PPE before reuse; mark single use items as NORM and send them onshore; must not eat, drink, use snuff or chew gum; wash hands and face after handling NORM; take a shower after the shift.
- Accidents may happen if personnel works with contaminated equipment that is not NORM classified or after spilling NORM onto the platform.
Existing Barriers:
- After contamination, one should: close off the area; remove NORM (shower/wash contaminated personnel, contain polluted material); keep NORM moist; use protective equipment; document the unwanted event (what, where, when did it happen); document the cause of the incident and doses to personnel.
- Plastic barrels containing NORM must be locked and lids should be secured.
- Upon undressing contaminated cloths, one must remove her/ his respiratory mask at the end to avoid inhaling the dust.
Practical Experiences:
- It may happen that workers do not use RPE while handling NORM. Thus, workers may be exposed for contaminated dust or aerosols. The RPE used is a common one, the FFP (Filtering Face Piece Respirator). Contaminated equipment is sometimes removed and improperly stored so it may get dry. Better cleaning routines are needed.
-1g of inhaled or ingested concentrated NORM dust (150 Bq/g) containing ^{210}Pb gives 0.25-0.75 mSv; containing ^{226}Ra gives 1.5-2.5 mSv; containing ^{228}Ra gives 3.5-6 mSv. The rule of thumb is that 1 g NORM gives an approx. equal dose to one X-ray photography (i.e. 0.05-0.1 mSv/år).Workers that clean inside tanks are susceptible to get internal doses and they are required to wear personal dosimeters. Personal dosimeters are actually not good barriers against the hazard of internal exposure and they can give a false safety feeling. Cleaning workers should always use filter mask (combi filter with P3) and just monitor external dose rates.
- When it comes to the storage of NORM, NORSOK S-002 is actually stricter than the Radiation Protection Regulations. It requires that NORM must not be stored together with combustible material, i.e. NORM cannot be contained in plastic barrels and then stored in fireproof containers. However, NORSOK is only a guide.
- LRA waste is usually sent to the land base to be packed.</td></tr>
<tr><td>7.1</td><td>NORM in oil</td><td>Unsealed</td><td>^{226}Ra</td><td>α</td><td>4700</td><td>1600</td><td>10-100</td><td>Sources offshore on the NCS: Confirmed</td></tr>
</table>

No	Source	Sealed/ unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from INFORMANTS
	production equipment		^{228}Ra	β γ	2000 900	5.6	**k**Bq/kg	
7.2	NORM in gas production equipment	Unsealed	^{210}Pb	α β (γ)	5300 1100 46	22	10-100 **k**Bq/kg	***Sources offshore on the NCS:*** Confirmed
7.3	NORM in natural gas equipment	Unsealed	^{222}Rn	α	7690	3.8 days	5-200000 Bq/m^3	***Sources offshore on the NCS:*** Confirmed
7.4	Produced water (1)	Unsealed	^{226}Ra ^{228}Ra	α β γ	4700 2000 900	1600 5.6	1-15 Bq/l	***Sources offshore on the NCS:*** Confirmed Existing barriers: None. Not considered hazardous for workers' health
7.5	NORM Sludge	Unsealed	^{226}Ra; ^{228}Ra; ^{210}Pb; ^{210}Po	α β γ	^{210}Po: 5305(α) The rest: like before	^{210}Po: 138 days The rest: like before	0.05-800; 0.5-50; 0.1-1300; 0.004-1600 [Bq/g]	***Sources offshore on the NCS:*** Confirmed

Table 12: Typical radioactive sources on offshore installations from the NCS

10.1.1. Unconfirmed radioactive sources from the literature research

No	Source	Sealed/Unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from informants
1	**Well logging**							
1.1	Gamma-gamma or	Sealed		γ	662	30.2	Up to 75	

No	Source	Sealed/Unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from informants
	density tool		^{137}Cs				GBq	
1.2	Well logging by use of ^{252}Cf	Sealed	^{252}Cf	N	2000	2.6		
1.3	'Depth correlation markers'- Malleable metal strips/tags or point sources (pellets)	Sealed	^{60}Co	γ	1300	5	Ca. 50 kBq	
2	**Mobile gauging equipment and articles**							
2.1	Hand held probe used to detect water trapped between insulation and the surface of a pipe or vessel	Sealed	^{241}Am+Be	γ, N	^{241}Am: 60	^{241}Am: 433		
2.2	'Pipe wall profiler'	Sealed	^{137}Cs	γ	662	30	GBq	
2.3	For 'density profiling' of distillation columns	Sealed		γ				
3	**Tracers**							
3.1	Gamma emitters	Unsealed	^{46}Sc, ^{140}La, ^{56}Mn, ^{24}Na, ^{124}Sb, ^{192}Ir, ^{99m}Tc, ^{131}I, ^{110m}Ag, ^{41}Ar, ^{133}Xe					

No	Source	Sealed/Unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from informants
3.2	Upstream radiotracers (glass ampoule containing scandium oxide)	Unsealed	^{46}Sc	γ	357	83.83 days	750 MBq	
3.3	Upstream radiotracers (plastic pellets coated with radioactive source)	Unsealed	^{110m}Ag	β	530 (30%), 83 (67.5%)	249.9 days	10 GBq	
3.4	Upstream radiotracers (‘spikes’)	Unsealed	^{99m}Tc and ^{131}Ir solutions					
3.5	Upstream radiotracers ('spikes')	Unsealed	^{3}H (tritium) and ^{14}C- sometimes 'spiked' with ^{82}Br or ^{85}Kr (Ref. 2)	β (^{82}Br is γ)	19; 157	12; 5730	Up to 1 TBq when injected but very low at the producer wells	
3.6	Downstream radiotracers for flow rate measurement	Unsealed		γ				
4	**NORM**							
4.1	NORM- Hard scale	Unsealed	^{226}Ra, ^{228}Ra, ^{210}Pb	α, β, γ	^{226}Ra and ^{228}Ra: 4700;2000;	1600; 5.6; 22	^{226}Ra: 0.001-0.5 ^{228}Ra:	

No	Source	Sealed/Unsealed	Typical nuclides	Radiation type	Energy [keV]	Half life [years]	Typical activities	FEEDBACK from informants
					900 ^{210}Pb: 5300;1100; 46		0-2800 ^{210}Pb: 0.02-75 Bq/g	
4.2	Produced water (2)	Unsealed	^{226}Ra, ^{228}Ra	α, β, γ	4700;2000; 900	1600; 5.6	0.002-1200; 0.3-180 Bq/L	
4.3	Produced water (3)	Unsealed	^{210}Pb	α, β, (γ)	5300;1100; 46	22	0.05-190 Bq/L	
4.4	Produced water (4)	Unsealed	^{224}Ra	α	5700	3.6 days	0.5-40 Bq/L	
4.5	NORM- Crude oil	Unsealed	^{226}Ra	α	4700	1600	0-0.04 Bq/g	

Table 13: Radioactive sources from the literature research that the informants have not confirmed

10.2. Mapping of sources of EMF on offshore installations from the NCS

In the following tables there are presented sources of ELF electric and magnetic fields, SMF and RF electromagnetic fields, informants have confirmed to be relevant on the NCS, as well as the informants' feedback.

10.2.1. Typical sources of ELF and SMF

No.	Source/ Critical zone	FEEDBACK from informants

1.	**Low-voltage transformer** ('LV traforom')	***Sources offshore on the NCS:*** Source confirmed (multiple times). Powerful ***Existing barriers:*** Access restricted ***Practical experiences:*** The doors are not always locked and it happens that workers go /take shortcuts through restricted rooms. Further assessment of ELF levels in manned areas close to/ inside the transformer room, is needed
2.	**High-voltage transformer** ('HF traforom')	***Sources offshore on the NCS:*** Source confirmed (multiple times). Powerful ***Existing barriers:*** Access restricted ***Practical experiences:*** The doors are not always locked and it happens that workers go /take shortcuts through restricted rooms. More knowledge needed
3.	**Low-voltage switch gear room** ('LV tavlerom')	***Sources offshore on the NCS:*** Source confirmed (multiple times). Powerful ***Existing barriers****:* Access restricted ***Practical experiences:*** The doors are not always locked and it happens that workers go/take shortcuts through restricted rooms. More knowledge needed
4.	**Drive space** ('Frekvens omformer rom')	***Sources offshore on the NCS:*** Source confirmed (multiple times). Powerful ***Existing barriers:*** Access restricted ***Practical experiences:*** The doors are not always locked and it happens that workers go/take shortcuts through restricted rooms. More knowledge needed
5.	**Powerful supply cables to/from land**	***Sources offshore on the NCS:*** Source confirmed (multiple times). Powerful at short distances ***Practical experiences:*** For the time being, only present on some of the platforms (sometimes very numerous). It is an increasingly relevant issue. Further assessment of ELF levels close to electricity supply cables is needed
6.	**Zones with large power consumers and generators (i.a. 30 MW engines)**	***Sources offshore on the NCS:*** Large power consumers and generators as sources of ELF confirmed. Powerful ***Existing barriers:*** Access restricted ***Practical experiences:*** The door to the generator room is not always locked and it happens that workers go /take shortcuts through the room. Further assessment needed

7.	**Cabins for personnel**	***Sources offshore on the NCS:*** Usually under stated limits
8.	**Handheld electric tools**	***Existing Barriers:*** Not considered a hazard
9.	**Office machines**	***Sources offshore on the NCS****:* Confirmed
10.	**Heating**	***Existing Barriers:*** Not relevant. By ventilation and it is not an ELF source
11.	**SMF on engine surfaces**	***Sources offshore on the NCS***:Confirmed

Table 14: Typical ELF sources on offshore installations from the NCS

10.2.2. Typical RF sources

No.	Source	Frequency (MHz)	Irradiated Effect (W)	FEEDBACK from informants
	In general	*Practical experiences from informants:* Radar and communication equipment are usually no bigger issue on offshore installations than it is on land. There is usually only one (or two?) radar (s) and they are related to helideck. A platform is larger than i.a. a small boat and distances between the equipment and manned places are relatively large. This also applies for antennas for communication. Moreover, the radar transmission is directed away from places where there can be personnel ('sector blanking'). There have been questions about radiation from radar on boats located at installations for loading and unloading, but these are much lower than the platform decks, so the radiation will not reach the personnel. When it comes to floating platforms, loading/unloading boats are about at the same height and the exposure can happen if e.g. radars are on during operations. Radiation from radar and antennas is below exposure limits in areas that are accessible to normal traffic. There is a need for better general knowledge and information regarding radiation offshore.		
1.	**SHF**			
1.1	Radio link 1	7428	1	*Sources on NCS:* Confirmed source (multiple times). Powerful
1.2.	Radio link 2	7484	1	*Sources on NCS:* Confirmed source (multiple times). Powerful
1.3.	Radio link 3	7428	2	*Sources on NCS:* Confirmed source (multiple times). Powerful
1.4	Radio link 4	7484	2	*Sources on NCS:* Confirmed source (multiple times). Powerful
1.5	Maritime Radar S-band (in antenna	3000	30000 for max.	*Sources on NCS:* Confirmed source (multiple times). Powerful

No.	Source	Frequency (MHz)	Irradiated Effect (W)	FEEDBACK from informants
	tower)		pulse	
1.6	Maritime Radars X-band	9410	25000 for max. pulse	*Sources on NCS:* Confirmed source (multiple times). Powerful *Existing barriers:* 'Sector blanking'
	UHF			
	Radio link 5	814	2	*Sources on NCS:* Confirmed source
	UHF base station Helitower	410	2	*Sources on NCS:* Confirmed source
	UHF portables close by	410	1	*Sources on NCS:* Confirmed source
	Portables in general	410	1	*Sources on NCS:* Confirmed source
	UHF in cranes	410	2	*Sources on NCS:* Confirmed source
	UHF link to rigs/ ships (Shipcom)	420	5	*Sources on NCS:* Confirmed source
	UHF Pager	420	5	*Sources on NCS:* Confirmed source
	DME for helicopters	1100	100	*Sources on NCS:* Confirmed source
	GSM antenna	900		*Sources on NCS:* Confirmed source
	CCTV Transmitter	2450	0.1	*Sources on NCS:* Confirmed source
	VHF			
	VHF marine in Emergency Room	160	3.5	*Sources on NCS:* Confirmed source
	VHF marine in Radio Room	160	3.5	*Sources on NCS:* Confirmed source
	VHF marine in Control Room	160	3	*Sources on NCS:* Confirmed source
	VHF marine in Helitower	160	3.5	*Sources on NCS:* Confirmed source
	VHF marine in Telecom Room	160	3.5	*Sources on NCS:* Confirmed source
	VHF in cranes	160	1/2	*Sources on NCS:* Confirmed source
	VHF aeromobile in Helitower	130	6	*Sources on NCS:* Confirmed source
	VHF aeromobile in Radio Room	130	5	*Sources on NCS:* Confirmed source
	VHF aeromobile Telecom Room	130	10	*Sources on NCS:* Confirmed source
	VHF aeromobile portable	130	1	*Sources on NCS:* Confirmed source
	MF			

No.	Source	Frequency (MHz)	Irradiated Effect (W)	FEEDBACK from informants
	NDB for helicopters	0.561	100	*Sources on NCS:* Confirmed source

Table 15: Typical RF sources on offshore installation from the NCS

11. DISCUSSION

The analysis in this chapter is aimed at identifying the most important sources of radioactive and electromagnetic radiation on offshore installations from the NCS, as well as efficient physical and organizational barriers against radiation exposure. The discussion is based on the results presented in the former chapter and on the literature study.

11.1. Mapping of radioactive sources on offshore installations from the NCS

Among the radioactive sources the informants have confirmed and highlighted there are the: industrial radiography, well logging by use of neutron and gamma radiation, installed gauges, 'intelligent pigs', radiotracers, as well as NORM in gas and oil equipment.

In Table 17 there is presented a brief review of the barriers (protection measures) against radiation introduced in Ch. 6.1. that will serve as a reference throughout this section. The barriers are divided into: 'General organisational barriers', 'Preventive barriers' that focus on eliminating the source of harm, 'Controlling barriers' efficient at minimising the radiation at the source, and 'Mitigating barriers', aimed at minimising workers' exposure and protecting them against uncontrolled radiation.

Each protection measure is related to either one of the three alternatives: to the organisation, to physical entities or to both. According to this classification, a barrier is related to the organisation when its protection function depends primarily on personnel, and to physical entities when the protection function depends mainly on the design of the: radiation sources, the workplace or the PPE. The three last categories and their corresponding barriers can be usually considered in descending order of priority (if the first measure is not possible, the following should be considered), while the 1st category contains barriers that usually are equally relevant. In line with the Energy-Barrier model explained in Ch. 6.1. one can imagine that the largest the distance from the source of harm the better for the affected worker. The ideal will always be to substitute the radiation source with other safer solutions. Moreover, in the context of radiation protection it is considered that barriers like the ones included in the three last groups tend to be more reliable if they follow the principle of radiation protection at the source, i.e. they are physical barriers. However, one measure does not exclude the other. Implementing several barriers would normally decrease the exposure level.

In the following subchapters there are presented several efficient barriers against exposure to the radiation sources the informants have highlighted. Each measure will be classified as either physical or organisational and it will be attributed to one of the four barrier categories. The classification is just a proposal and it depends on the assessment performed. Its purpose is to trigger reflection about the reliability of barriers.

Barriers primary related to organisation (O)/ physical entities (P)	**<u>Barrier types and their functions</u>** **Radiation protection principles**
General organisational barriers:	
O	Risk assessment
O	Workers and the service providers' competency
O	Communication and learning within the organisation and across the industry: e.g. emergency drills
O	Maintenance, including periodical leakage testing of shielding containers and keeping an updated technical measurement protocol for the devices
O	Housekeeping
O	Monitoring: Select the correct type of monitor. Monitor the radiation doses of maintenance and service personnel, as well as of all the workers likely to exceed the limit for general population of 1 mSv/year. Inform personnel about their own recorded doses in writing
O	Work procedures and instructions: i.a. a contingency plan
O	Maintain an updated inventory of sources. Check once a week that they are in place
Preventive barriers (eliminate the source):	
O	Eliminate the radiation source if it is not 'justified'. Substitute the radiation source by methods that do not request use of radioactive sources ('inherent safe by design')
O	Relocate workers at risk to other work tasks: e.g. pregnant women likely to receive radiation doses above 1 mSv/year
Controlling barriers (minimise the radiation at the source):	
O	Avoid short term health effects and restrict long term health effects by applying the ALARA and the 'limitation' principle
O	Use less hazardous radiation sources (e.g. least likely to spill)
P	Use BAT equipment: i.a. in compliance with the standards, with minimal need for maintenance and cleaning, with fireproof shielding of the radiation source
O/P	Maximise the distance from the source by design
P	Use active barriers (activated by the user)
P	Shield the radiation source: e.g. shield γ and X-rays by a layer of lead
Mitigating barriers (minimise personnel exposure):	
O	Avoid short term health effects; restrict long term health effects by applying ALARA and the 'limitation' principle
O	Minimise the storage time of radiation sources close to manned areas
O	Keep NORM moist
P	Use extraction ventilation with HEPA
O	Plan the work thoroughly: e.g. start with a risk assessment
O	Minimise exposure time
O	Maximise the distance from the source
O/P	Mark radiation sources and restricted areas
O	Prohibit smoking, eating or drinking with contaminated hands, or working with unprotected wounds, grazes or cuts. It is particularly important to prevent internal exposure

Barriers primary related to organisation (O)/ physical entities (P)	<u>Barrier types and their functions</u> **Radiation protection principles**
P	Protect surfaces against contamination by use of durable covers
O/P	Provide correctly selected and maintained PPE: e.g. hoods, visors, blouses or suits for workers with glasses or facial hair
O	After work completion: Contain radioactive waste. Seal contaminated equipment. Decontaminate the working site. Perform control measurements of the dose rates after work completion

Table 16: A review of the protection measures against radiation exposure from Ch. 6.1

11.1.1. Gamma and X-ray radiography

Gamma radiography is a form of non-destructive inspection of welds and detection of cracks in the components by help of powerful radioactive sources such as, ^{75}Se, ^{60}Co, and ^{192}Ir. The application of these radionuclides has been confirmed by two consultants and it has been also reported by NRPA (NRPA, 2014). There are used extremely high concentrations of these radionuclides (specific activity in TBq). In addition, the energies of ^{60}Co and ^{192}Ir reach as much as 1300 keV and respectively 1050 keV.

One physical barrier reported by informants is cordoning off the area where the industrial radiography is performed in order to restrict the access of unauthorised workers (organisational 'mitigating' barrier). Industrial radiography is performed by certified NDT companies and the risk level is assessed by dose rate measurements (general organisational barriers). These are the organisational measures reported by the informants to be common on installations from the NCS.

Moreover, gamma radiography is sometimes substituted by X-ray radiography (organisational 'controlling' measure), which has the great advantage that the radiation is lost when the power is interrupted (NRPA, 2012a). However, the latter one is much less frequent as the methodology is not explosion proof. One of the informants mentions that gamma radiography is sometimes performed in areas where the X-ray technique would have not represented an explosion hazard. This observation is also supported by the literature and NRPA, in line with the requirements from the Radiation Protection Regulations encourages the undertakings to use the X-ray equipment whenever possible. (NRPA, 2014)

When this is not reasonable, the radioactive concentrations should however never exceed 400 GBq for ^{60}Co, 1.5 TBq for ^{192}Ir and 3 TBq for ^{75}Se (NRPA, 2012a). This last requirement is introduced by Guide No. 1 to the Radiation Protection Regulations, and just like the substitution measure it can be considered an efficient ‘controlling’ barrier against overexposure.

Furthermore, according to Guide 1 and ISO 3999, the leakage radiation from portable radiography containers must not exceed 500 μSv per hour at a 5 cm distance from the surface of the container, or 20 μSv per hour at 1 m. This means that the radiation source should be as safe as possible by design (physical ‘controlling’ barrier). In addition, it should be always accompanied by the following ancillary equipment: remote handling tongs that are at least 1 m long, lead blocks or bags of lead shot for source shielding and cordoning equipment such as ropes and warning signs. For the event when the source gets stuck in cables or detaches from the wire, the device should also be accompanied by a monitoring instrument with telescope detector to locate the radiation source and an emergency container where the detached source can be quickly contained. All transfers of unshielded radioactive sources must be made with the greatest possible distance between the source and the body (organisational ‘mitigating’ barrier) (NRPA, 2012a). Normally, passive physical barriers at the source, that do not need man intervention (e.g. a radiation source that is least likely to leak by design) are considered to be more effective than other controlling measures at the source (e.g. mobile shielding screen), or than ‘mitigating’ barriers between the source and the user (e.g. the use of remote handling tong or PPE). On the other hand, one barrier must not exclude the other since it is always more reliable to implement redundant measures.

Whenever possible, the industrial radiography should be performed (or the items to be inspected should be moved) as far away from the living areas as possible e.g. to the cellar deck or in the vicinity of storage tanks that provide shielding (organisational ‘mitigating’ marries). If this is not possible, there should be placed a lead shielding screen near the radiation source (physical ‘controlling’ barrier). A flashing light placed outside the working site would aid restricting the access to the controlled area (organisational ‘mitigating’ barrier) (IAEA, 2010)

As an organisational barrier, the undertaking shall make sure that industrial radiography on open installations is always performed by two certified specialists: operator and supervisor (general organisational barrier). (NRPA, 2012a). Furthermore, if the encapsulation of the gamma sources is damaged, the consequence can be extremely large internal and external doses to those exposed, thus leakage tests should be performed regularly and the tests should be well documented (general organisational barrier). (IAEA, 1998)

Everyone working with industrial radiography sources must wear personal dosimeters (Radiation Protection Regulations, 2011) and dose rates at the radiography site, as well as the position of the radiation source shall be constantly checked by help of the hand held monitor (general organisational barriers) (se Appendix C). Thus, any abnormalities with the source will be soon detected and the rescue work can be initiated as early as possible, without overexposure to personnel. Workers who accidentally receive high doses may have their work with radioactive sources restricted for the rest of their working life (IAEA, 2010).

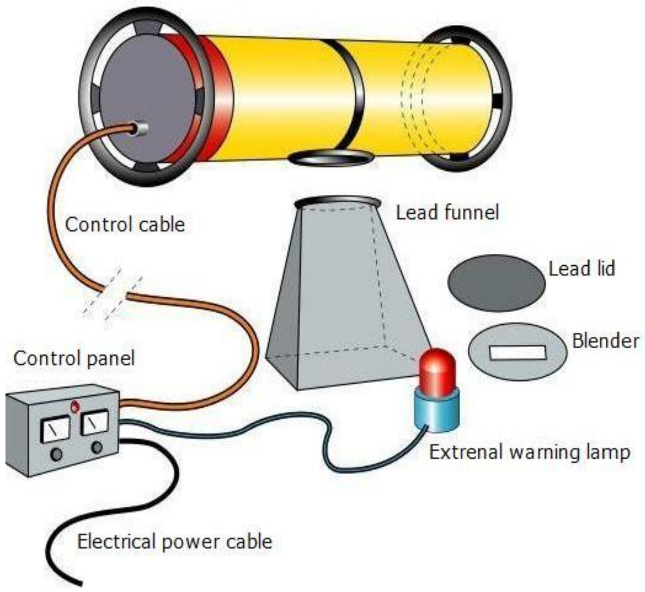

Figure 30: X-ray tube with accessories: panel, warning lamp, lead lid and funnel, blender. Adapted after (NRPA, 2012a).

Emergency drills should be held annually to ensure that radiography workers are familiar with the procedures and the use of the emergency equipment (general organisational barrier). (NRPA, 2012a). Drills are efficient administrative measures leading to increased risk awareness, and to knowledge and experience sharing within the company and across the rest of the industry.

In what concerns the *X-ray apparatus*, some of the required physical barriers need to be redundant for an increased reliability. For instance, the control panel (Figure 31) of the apparatus must be equipped with key activated exposure control (physical 'controlling' barrier) and several independent signalling devices indicating that X-rays are generated, one of them being an external warning lamp (organisational 'mitigating' barrier). In addition, both the supervisor and the operator should wear an audible or vibrating radiation alert (general organisational barrier). The machine shall also have a thick lead cover that can be fitted onto the 'primary beam window' during testing and heating, as well as blenders for graduating the primary beam (physical 'controlling' barriers when they are in use). (NRPA, 2012a)

Finally, in order to fulfil the requirements of written instructions and procedures for both gamma and X-ray radiography, the undertaking should as a minimum, prepare the following: instructions for the radiation protection coordinator including a description of hers/his responsibilities, instructions for supervisors and operators, working procedure for the use of radiography devices and special procedures for access restriction, marking and warning, as well as a procedure for the use of the measuring instrument. In this procedure there should be also specified that operators must use the hand held monitor to ensure that the X-ray device is off or that the gamma source is back to sheltered position (general organisational barriers). (NRPA, 2012a)

According to NRPA, radiation dose rates related to the industrial radiography are normally below 3- 5 mSv/year (NRPA, 2012a), so above the limit for general population of 1mSv/year but bellow the occupational limit of 20 mSv/year. However, accidental overexposures have been registered, and one should always keep in mind the ALARA principle, and reduce workers' radiation exposure as much as possible. The powerful γ

radiation used is also one type of radiation that easily penetrates the human skin and can lead to considerable internal doses. NRPA does not record these doses being difficult to collect accurate and complete data. Industrial radiography is the operation that leads to the highest external doses within the petroleum industry, followed by well logging.

11.1.2. Well logging

Well logging is another critical operation highlighted by all of the informants, as well as in various publications. Measurements by help of radioactive materials give useful information about the bedrock and the well, indicating whether the discoveries are commercial or not (NRPA, 2014). The use of ^{241}Am together with Be (beryllium) has been confirmed by two HSE consultants and is mentioned by NRPA and IAEA. Be generates neutron radiation when bombarded with γ- radiation from ^{241}Am. There are usually generated several GBq of this neutron radiation. One consultant has also confirmed the use of a small ('sewing needle' shaped) logging tool for the measurement of the fluid density in the well, possibly called 'FDR tool'. This tool contains several GBq of ^{241}Am.

Figure 31: Empty source capsule (NRPA, 2014)

As previously mentioned in subchapter 3.1.3, neutron radiation gives almost as high radiation doses as alpha and penetrates the body almost as easy as gamma, thus being particularly hazardous. ^{241}Am has a relatively low energy, 60 keV, but it has a long half life of 433 years, which sometimes can be a relevant issue. Two of the informants (one consultant and the informant representing the employee trade union) have named one possible accident scenario with these sealed but unshielded sources (Figure 31), which is losing the source inside the well. If the source falls into the well it could be damaged, contaminate the well, and the logging operators could easily receive considerable radiation doses. The long half life of ^{241}Am means for instance that the contamination would also have high consequences over the long term.

Operators can also receive considerable external radiation doses when the source is not damaged but is difficult to locate, because of the long exposure periods. Well logging personnel that worn dosimeters from NRPA in 2012, registered annual external doses of about 0.3 mSv, so below the limit for general population of 1 mSv/year (NRPA, 2014). Accidents such as breaking a capsule containing radioactive material may lead to doses exceeding the occupational limit and in addition, high doses would be received over a relatively short time interval (e.g. one day). As explained in chapter 5, a radiation dose given during a short time is far more dangerous than an equivalent dose given during a longer time interval (Henriksen, 1995). The risk for unrepaired, mutagenic cells in the body will be higher.

Figure 32: Wire-line engineers transferring radioactive sources to logging tools, by use of handling rod (IAEA, 2003)

A plate covering the annulus around the logging tool and a chain connecting the source to the handling rod while it is being screwed into the logging tool would prevent the radiation source from falling into the well (physical 'controlling' barriers). Moreover, there must be always used a hand held monitor in order to detect any hazardous dose rates in the well (organisational barrier). If the source has been disconnected but it has landed on the plate, it could be easily recovered by help of a handling rod, about 1.5 m long (physical 'mitigating' barrier) (IAEA, 2010). This long rod is a protective tool that must be used by workers whenever they need to manoeuvre a capsule, in order to maintain a safe distance from the radioactive material (Figure 31) (NRPA, 2014). In the event that the source cannot be recovered and it has to abandoned inside the well, one should cement it in, eventually by use of coloured cement, and the wellhead should be marked with a clear warning notice about the abandoned source (physical 'controlling' barrier). (IAEA, 2010)

Furthermore, for well logging one should keep in mind that both neutron and gamma radiation can penetrate the skin surface and give internal doses to people. NRPA does not record internal doses, being difficult to collect accurate and complete data.

One physical barrier reported by two of the consultants and one offshore worker is a controlling measure aimed at shielding the radioactive source during its transport to/from the deck, as well as during temporarily storage on the deck. The sources are packed inside massive containers that are delivered back to the suppliers' land stations after work completion. This measure is also mentioned by NRPA (NRPA, 2014) and described by IAEA. The containers have thick walls and may reach op to 1.75^{3}m, especially for neutron sources, which have a high penetration capacity (IAEA, 2003). With respect to the small gamma logging tool, the device has a design that gives the user the possibility to hold it away from the body. Apart from these, no other particular physical barrier has been mentioned by informants.

Informants report that just like industrial radiography, well logging operations on the NCS are performed by authorised specialists, and that usually their personal doses are being monitored during operations. This is in line with the Radiation Protection Regulations, NRPA adding also that one has to make sure that the dosimeters are able to record both gamma and neutron doses (organisational barrier) (NRPA, 2014). One of the informants (offshore worker) mentions that at his workplace, the internal rule for workers other than the logging personnel is to remain 30 m away from the logging site. Another informant (specialist representing a corporate health care service company) declares that crane drivers and especially well operators may get exposed while helping wire-line engineers to transport the equipment (e.g. to the well deck) and well operators may also stay too close to the logging site. The informant means that their exposure should be assessed (organisational barrier). Additional physical 'controlling' barriers from the literature study, such as shielding walls placed near the source, as well as audible and visible signals would mark better the logging site and they would possibly reduce the extent of the restricted area. Moreover, logging specialists shall always direct the primary radiation of the source away from any manned areas (IAEA, 2010).

11.1.3. Installed gauges

Level and density gauges are two types of installed gauges emphasised by several informants (7 out of 9) and well described in studied literature. Installed gauges, also known as industrial control sources or nuclear gauges, are usually mounted on pipelines, tubes or vessels to measure a range of physical parameters. ^{85}Kr, ^{241}Am, ^{60}Co and ^{137}Cs are the radionuclides that are commonly used inside gauges, as reported by one HSE consultant and NRPA (NRPA, 2014). The use of ^{60}Co and ^{137}Cs has been confirmed by two consultants. This measurement device contains radionuclides in sealed form but with a high concentration (kBq-MBq and sometimes up to GBq) and high energy. As already mentioned, ^{60}Co has an energy of 1300 keV, while ^{137}Cs has en energy of 662 keV. One informant has registered measurements of 370 MBq and even 3.7 GBq of ^{137}Cs.

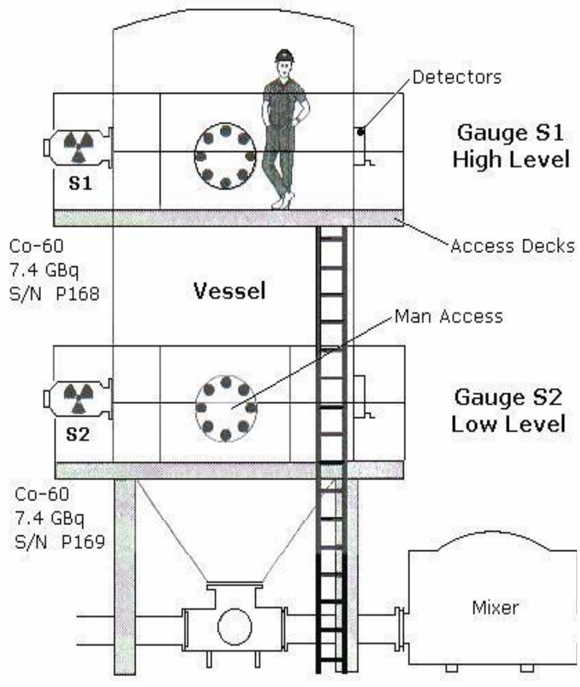

Figure 33: Schematic diagram of a vessel with 2 installed level gauges and man access from the deck (IAEA, 2010)

According to NRPA, there may be also used ^{133}Ba, that is a γ- emitter and 2 neutron sources, ^{241}Am+Be and ^{252}Cf. All of them have in common long half lives and high energies. The larges the object to be measured or the highest the density, higher the radioactive energy needed. (NRPA, 2014)

Informants report that sources are usually positioned so that at 1 m, or even at 10 cm from the source container, dose rates are well below the dose limit of 7.5 μSv/ h (organisational 'controlling' barrier). They are in addition marked with warning signs. One offshore worker adds that at his workplace, the warning sign indicates that one should keep a distance of 1 meter from the gauges (organisational 'controlling' barrier). As commented several times throughout the literature study, keeping the distance from the radiation sources by either physical or administrative controlling measures is one of the main radiation protection strategies. However according to several informants, gauges can be installed close to walkways and it happens relatively often that workers pass by in front of these sources without noticing them or keeping the correct distance.

Moreover, one opinion shared by two of the consultants is that workers do not have enough knowledge about the significance of the dose concepts and how to protect themselves. For instance, one of the factors workers should be aware of is the reflected radiation from gauges, meaning that if one worker stays close to the primary beam, she/he will not be completely safe outside the primary beam.

One physical measure recommended by IAEA in order to prevent workers from coming to close to these sources, is mounting the gauges in additional steel or lead housings of about 30 cm in diameter (physical 'controlling' barrier), as shown earlier in Figure 22, Ch. 6.2.3. The containers should be in addition brightly coloured and labelled with clearly visible warning signs (organisational 'mitigating' barriers) (IAEA, 2010). In line with the IAEA, NRPA emphasises the importance of maintaining the warning signs clean and readable, both on shielding containers and on access doors to e.g. tanks where gauges are installed (general organisational barrier) (Figure 33) (NRPA, 2012b). Workers may accidentally go inside tanks while the radioactive devices are on and get considerable radiation doses. Thus, NRPA also highlights the importance of a robust equipment design (physical 'controlling' barrier). This implies i.a. that the closing mechanism of the equipment shall have clear positions for 'open' and 'closed' and shall be reliable (NRPA, 2012a). In addition, the equipment must be designed in a way that workers cannot open the door or remove the container from its installed position before the gauge is closed and locked. (IAEA, 2010). Furthermore, there shall be impossible to disassemble installed gauges without using special tools (Radiation Protection Regulations, 2011). Any source container must be able to withstand difficult weather and working conditions, without getting damaged. They should be also fireproof and be able to withstand a 'normal' fire. (NRPA, 2012a). One last relevant physical measure is mounting gauges on pipelines or vessels without any clearance that would allow workers hands or fingers to gain access to the primary beam (organisational 'controlling' barrier) (IAEA, 2010).

One of the most important organisational measures is establishing a good maintenance program (general organisational barrier). All the installed gauges should be regularly monitored by using the dose rate meter e.g. monthly. The dose rate meter should be also switched on upon any working operation involving nuclear gauges (general organisational barriers) (IAEA, 1996b)

If the shielding container or the sealed source seems to be damaged, one should as a precautionary measure, always monitor local dose rates and restrict personnel's access There should be also performed a leak test to find out whether the source has been severely damaged. Workers suspected to have touched the contaminated surfaces must remain inside the marked area and the supervisor should be noticed (organisational 'mitigating' barriers). (IAEA, 1996b).

Another important administrative measure is related to workers' competence. Work with powerful installed gauges (often above 10 GBq) should be performed by trained and authorized workers (NRPA, 2012b). According to NRPA, external radiation doses from unwanted incidents implying control sources are usually below 5 mSv per year (NRPA, 2012b), so above the allowed limit for general population, but below the one for occupationally exposed. However, just as for industrial radiography and well logging, accidents can occur and the exposure should be constantly reduced by implementing efficient measures. On one hand, accidentally acute doses (e.g. upon entering a tank and coming into the primary beam while the gauge is on) can produce larger cell damages than smaller dose rates and on the other hand, one's lifetime dose should be as low as possible (see Ch. 5).

Figure 34: The removal of a pipeline pig (Source: http://www.nord-stream.com/press-info/images/arrival-of-the-inline-inspection-tool-in-lubmin-3502/)

11.1.4. Mobile gauging equipment. Intelligent pigs

One type of mobile gauging equipment that has been confirmed is the 'intelligent pig'. Four informants (3 HSE consultants and 1 offshore worker) have reported their use on the NCS. Out from the earlier mentioned mapping collected from one of the experts, 'intelligent pigs' are labelled with sealed sources containing up to several MBq of the powerful radionuclides ^{60}Co and ^{137}Cs. NRPA and IAEA describe briefly these gauges but give no details about the radionuclides contained.

The consultants explain that 'intelligent pigs' are robotic instruments, sent through pipelines and removed at the opposite end by operators, by help of lifting equipment (Figure 34). Pigs should be always sealed while they are wet (physical 'controlling' barrier) to avoid air contamination and they must be well marked and stored away from any manned area (organisational 'mitigating' barrier). It is essential that operators at both ends are aware about the hazards (general organisational barrier) and that appropriate protective measures are taken. They must avoid coming in contact with the radioactive capsules and wear suitable personal protective equipment (physical 'mitigating' barrier). One opinion shared by the consultants is that these barriers are not always in place.

Based on the informants' affirmations and on the scarce information in the studied literature, one should be started by further assessing these sources and then share the experience across the industry.

11.1.5. Radiotracers

The injection of radiotracers into the wells is another operation involving ionising sources that has been confirmed by informants (3 consultants and 2 offshore workers, one of them radiation coordinator), and reported by NRPA (NRPA, 2014). Their application is mainly tracing chemical molecules of oil, gas or water in the production flows, in order to assess process operations. There are exclusively used unsealed radioactive sources, meaning that the use of radiotracers represents a risk for internal exposure and that this type of activities needs to be performed with care.

Two HSE consultants have specified that the radionuclides that are commonly used in tracer operations on the NCS are the ‘soft’ beta emitters ^{3}H (tritium) and ^{14}C, with a concentration of several kBq. The use of ^{14}C in tracer operations is also reported by NRPA in the study literature (NRPA, 2014).

According to IAEA, the radioactive concentrations of these soft beta sources at the surface of the wellheads are very low, thus not representing a hazard of external radiation for the specialists. However, if they are spiked with hard beta emitters such as ^{82}Br, then workers should always wear personal dosimeters (general organisational barrier) in addition to the PPE (physical ‘mitigating’ barrier) (IAEA, 2010). Most of the protection measures reported in the study literature are organisational. For instance, according to IAEA and in line with principles from the Chemical Regulations, by selecting non-volatile radionuclides whenever possible one would eliminate the risk of inhaling hazardous particles and consequently of internal radiation (organisational ‘controlling’ barrier) (IAEA, 2010). ^{14}C is one example of radioactive material that can be found in gas form but also in liquid and solid form (NRPA, 2014). In what concerns ^{3}H, it is mainly used in liquid form in tracer operations for the petroleum industry (‘tritiated water’) (IAEA, 2010). Other safety and functional requirements tracers need to fulfil are: to have a stable form, to be easily detectable by monitors and to have as low as possible radiotoxicity (organisational ‘controlling’ barriers). (IAEA, 2010)

Moreover, the injection company must prepare thoroughly the well site before tracer operations. There should be i.a. performed a survey of the working site (general organisational barrier), then the working site should be delimited and the area should be restricted to unauthorised workers (organisational ‘mitigating’ barrier). The injection company should be in addition responsible for bringing appropriate containment for contaminated items, necessary monitors, a contingency plan and all the equipment needed in the event of an unwanted event (general organisational barrier). The well injection operators should always use appropriate PPE against internal contamination with radioactive particles (e.g. Figure 35). Furthermore, it is essential to check that valve systems have all the connections tight (general organisational barrier), and to protect the surface around the wellhead and other relevant areas against contamination from the backward flow of fluids, e.g. by use of durable plastic covers (physical 'mitigating' barriers).

Because of the hazard of internal contamination, smoking, eating or drinking and working with unprotected wounds, grazes or cuts should be prohibited (general organisational barrier). After work completion, injection companies have normally the responsibility of monitoring (organisational 'mitigating' barrier) and if needed, decontaminating the equipment and the contaminated surfaces until allowed clearance levels (organisational 'mitigating' barrier). The radioactive material shall be contained and returned to the land base as soon as possible (organisational 'mitigating' barrier). (IAEA, 2003)

Since radiotracers represent a hazard of internal contamination, one should first and foremost only use them if they are 'justified', as seldom as possible and in a form that is least likely to contaminate the workers.

11.1.6. NORM

NORM is a well known issue across the petroleum industry and almost all of the informants have named it (8 out of 9). NORM has started to appear on some of the platforms from the NCS, mainly the older ones. The presence and amount of NORM depends much on the salinity and acidity of the produced water. The more seawater is injected into the wells, most likely it is to accelerate the formation of radioactive deposits inside the facility. NORM is encountered in largest amounts in oil and gas equipment. It can be also measured in the produced water and sludge but here it is not considered a hazard for worker's health, since specific activities are very low and contaminated particles will normally not be inhaled or ingested.

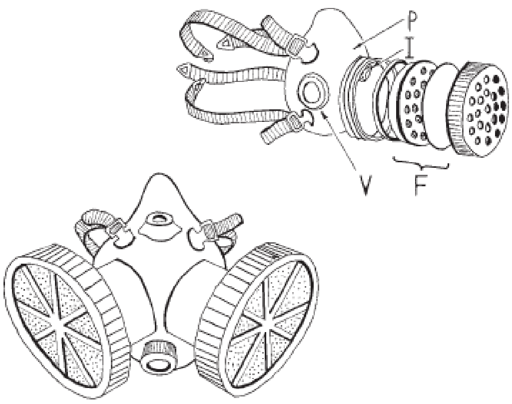

Figure 35: Example of half face masks with P3 filter and single or multiple cartridges (IAEA, 2010)

NORM represents both a hazard of external and internal radiation. It emits gamma radiation meaning that people can be irradiated in the presence of NORM. However, the concentration of γ-emitting radionuclides is normally low so in reality, workers are primarily susceptible to irradiation from NORM where large amounts of waste are gathered, e.g. inside contaminated tanks during cleaning operations, or close to storage areas for contaminated equipment. Thus, according to OGP temporary deposits of NORM should be cordoned off and marked with the warning: "Containing Radioactive Materials". (OGP , 2008) Moreover, personnel that works inside tanks, or generally at places where they are likely to receive doses higher than 1 mSv/year from NORM, shall wear personal dosimeters. One HSE consultant emphasises that dosimeters may actually give a false safety feeling, and that workers should rather use a 'combi mask' with P3 filter and just measure external dose rates by help of a monitor (general organisational measure).

Generally, dose rates to workers from external exposure to NORM are under the maximum exposure limit for general population (NRPA, 2014), but the radioactive material is unsealed and it emits α and β-radiation, so one should avoid inhaling or ingesting contaminated particles. The radioactive concentration is normally low but often contaminations would lead to a considerable lifetime dose. One of the interviewed consultants mentions one possible rule of thumb i.e.: 1 g of very concentrated NORM (150 Bq/g) can give an approximately equal internal dose to one X-ray photography (i.e. 0.05-0.1 mSv/år). Normally, the radioactive concentration of NORM is reported to be between 10 and 100 Bq/g, as seen in Table 13. Moreover, the material contains high energetically radionuclides emitting α and β, meaning that the biological damaging potential is particularly high.

NORM from gas production does not lead to external radiation to personnel due to its low γ emissions. However, the radioactive concentration of NORM tends to be higher here and it can consequently lead to higher internal doses. NORM from gas production contains ^{210}Pb, a α and β-emitter.

According to IAEA, NORM in natural gas equipment contains ^{222}Rn and this has been confirmed by one of the consultants. By ventilating tanks and vessels in gas plants before cleaning or maintenance operations one would release out the radon gas accumulated inside (organisational preventive barrier). Otherwise, radon does not represent a risk factor for platform workers in the same way as it does on land, due to seldom and short exposures (OGP , 2008).

Some challenges reported by informants are that operators may work in NORM contaminated environments without using protection or that they may use inappropriate masks (dust masks), and that contaminated equipment may be stored unsealed on the platform and it gets dry (reported by two of the consultants). Generally, better cleaning routines are needed (reported by one consultant).

Common barriers on the NCS, according to one HSE consultant, are e.g. restricting the area where work with NORM is carried out, marking it with the radiation trefoil sign, the use of PPE (physical 'mitigating' barriers); securing waste barrels against spillage and sealing contaminated equipment (physical 'controlling' barriers). Physical barriers common on some of the installations and recommended by the informant are: the use of chemical resistant gloves (e.g. 'nitrile' gloves), 'comb filter' masks with P3 filter for radioactive particles (Figure 35; Appendix B), boots, chemical goggles, as well as the use of dust proof and water resistant disposable coveralls (physical 'mitigating' barriers). According to OGP, other efficient barriers would be protecting surfaces by robust plastic covers before work with NORM or e.g. before opening 'pig' receivers, as well as segregating the entrance to the restricted area from the exit way, and placing containers for discarded PPE and contaminated waste at the exit of the site to avoid contamination spreading (physical/ organisational 'mitigating' barriers) (Figure 35). (OGP , 2008).

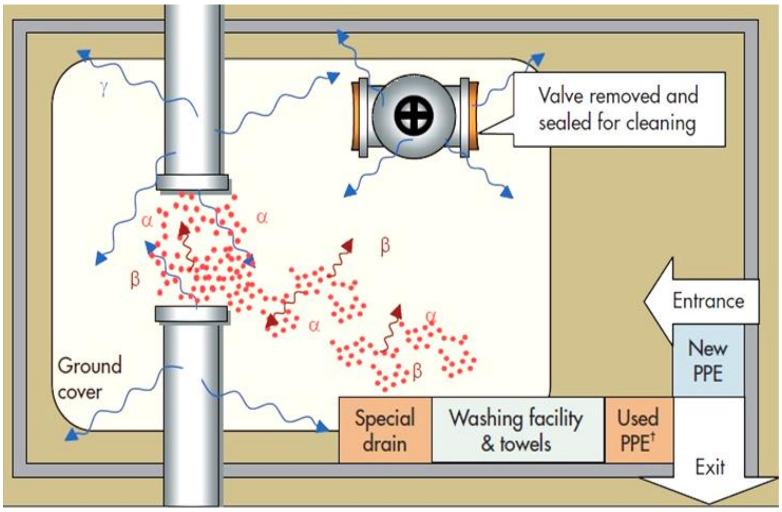

Figure 36: Measures against contamination with NORM: boundary, protective ground cover, special drain, washing facility, separation between entrance and exit and between new and used PPE, sealing of contaminated equipment (OGP , 2008)

Organisational barriers common on some of the installations and recommended by 3 HSE consultants are: routines for regular wetting of contaminated waste and equipment (organisational 'controlling' measure), the prohibition of any eating, drinking and of using snuff or chewing gum during work with NORM, good inspection, cleaning and hygiene routines (e.g. washing hands and face after work completion), and the removal of the RPE only after undressing contaminated cloth and in the absence of any internal exposure hazard (reported by one offshore worker, general organisational barrier). In addition contaminated equipment should be clearly marked, sealed and sent as soon as possible on shore (organisational 'mitigating' barrier). The informant highlights also the importance of appropriate contingency routines after NORM spillages, such as: cordoning off the area, containment of polluted material (physical 'mitigating' measures); keeping NORM all the time moist, the use of PPE, washing of contaminated surfaces, recording of the incident scenario and of measured doses to personnel (organisational 'mitigating' measures).

According to two of the informants (one offshore worker and two consultants), workers can accidentally get high doses when: they work on a platform where NORM has started to appear and it has not been detected, when they work with contaminated equipment that is not NORM classified or after spilling NORM onto the platform. Several of the above mentioned physical and administrative measures are the informants' recommendations against this type of exposure scenarios. In addition, as suggested by IAEA, regular (e.g. triennially) monitoring should be performed in order to assess whether NORM is present at an installation (general organisational barriers). Assessments should be carried out even more frequently after e.g. changes in the salinity of produced water (IAEA, 2010). When measurements show that the specific activity of deposits exceeds 1 Bq/g dust of either one of the radionuclides typical for NORM, the deposits must be classified as radioactive material and appropriate protective measures shall be immediately implemented (Pollution Control Act, 2013).

Measures reported by informants to be common on some or all the installations are similar to the ones recommended by the study literature (se subchapter 6.3.2. for a review of recommendation in their chronological order, from the beginning of NORM operations to work completion). Undertakings should focus more on their implementation and follow up: e.g. make sure that operators always wear correct PPE when handling radioactive waste, and that the working site is thoroughly prepared before the commencement of any operation involving NORM in order to control contamination spreading.

Generally, according to one of the consultants, offshore workers should have better knowledge about radiation sources, dose concepts and how to protect themselves against exposure. Many workers do not receive sufficient training about radiation protection. The ones who are required to take radiation courses are either specialists considered 'occupational exposed' or workers who may actually be less exposed than e.g. the operators (operation manager etc.). Moreover, most of the workers are not considered to be occupational exposed but still, they can receive high doses when they are not aware of the hazards and if there are not enough radiation barriers in place. Also according to another consultant, being aware of the place where the sources are and keeping a safe distance from them is one of the most important protection principles. Making measurements that are accurate and providing accurate results to those handling contaminated equipment is equally important (e.g. to service companies repairing NORM contaminated equipment). According to the Radiation Protection Regulations, the undertaking shall actually ensure that all the workers, who may become exposed to radiation, have sufficient competence with regard to the safe handling of radiation sources, radiation monitoring and the use of protective equipment (Radiation Protection Regulations, 2011). Thus, further assessment is needed to identify all the offshore workers that need radiation protection training (general organisational barrier). NRPA emphasises also the high priority undertakings should attribute to workers competency.

Other aspect that one should keep in mind is that it is particularly important to avoid inhaling or ingesting radioactive particles often, because of the close proximity to body organs and the risk it represents for cell mutations. Therefore, as explained by an HSE engineer one should as a precautionary measure, always restrict and mark with warning signs areas where contaminated dust is likely to arise, no matter how large the yearly dose rates would be and if they will reach the limits for 'supervised' or 'controlled area' or not. (organisational 'mitigating' barrier).

As recommended by NRPA, the uttermost important is to keep exposure as low as practicable by reducing the time workers will be exposed to the radiation source, maximising the distance from the source and shielding by physical barriers. Unshielded radiation will always be reduced by the square of the distance.

11.2. Mapping of sources of EMF on offshore installations from the NCS

Among sources of ELF the informants have emphasised there are the: generators, low and high voltage transformers, low-voltage switch gear room, the drive space, as well as power supply cables to/from land. RF sources highlighted by informants are the maritime radars and the Radio link. No source of static magnetic field has been commented in particular.

In the same way as for ionising radiation sources, Table 18 provides a brief review of the barriers (protection measures) against EMF introduced in Ch. 7 and 9. The barriers will serve as a reference throughout this chapter. Protection measures from the three last categories can be considered also this time in descending order of priority. For every single hazard there are usually required multiple barriers.

Most of the barriers against EMFs are similar to the ones against ionising radiation sources, but there are also a few that are specific to sources of ELF, SMN or RF e.g. 'Take frequent brakes without exposure to reduce the likelihood of thermal affects from RFs'. One may have nevertheless noticed that there is a higher variety of barriers against ionising radiation, in line with the higher severity of their health effects.

In the two following subchapters there are presented several efficient barriers against exposure to the sources of ELF, SMF and RF that the informants have highlighted. Just like in the previous subchapter, each measure will be classified as either physical or organisational and it will be attributed to one of the four barrier categories. The classification is just a proposal, depending on the context of the assessment performed, and it is aimed at triggering the analyst's reflection about the reliability of the barriers.

Barriers primary related to organisation (O)/ physical entities (P)	**Barrier types and their functions** **Radiation protection principles**
General organisational barriers:	
O	Risk assessment. Monitoring. E.g.: the assessment of the exposure level for maintenance and service personnel, of combined exposure to several types of EMF, and of co-exposure to EMFs and other stressors
O	Workers and service providers' competency
O	Communication and learning within the organisation and across the industry
O	Maintenance
O	Work procedures and instructions
O	Maintain an updated inventory of strong sources of EMF
O	Adopt a precautionary strategy when adverse health effects are not proved but yet likely to occur

Barriers primary related to organisation (O)/ physical entities (P)	<u>Barrier types and their functions</u> Radiation protection principles
Preventive barriers (eliminate the source):	
O	Eliminate the EMF source if it is not 'justified'. Substitute the EMF source by methods that do not lead to EMF
O	Unplug equipment that is not in use
O	Relocate workers at risk to other work tasks. E.g.: pregnant women; carriers of peacemakers that are exposed to SMF
Controlling barriers (minimise the radiation at the source):	
O	Avoid the acute effects of muscle and nerve cells simulation from ELFs, the acute thermal effects of the RFs and their possible long term effects by applying ALARA and the 'limitation' principle
O	Purchase less powerful EMF sources
P	Use BAT equipment i.a. with minimal need for maintenance
P	Use passive barriers: e.g. enclose powerful sources in separate rooms
O/P	Maximise the distance from the source by design e.g.: place sources of powerful EMF away from permanently manned area; mount antennas high above the ground; direct the sources' transmission away from manned area; use remotely controlled sources
O/P	Use active barriers : e.g. mobile shielding screens
Mitigating barriers (minimise personnel exposure):	
O	Avoid the acute effects of muscle and nerve cells simulation from ELFs, the acute thermal effects of the RFs and their possible long term effects by applying ALARA and the 'limitation' principle
O	Plan the work thoroughly: e.g. start with a risk assessment before working in the vicinity of powerful EMF sources
O	Minimise exposure time
O	Take frequent brakes without exposure to reduce the likelihood of thermal affects from RFs
O	Maximise the distance from the source. Unshielded radiation is reduced by the square of the distance.
O/P	Mark EMF sources and restricted areas
O/P	Use PPE: e.g. insulating gloves against high-frequency shock and burns

Table 17: A review of the radiation protection measures against exposure to EMF from Ch. 7 and 9

11.2.1. Typical sources of ELF and SMF

All informants have mentioned generators, transformers and the switch gear room ('tavlerom') as sources of powerful magnetic fields on installations from the NCS. One administrative barrier known to be implemented on NCS is the access restriction to these rooms. However, as commented by one of the HSE consultants doors are not always locked and it may happen that unauthorised workers go or take shortcuts through restricted rooms.

Both offshore workers and consultants (one radiation protection coordinator, one offshore security officer, one consultant representing a corporate health care and one representing an employee trade union) have emphasised a general need for further knowledge about EMF sources and exposure levels. One informant (radiation protection coordinator) has for instance specified that ELF levels in manned areas close to or inside the transformer room should be measured and evaluated and that an exposure assessment should be also performed for power supply cables to or from land. One security officer explained that there are numerous power supply cables from the shore on his platform, and personnel works in their vicinity, while one HSE consultant mentioned that several platforms may get their power from land in the future, EMF thus becoming an increasingly relevant issue.

The pilot project presented in Ch. 7, concluded that in zones with large power consumers and generators, within 0.5- 1 m from the sources (e.g. at 1 m from a 30 MW electric motor) exposure levels could exceed the occupational limit of 500 μT (1000 μT in 2014). Thus, it was decided that measures like warning signs and access restriction were necessary. The LV transformer room, HV transformer room, LV switchgear room and the drive space ('frekvens omformer rom') had levels over the background level but below recommended exposure limits. The LV transformer room had levels over 10 μT, while the HF transformer room and the LF switchgear room had levels over 0.4 μT. The higher the voltage, lower the magnetic fields around the transformer rooms. The access to the rooms was restricted and they were marked with warning signs about strong magnetic fields.

NRPA reports also very high magnetic fields close to powerful substations but low levels, of less than 0.5 μT, at 5 meters from the source. Furthermore, NRPA specifies that the components that generate highest magnetic fields are the transformer, the switchboard and the power transmission between the transformer and the switchboard (NRPA , 2000). Placing powerful ELF sources inside separate rooms and restricting the access to unauthorised people by e.g. locking the entrance doors can be considered as an efficient physical 'controlling' barrier against exposure, if, based on the informant's comments, doors are always kept locked. EMF fields decrease very rapidly, with the square of the distance, as explained in Ch. 9. By making sure that the entrance is restricted, one ensures that no unqualified worker comes into the strong fields, being unnecessarily exposed. In addition, the walls of the room will have an efficient shielding effect against the magnetic fields and will block all the electric fields, which could affect the people outside the room (physical 'controlling' barrier). However, magnetic fields are difficult to shield, so in line NORSOK S-002 strong EMF sources should not be placed in the vicinity of permanently manned area (physical 'controlling' barrier).

As part of the pilot project, there has been also assessed that magnetic fields around equipment (e.g. around a 7.3-2.9 MW HV transformer room) were much higher right after the equipment had been switched on, and that they decreased very quickly as the voltage increased. This is also mentioned in the studied literature (SCENIHR , 2013). Thus, it is particularly important to keep the distance from the source while the equipment is heating (organisational 'mitigating' barrier). Furthermore, magnetic fields around powerful supply cables were exceeding the exposure limit for general population at about 20 cm from the source, but at only 1 m they were below background level. This also applied for SMF on the surface of powerful motors, although levels were well below exposure limits even at the worst point.

According to various publications, welding operations are characterised by strong magnetic fields. The SMF are estimated to get as high as 10 mT, while the time varying ones can reach up to 500 μT. Only body parts that come in contact with components such as the power cable will be exposed to these field levels (Tynes, 2003). As commented by two HSE consultants and one offshore worker, welding is sometimes performed in connection to repair and maintenance operations on the platforms but it has not been assessed yet. Thus, more consideration needs to be given to this strong EMF source. Welding is also known to be a source of exposure to optical radiation.

Assessed exposure levels inside personnel cabins were below background level despite longer exposure times.

The general conclusion of the pilot project was that ELF and static magnetic levels were normally low, but it was nevertheless decided to adopt a precautionary strategy and to try to reduce exposure levels as much as practicable 'at the source' and by help of engineering measures. This meant for instance that there shouldn't be purchased and installed stronger radiation sources than necessary (organisational 'control' measure). According to the Norwegian Institute for Public Health, an undertaking should adopt a precautionary strategy in the situation when adverse health effects cannot be proved but there are many reasons to believe that there could be unwanted effects with potentially severe consequences. The exposure hazards would then exceed the benefits and the radiation source would not be justified anymore (general organisational measure). (Folkehelseinstituttet, 2012)

Furthermore, as explained in Ch. 7, there was decided that ELF sources would not be placed in the vicinity of permanently manned areas if the magnetic fields exceed 0.4 μT (physical 'controlling' barrier). 0.4 μT is the threshold for increased risk of leukaemia upon long-term exposure to magnetic fields (ICNIRP, 2010b). After 10 μT there was also recommended to reduce the exposure time as much as practicable (organisational 'mitigating' measure). The access to the EMF sources was restricted to unauthorised people above the exposure limit for the general population (200 μT in 2014). For magnetic fields above the occupational limit (1000 μT in 2014), there was in addition required to keep a safe distance (organisational 'mitigating' barrier), to perform a SJA (general organisational barrier) and to implement exposure reducing methods. As one can easily notice, the focus of the strategy lay on physical and organisational barriers, and no personal protective measure was mentioned in particular.

Finally, workers considered to be at risk should always receive particular attention. The

Figure 37: Example of Radio Link with sender and receiver (RadioLink Telemark AS, 2014)

undertaking should try to relocate pregnant women to other work tasks during their pregnancy, if they work in close proximity to strong electric and magnetic fields. Their exposure limits should not exceed the ICNIRP limits for the general population [5 kV/m and 200 µT n 2014] (NOU, 1995). Other workers considered at risk are carriers of peacemakers or other electronic implants. According to ICNIRP, they should not get exposed to SMFs above 0.5 mT. As seen in Ch. 9, the exposure limit for general population is 400 mT. Thus, these workers too, should be relocated to other activities. (ICNIRP, 2009)

Apart from the increased risk of leukaemia as a consequence of long term exposure to high magnetic fields, other health effects the above presented barriers are based on are the acute effect of muscle and nerve cells excitation with possible but uncertain impact on the development or progression of Alzheimer's and neurodegenerative diseases, but also the electric charge effects on the surface of the body and the disturbance of the visual field. With respect to SMFs, strong magnetic fields may affect the expression of certain genes on the long term, primarily in mammalian cells. As already noticed, the most effective barriers against ELFs and SMFs are based on the principle of maximising the distance from the source, especially related to strong magnetic fields. The electric fields are easily shielded by materials in the environment e.g. trees or walls.

11.2.2. Typical RF sources

RF sources that have been mentioned by most of informants (7 out of 9) are: the X and S band maritime radars (Figure 28, Ch.7.2), Radio Link (Figure 37) and communication antennas (Figure 27, Ch.7.2). All of them function at super high and ultra high frequencies i.e. SHF and UHF. In addition, both maritime radars have irradiated effects with very high maximum pulses. Three HSE consultants have mentioned that one common barrier on the NCS is 'sector blanking', a design setting consisting of directing the radar transmission away from any manned areas by restricting its sector (physical 'controlling' barrier).

One informant (HSE consultant) comments that on offshore installations from NCS, radars related to helicopter deck and communication antennas are placed far away from manned areas (physical 'controlling' barrier). Thus, radars and antennas normally do not represent an exposure source for personnel. The informant also confirms that radar transmission is directed away from manned places, and adds that this radiation is not a reason of concern with respect to boats located at installations for loading and unloading either, since these boats always lie at a lower level than the transmission. When it comes to floating platforms, the loading/unloading boats are about at the same height and the exposure may happen if e.g. radars are on during operations, meaning that this scenario should be further investigated.

RF levels from radars and antennas, measured during the pilot project from Troll A, were below the exposure limits in areas available for normal traffic. The maritime radars were set on 'Sector blanking', and they were placed away from any manned area and marked with warning signs. In the same way as for ELFs, there was adopted a precautionary strategy (general organisational barrier) and priority was given to design measures. For mean EMF power densities above 0.1 W/m^2 and 1 W/m^2, it was decided that the RF sources should be placed away from personnel cabins and permanent offices (physical 'controlling' barrier), or else protective measures must be implemented. For the latter situation, the exposure time should be reduced as much as possible. For levels above the international limit for general population of 10 W/m^2, the access to the RF sources was only allowed to authorised personnel (organisational 'controlling' measure). Finally, for power densities above the occupational limit of 50 W/m^2 there were in addition required a SJA, documented and well implemented protection measures (general organisational barriers) and it was underlined that there should be kept greatest possible distance to the source (organisational 'mitigating' barrier).

Furthermore, NRPA recommends that antennas with high transmission effects and high frequencies (e.g. UHF and SHF) should be mounted high above the ground (organisational 'controlling' barrier) (NRPA, 2005). The 'square low' applies also for RF fields, therefore most of the physical barriers are related to keeping distance from the source and avoiding the radiation transmission. The low also applies for organisational measures even though, in the same way as for other radiation sources, physical and especially design barriers are considered to be more effective.

Exposure levels are normally low but service personnel working with antennas and their transmitters, can get overexposed when the antennas are in operation (NRPA, 2005). As suggested in one comprehensive EU project about occupational exposure to EMF, when personnel need to work or walk by powerful antennas (e.g. a GSM antenna) and through the antennas' transmission, a general rule of thumb is that there should be kept a distance of at least 1 meter away from antennas, in front of them (organisational 'mitigating' barrier). Behind antennas the RF fields are normally below background levels. (EMF-NET/European Commision, 2008)

The type of health effects described barriers are based on, are acute 'thermal effects' in the tissues after a temperature increase of 1-2 ^{o}C caused by extremely high exposure levels. There are several hypotheses about the RFs exact biological effects e.g. their impact on reproduction, but none well established. Thus, most of the barriers are based on a precautionary strategy and they are usually related to minimising the exposure time to avoid tissue heating, and maximising the distance from the source.

For both ELF and RF sources, it is important to implement a thorough inspection and maintenance programme (general organisational barrier) in order to ensure that equipment and its safety barriers function as intended (EU, 2012). There should be e.g. inspected whether all the shielding covers (at e.g. radars) are on and screws are tight, if the locations where machines are placed are optimal for EMF reduction, and any damaged brass foils used for conducting the current and for grounding should be replaced. (EMF-NET/European Commision, 2008).

Finally, in order to enhance the level of competency and knowledge within own organisation but also across the industry, undertakings should in line with the 2012/11/EU Directive , ensure that workers who may become exposed to EMF and their representatives receive all the necessary training (general organisational method) about i.a.: safe working methods; the meaning of the ICNIRP exposure limits; protection measures; results from exposure assessments such as measured field levels and results from SJA; how to detect adverse health effects caused by exposure to EMF, how to report them and when it is appropriate to undergo a health surveillance (EU, 2012). With respect to SJA, it is generally considered that engaging as many workers as possible in this activity has clearly positive effects on the level of risk awareness and competency within the organisations. As often emphasised by NRPA, workers expertise is always decisive for the safe handling of radiation sources.

12. RECAP OF THE MAIN RESULTS. CONCLUSIONS

12.1. Recap of main results

The objective of this thesis has been the mapping of radioactive sources and of sources of EMF on offshore petroleum installations from the NCS, how they are handled, their health effects, and appropriate physical and organisational barriers against exposure. The starting point for the topic has been the radiation protection requirements from NORSOK S-002. The task has implied the study of both national and international publications about radiation concepts and principles, radiation sources generally used offshore, their related health effects and protection measures. Furthermore, data about typical radiation sources on the NCS, relevant barriers, and practical experiences has been collected from HSE specialists and compared to the literature results. This was aimed at identifying the most hazardous radioactive sources and EMF, existing on installations from the NCS, as well as efficient physical and organisational barriers.

The results show that among the most hazardous radioactive sources on the NCS there are: industrial radiography, well logging by use of neutron and gamma radiation, installed gauges, 'intelligent pigs', radiotracers, as well as NORM formed in gas and oil equipment.

Among the most important sources of ELF, are: generators, low and high voltage transformers, low-voltage switch gear room ('tavlerom'), the drive space ('frekvens omformer rom'), as well as power supply cables to/from land. RF sources highlighted by experts are maritime radars and the Radio link, while SMF are generated by powerful electric motors (e.g. of 30 MW).

As previously explained in Ch. 5, the most severe acute health effect from exposure to radioactive sources is death, occurring after extremely large radiation doses, of about 10 Gy or after an effective dose between 3-4 Sv. (IAEA, 2010). Well established long term effects of smaller radiation doses are cancer and genetic damages, both depending primarily on how high the individual's lifetime dose is. Both dose rate limits allowed in addition to background radiation and protection measures are based on avoiding the acute health effects and on restricting as much as possible the lifetime dose people can receive. Most of the barriers are related to radiation protection principles like minimising the exposure time, maximising the distance (effective doses decrease rapidly with the square of the distance) and shielding the radiation source.

An acute health effect from exposure to ELF (see Ch. 8) is the excitation of muscle and nerve cells, with possible but uncertain impact on the development or progression of Alzheimer's and neurodegenerative diseases (SCENIHR , 2013). A long term health effect that has been proven by multiple studies is the increased risk of leukaemia for children exposed to average magnetic fields above 0.4 μT, and several studies have also proven an increased risk for chronic lymphatic leukaemia for occupationally exposed (Tynes, 2003).

In what concerns the exposure to SMF, possible short term health effects are subjective symptoms like vertigo or nausea, while walking or moving in the presence of these fields, and a possible long term effect is the impact of strong SMFs on the expression of certain genes, primarily in mammalian cells (SCENIHR , 2013). SMF may also interfere with pacemakers or other electronic implants. Recommended exposure limits from ICNIRP, as well as barriers against overexposure are mainly based on the acute effects of these low frequency electric and magnetic fields. The ICNIRP limits also consider the interference with medical implants. Most of the barriers are related to the principles of maximising the distance from the source and minimising the exposure time to ELF and SMF sources, since strong magnetic fields are difficult to shield and the exposure levels decrease very quickly with the square of the distance.

The biological effects from overexposure to RF, the ICNIRP recommended limits and the protection measures are based on, are acute tissue damages after a temperature increase in the body of 1-2 ^{o}C, caused by extremely high exposure levels. There are several hypotheses about the RFs exact short term and long term health effects, such as their impact on reproduction or the increased risk for developing a benign brain tumour (acoustic neuroma), but none of them is well established. Thus, most of the barriers are based on a precautionary strategy and they are primarily related to minimising the exposure time to avoid tissue heating and maximising the distance from the source.

In Table 17 and 18 there has been presented an overview of protection measures against radiation, introduced in earlier chapters. The barriers have been structured into: 'General organisational barriers' that are almost always applicable; 'Preventive barriers' aimed at eliminating the source of harm; 'Controlling barriers' suitable for minimising the radiation at the source, and 'Mitigating barriers', aimed at minimising workers' exposure and protecting them against uncontrolled radiation. This type of structure has been based on a classical safety model, the Energy-Barrier (see Ch. 6.1), commonly used to evaluate the reliability of protection measures and to prioritize them. The model has roots in health care, therefore one can imagine that (in direct order of priority): the largest the distance from the source of harm, the lowest the time spend in the vicinity of the source and the strongest the shielding, the safest for the affected person.

Furthermore, each barrier has been related to either one of these three alternatives: to the organisation, when its protection function depends mainly on the personnel; to physical entities, when the protection function depends primarily on the way radiation sources are designed, on the layout of the workplace or on the PPE, or to both. Within the field of radiation protection, it is considered that protection measures like the ones included in the three last groups are usually more reliable when they primarily depend on design solutions (i.e. physical barriers) and follow the principle of radiation protection 'at the source'. Moreover, for every single hazard there are normally required multiple barriers.

Most of the barriers and radiation protection principles are common for radioactive sources and EMF. However, the energy of the radioactive sources and their damaging potential are higher and this will be normally reflected in the variety of barriers needed. Moreover, nuclear (radioactive) radiation originates from the nucleus and transmits its energy in the form of high energy particles emitting α and β radiation spontaneously, or neutron radiation artificially, and in the form of electromagnetic radiation- the γ radiation. X-ray is also ionising radiation, capable of breaking chemical bonds (ionise materials) and it is very similar to γ radiation. What differentiates X-rays from γ rays is their origin: X-rays always come from electrons and they are artificially generated.

Thus, several of the barriers that are typical to radioactive sources are aimed at containing the radioactive materials to prevent radioactive particle from spreading in the air, contaminating surfaces and consequently human organs, by inhalation and ingestion (e.g. the measure of sealing radioactive materials inside capsules). Certain radioactive particles and electromagnetic radiation are capable to give doses to human organs without being inhaled or ingested, i.e. by penetrating human skin and irradiating the organs. These are neutron radiation, γ radiation and X-rays. α and neutron radiation have the highest energy. It is particularly important to avoid often inhalations or ingestions of radioactive particles e.g. upon working with NORM, because of the close proximity to body organs and the increased risk for cell mutations. How large the internal doses can get will e.g. depend on the amount of NORM dust inhaled and on the radioactive concentration of the dust. Internal doses are difficult to measure and NRPA does not record them, so further research is needed to improve this situation. Moreover, most of the protection measures against internal radiation from unsealed sources like NORM are organisational and related to the use of PPE, so one should investigate whether several engineering barriers could be developed.

In the context of the radiation protection against exposure to radioactive sources and the assessment of related hazards, there are used a range of dose concepts, and barriers will often relate to the monitoring of radiation doses. Measurements are also performed with respect to the EMF, however, not that frequently and dose concepts used in risk assessment are actually physical quantities (magnetic flux density, irradiation strength etc.). EMFs, same as X-rays and γ radiation, generate electromagnetic waves- electric and magnetic fields in motion. However, unlike these two ionising sources, EMFs do not have enough energy to break chemical bonds and ionise materials, so they belong to the non-ionising category of radiation, together with the optical radiation. When non-ionising radiation strikes a material, instead of breaking chemical bonds, the energy will go over to heating. Thus, specific barriers against overexposure to RF and the ICNIRP exposure limits are aimed at avoiding tissue heating e.g.: 'Take frequent brakes without exposure to reduce the likelihood of thermal affects from RFs'.

Moreover, within the electromagnetic spectrum, the lowest the frequency the waves have the lowest the energy, so SMF have the lowest energy of all the EMFs, followed by ELF, radio-waves and microwaves. On the other hand, SMF and ELF have higher penetration capability than the other non-ionising radiation types. ELF can penetrate the body and excite nerve and muscle cells, so both the ICNIRP exposure limits and related barriers are aimed at restricting these effects, mainly by maximising the distance from the sources and minimising the exposure time, as explained earlier.

12.2. Conclusions

All the recommended barriers from Ch. 11 are either based on requirements and recommendations from lows and regulations (i.a. the Radiation Protection Regulations, ICNIRP's guidelines, the EU Directive 2011/11 and NORSOK S-002), or on recommendations and practical experiences from informants, thus, all of them are highly relevant. Moreover, one could say that what informants report about existing barriers on the NCS is in line with requirements and recommendations from the authorities and generally in line with the studied literature. Based on the data collected from informants, it seems that challenges arise in relation to the implementation of certain barriers e.g.:

- Appropriate PPE (including respiratory masks) is not always used when handling NORM
- Contaminated equipment is not always sealed soon enough and it gets dry
- Well operators may receive high radiation doses while helping logging specialists with the transport of the source containers or by standing to close to the logging site, thus their exposure level should be also assessed
- Offshore workers are not always aware of the presence of installed gauges even if they are marked, and they stand too close to them
- Many offshore workers, especially the operators do not have enough knowledge about the meaning of the radiation dose concepts, measuring units and how to protect themselves. Operators and other relevant occupations should receive more training about radiation protection
- NORM contaminated equipment is not always 'NORM classified'. Thus, maintenance workers may get exposed. Sometimes measuring units are mixed up, so this could lead to unwanted events
- The development of NORM is not always monitored early enough, so NORM may appear on the platforms without workers being prepared for it
- Sealed sources may be lost inside the wells and be damaged, and workers may enter tanks and go through the primary radiation beam while installed gauges are on (in extreme situations)
- The doors to the rooms where strong ELF sources are found (e.g. generator and transformer room) are not always locked and unqualified workers can go through these rooms. A range of recommended barriers against these scenarios have been given in Ch. 11.

Furthermore, conclusions based on the amount and content of information received from consultants compared to offshore workers are as follows:

- There is a need for several specialists within radiation protection offshore

- Several occupations offshore should receive training about radiation protection, and special attention should be given to aspects, such as the meaning of the different measuring units, how to carry out dose measurements and which are the most important barriers against exposure. Workers competency is a factor that NRPA also places very high on the agenda
- There is a need for better communication within organisations and across the petroleum industry with respect to radiation protection
- There is a need for as much as possible transparency and collaboration from the field operators

Radiation protection is a wide subject so there are many possible recommendations one could give about efficient protective measures, however one strategy that applies for both radioactive sources and EMF is: to only use radiation sources if they are justified and to reduce the exposure levels as much as reasonably achievable by barriers and principles such as: training and good communication within the organisation and across the petroleum industry, maximising the distance from the source, minimising the exposure time and shielding. Priority should be given to design and organisational barriers.

13. FURTHER WORK AND STUDIES

Greatest possible benefits from the use of radiation sources combined with the lowest level of harm requires thorough knowledge about radiation and appropriate protection measures, both within one individual business and across the industry. With the increasingly numerous applications of radioactive materials and generators in the petroleum industry and situations when they can represent a hazard, there is an ongoing need for best available information about radiation safety.

Thus, one initiative that should be further developed is the design of a user friendly tool, aimed at providing a clear and up-to-date overview of: radiation sources used on the offshore and onshore installations from the NCS, statutory requirements about their use and practical barriers against related hazards. Its accomplishment would require the engagement of several radiation specialists and users across the petroleum industry.

In connection with this thesis, there had to be collected data through expert interviews. Creating one database for ionising sources and one for electromagnetic fields, by use of Excel and mailing it to the experts for quality assurance was considered a practical and efficient solution in dealing with a high amount of details. Many experts had expressed the need for a better overview of radiation sources used in the petroleum industry and their properties, so these tools have been received positively by several of them. These databases could be further developed and published online, becoming the starting point of a virtual and interactive tool where specialists could for instance declare the use of new radiation sources and share experiences.

There has been expressed the need for a study about the occupational and non-occupational exposure on offshore installations, to 'Low frequency electric and magnetic fields' close to or inside transformer rooms, and close to power supply cables (to/from the shore). The study could possibly consist of measurements of the LF fields, exposure assessment and recommendations in line with applicable legislation. For this purpose, there could be relevant to study the results from the public consultation launched by SCENIHR (The European Commission and the Scientific Committee on Emerging Newly Identified Health Risks) in the beginning of 2014, about the potential health effects of exposure to electromagnetic fields. The results are expected to be published at: http://ec.europa.eu/health/scientific_committees/consultations/public_consultations/scenihr_consultation_19_en.htm. (SCENIHR, 2014)

Another study that is of interest for the petroleum industry is the assessment of the radioactive Thorium- 228 in produced water returned to the surface after scale dissolver treatments. The project could include a field study of 2-3 well treatments at an offshore platform, sampling and an evaluation of the usefulness and feasibility of this type of measurement.

NORSOK S-002 is under revision. Another proposal is to consider including in the future a definition of what it is meant by ‘electromagnetic fields’ and ‘high voltage equipment (> 690 V)’, as well as to take into account and eventually give guidance with respect to the Radiation Protection Regulation’s paragraph §20, about the requirement for overview and control of strong non-ionising sources.

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APPENDIX

Appendix A- Interview guide

First approach by e-mail

”Navnet mitt er Maria, er masterstudent innen HMS ved Instituttet for industriell økonomi og teknologiledelse, på NTNU, og jeg holder på med å skrive masteroppgave om et svært spennende tema: radioaktive kilder og elektromagnetiske felt i olje og gass industrien, på NKS. Oppgaven har fokus på strålevern jf. NORSOK S-002. Har limt inn oppgaveteksten nederst på siden.

I forbindelse med oppgaven har jeg laget 2 databaser, en for ioniserende kilder offshore og en for EMF. Jeg anvender disse databasene til å samle inn data og kvalitetssikre den med eksperter. Data er anonymisert. Sender dem som vedlegg. [...] har anbefalt meg til å ta kontakt med deg, så jeg vil gjerne spørre deg om du har mulighet for å ta en titt på databasene og om jeg kunne ringe deg for en samtale. Det vil være til stor nytte! Hvis du har kommentarer kan du gjerne skrive dem direkte i Excel tabellene.

Det er flere tabeller ("Sheets") i de to dokumentene, så du kan bla gjennom dem hvis du har anledning. Cellene i tabellen som har lyse grå bakgrunn kan evt. overses.

De aller viktigste tilbakemeldinger vil kunne angå:
1)aktuelle kilder på norske plattformer (kilder i tabellen som kanskje er overfladiske eller kilder som mangler);
2) praktiske erfaringer med strålevern på norske plattformer
3) effektive barrierer, som allerede har blitt implementert.

<<Oppgavetekst/Problembeskrivelse:
The objective of this thesis is to map the radioactive sources and electromagnetic fields on offshore installations on the Norwegian continental shelf, as well as how they are transported, handled, applied and stored, their potential health effects and appropriate physical and organisational barriers against exposure.

Følgende hovedpunkter skal behandles:
1.Literature research on radioactive sources and electromagnetic fields on offshore installations, their health effects and on potential barriers against exposure to radiation sources.
2.Data collection through expert interviews to identify radioactive sources and electromagnetic fields on offshore installations on the Norwegian continental shelf; existing barriers and practical experiences related to the protection of workers against exposure.

3.A discussion of the results in order to identify the most important radioactive sources and electromagnetic fields and efficient physical and organizational barriers against radiation exposure.
4.Propose further work and studies.>>

På forhånd takk!

Med vennlig hilsen,
Maria Flavia Mogos
Tlf. [...]“

Interview guide for telephone interviews:

Thank you for accepting to participate!

About the informant
What do you have most experience with?

About ionising sources

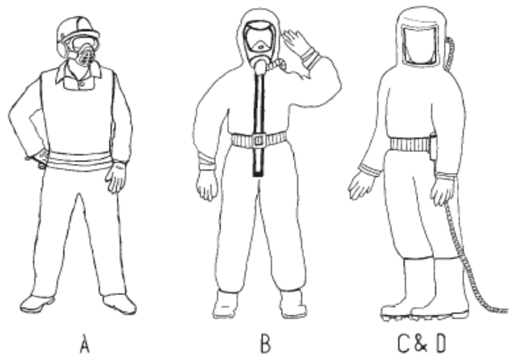
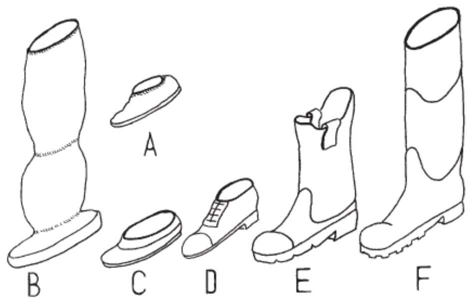
1. Are there any radioactive sources that are missing from the table?
2. Are there any sources that are not relevant on the NCS?
3. What types of protection measures have been implemented on offshore platforms from the NCS?
4. Which of the radioactive sources do you think that are critical?
5. Which of the protection measures du you think that are most effective?
6. Have there been any particular accidents?

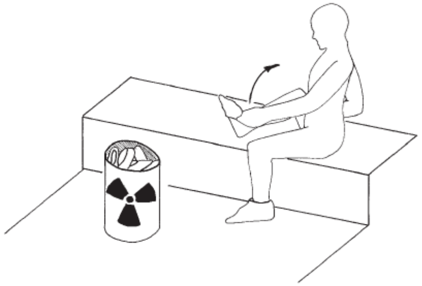
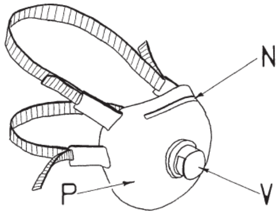
About EMF

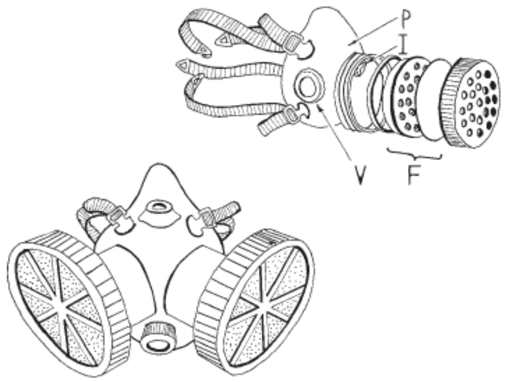
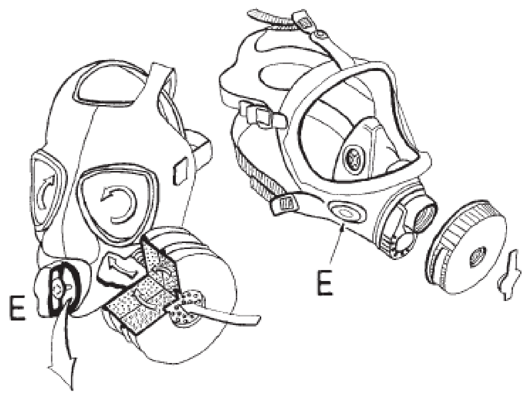
7. Are there any sources of EMF that are missing from the table?
8. Are there any sources that are not relevant on the NCS?
9. What types of protection measures have been implemented on offshore platforms from the NCS?
10. Which of the sources of EMF do you think that are critical?
11. Which of the protection measures du you think that are most effective?
12. Have there been any particular incidents?

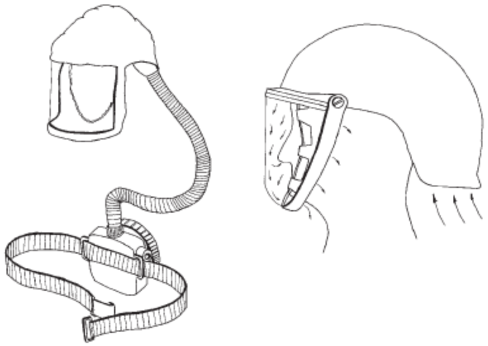
Thank you for your time! Your feedback is very useful!

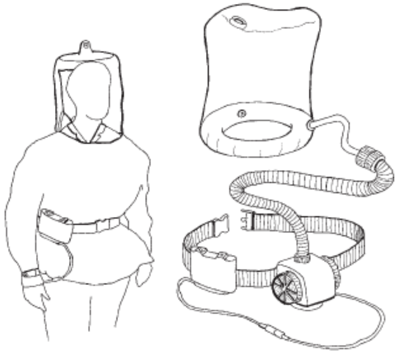
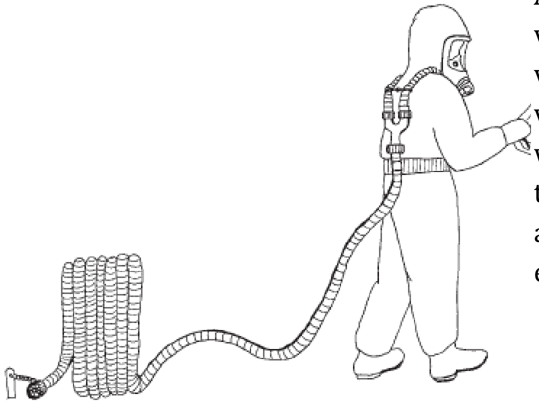
Appendix B- Types of PPE

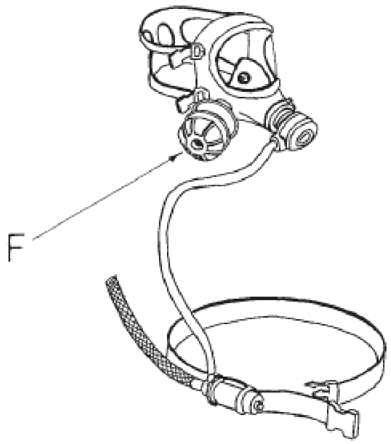
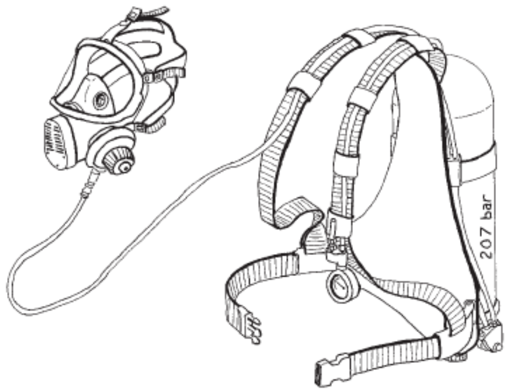
No	Types of PPE	Illustration	Working procedures	Abbreviations
1	Industrial suits of different types provide varying degrees of protection		Type A suits are unventilated and are made of permeable fabric or of nonwoven material. They are suitable for low solid surface contamination and weak aerosol contamination. Additional Respiratory PE is necessary. Type B suits are unventilated but impermeable. They are suitable for: low/high, solid/liquid surface contamination and weak aerosol and gas contamination. Additional Respiratory PE is necessary. Types C and D suits are ventilated and impermeable. Type C is suitable for low/high solid/liquid surface contamination and weak/high aerosol contamination. Type D is suitable for: low/high, solid/liquid surface contamination and to weak/high aerosol and gas contamination.	PPE- Personal protective equipment/ RPE- Respiratory protective equipment
2	Footwear- types		Overshoes, 'booties', shoes and boots. Overshoes allow personal footwear to be worn in areas where there is a risk of a minor spill or drips contaminating the floor. In their simplest form, overshoes are disposable, single size, foot shaped plastic bags with elasticized openings. More expensive and durable but possibly less effective are outsized plastic shoes (C). Fabric overshoes (A) with hard soles and booties (B) and fabric overshoes with legging supported at the knee by elastic or drawstrings provide further inexpensive options. In an industrial environment, where safety shoes (D) or	

No	Types of PPE	Illustration	Working procedures	Abbreviations
			'rigger' boots (E) with steel toecaps are needed, color coded footwear of the type is often issued for entry to designated areas. Rubber, rather than leather, safety boots (F) may be preferred to facilitate decontamination or to carry out wet work. Trouser cuffs, preferably elasticized, should be pulled down over the bootleg to complete the protection.	
3	Procedure for removing contaminated footwear		Barrier discipline is imperative to the effectiveness of protective footwear. A physical barrier should be set up between clean areas and the designated 'dirty' area.	
4	A filtering face piece respirator (FFP)		The nominal protection factor of FFP respirators is relatively low, but the highest retention efficiency filters, class FFP3, provide adequate protection for either low risk areas or for short exposures within the specified limits. Their use helps to keep contaminated gloves away from the mouth area but they provide no protection for the eyes and should not be used where skin contamination is a hazard. They should not be reused. They may retain contamination that can be monitored as an aid to assessing working conditions.	NPE- Nominal protection factor/ N- noise clip/ P- filtered material/ V-exhalation valve

No	Types of PPE	Illustration	Working procedures	Abbreviations
5	Half mask respirators with single and multiple cartridges		Their NPFs are usually much higher than for disposable FFP respirators but their real advantage is that the filter cartridges have a higher absorption capacity for gases and vapours and provide safe containment for subsequent disposal of the contaminant. Replaceable filters are available for particulate contaminants, gases and vapour. A combination of particulate and activated charcoal filters can to be used. They do not provide any protection for the eyes and should not be used where skin contamination is a hazard.	NPE- Nominal protection factor P- filtered material/ I- inhalation valve/ V-exhalation valve/ F- filter
6	Full face mask respirators with visor or individual eyepieces		The NPF offered against particles by a properly fitted full face mask respirator could be high. The wearer has to monitor the apparent protection being provided by RPE and has to leave the designated area if there is any noticeable deterioration. To prevent fogging due to moisture in exhaled air, antifogging compounds should be applied to the inside of the visor or the full face mask. The face mask can incorporate a speech diaphragm or microphone and provision for prescription corrective lenses. The low inward leakage at the face seal enables the use of high efficiency particulate air (HEPA) filters.	RPE- Respiratory protective equipment NPE- Nominal protection factor/ E-exhalation valve

No	Types of PPE	Illustration	Working procedures	Abbreviations
7	Powered respirator with full face mask		Powered air purifying respirators (Fig. 34) provide a continuous flow of air into the mask. Ideally, the NPFs are then only determined by the filter characteristics and are higher than the NPFs of non-powered respirators. Powered air purifying respirators are desirable under conditions of increased workload because they make breathing easier. If the ventilator fails, the face mask gives the wearer enough time to escape a contaminated area.	NPE- Nominal protection factor
8	Ventilated visor and helmet		Such equipment is normally used for protection against dust but some models are available for protection against gases and vapors. Ventilated visors can offer high NPFs but some helmets offer quite low protection. If the ventilator fails there is a possibility of exposure as a result of the drastically reduced protection. They are therefore best for use in low hazard situations or where prompt egress from a contaminated area is possible.	NPE- Nominal protection factor

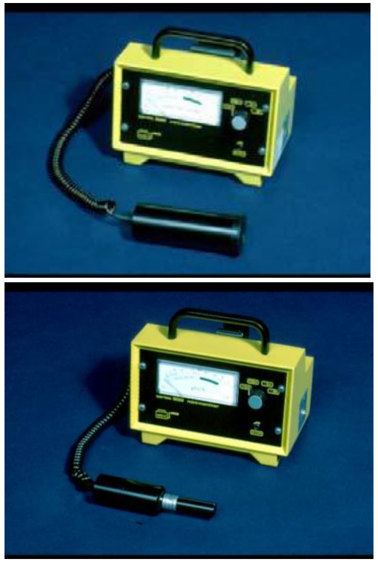
No	Types of PPE	Illustration	Working procedures	Abbreviations
9	Powered hood and blouses		Available for dusts, gases and vapors. Filtered air is fed directly into the hood, blouse or suit and is exhausted usually by leakage from the protective clothing or through exhaust valves. Workers will need more extensive practical training to use hoods, blouses and suits than is necessary for the RPE previously described. They should be prepared for being dependent on the equipment to provide an air supply. The inner surfaces of the equipment must be disinfected hygienically and the outer surfaces monitored and, if necessary, decontaminated before reuse.	RPE- Respiratory protective equipment NPE- Nominal protection factor
10	Fresh air hose supplying a full face mask		Air is supplied by either normal breathing (unassisted ventilation), manually operated bellows (forced ventilation) or a powered fan unit (powered ventilation). A large diameter air hose is necessary which, for unassisted ventilation, should not be longer than about 9 m. Such equipment is vulnerable, heavy and less comfortable to use than compressed air line equipment.	NPE- Nominal protection factor

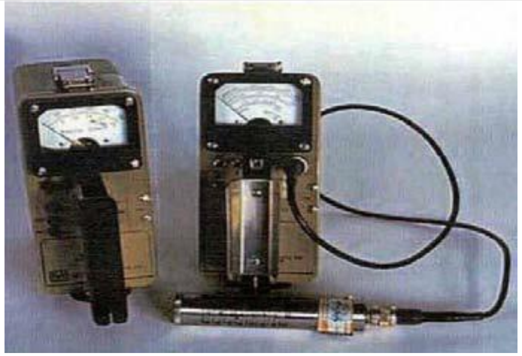
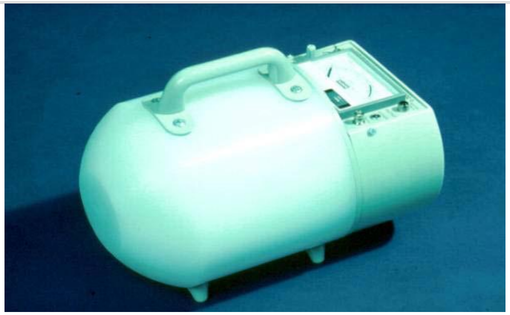
No	Types of PPE	Illustration	Working procedures	Abbreviations
11	Full face mask with compressed air line and auxiliary filter		The air may be supplied from a compressor or from compressed air cylinders that are outside the contaminated area. In using compressors, the air intake needs to be properly located to prevent the contaminant becoming entrained in the air supply. In-line filters and traps to remove oil, dust, condensate and odor from compressed gases should be provided as necessary to yield breathable air of an acceptable quality. A face mask is connected through a belt mounted flow control valve to the compressed air line. With an adequate airflow, an effective positive pressure can be maintained in the mask to provide a high NPF. The wearer's comfort is relatively high in combination with moderately high protection.	NPE- Nominal protection factor/ F- filter
12	Self contained breathing apparatus (SCBA) with a demand valve		It has a closed system that collects the exhaled gases, routes them through a soda lime cartridge to remove the carbon dioxide, and then adds oxygen to make up the fresh gas. It provides mobility but is bulky and heavy. Compressed air apparatus protects for up to 45 min and oxygen apparatus for up to four hours. Extensive training is necessary for the wearers and for those who maintain the equipment. An SCBA is difficult t decontaminate and should be worn under a protective suit when used in contaminated areas. A type of SCBA that generates oxygen chemically can be used in emergency situations for up to one hour. It is less bulky than compressed oxygen cylinders and has a long shelf life. Oxygen is generated from sodium chlorate or potassium superoxide.	NPE- Nominal protection factor

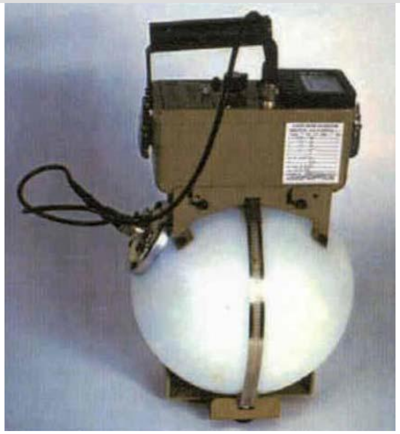
No	Types of PPE	Illustration	Working procedures	Abbreviations
13	A full suit supplied by compressed air line		Full suits offer among the highest NPFs of all PPE. The compressed air supply hose is attached to a belt to withstand the stresses of being dragged. Some substances can permeate or diffuse through the material, making the NPF dependent on the properties of the material and the flushing rate of the suit. An additional respirator should be worn under the suit if it is likely that a suit may become damaged.	PPE- Personal protective equipment/ NPE- Nominal protection factor

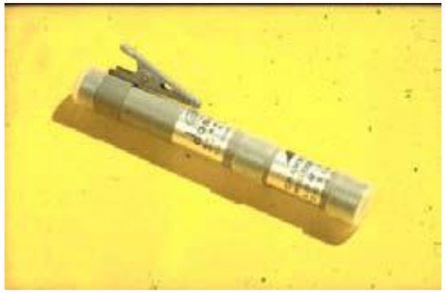
Table 18: Types of PPE (IAEA, 2010)

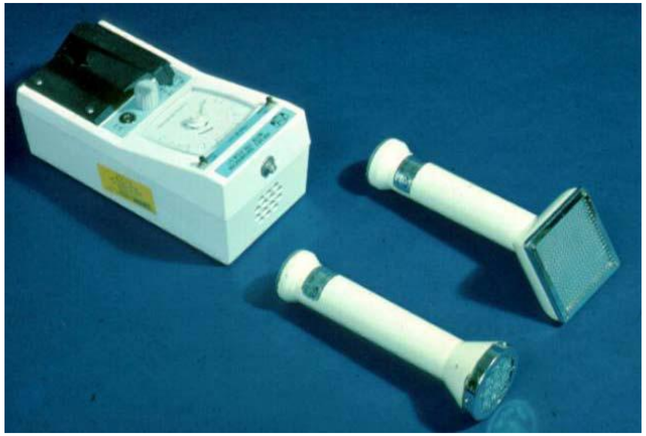
Appendix C- Types of Monitors

No.	Types of monitors	Illustration	Application
1	Ion chamber dose rate meter		Wide-range or multi-range instrument covering dose rates up to several mSv per hour. Particularly when working in remote locations, these may be supplemented by specialized high range instruments (indicating in Sv per hour) assigned to the emergency kit.
2	Compensated and end window dose rate meters		Instruments with sensitive probes capable of measuring low dose rate gamma radiation fields such as the background value at sea level (40–60 nSv/h). They can be used for monitoring mud returns when it is suspected that a sealed source might have ruptured downhole or when it is necessary to monitor over a wide area to find a lost source or equipment that contains a gamma source.

No.	Types of monitors	Illustration	Application
3	Dose rate meters		Instruments with sensitive probes capable of measuring low dose rate gamma radiation fields such as the background value at sea level (40–60 nSv/h). They can be used for monitoring mud returns when it is suspected that a sealed source might have ruptured downhole or when it is necessary to monitor over a wide area to find a lost source or equipment that contains a gamma source.
4	Intrinsically safe dose rate meter		Dose rate meter measuring both gamma and neutron dose rates. Suitable also for neutron sources used in well logging, typically 241Am–Be, which emit both gamma and neutron radiation.
5	Neutron dose rate meter (17 MeV energy response)		Dose rate meter measuring both gamma and neutron dose rates. Suitable also for neutron sources used in well logging, typically 241Am–Be, which emit both gamma and neutron radiation.

No.	Types of monitors	Illustration	Application
6	Neutron survey meter (10 MeV energy response)		Dose rate meter measuring both gamma and neutron dose rates. Suitable also for neutron sources used in well logging, typically 241Am–Be, which emit both gamma and neutron radiation.
7	Personal dosimeter- Thermo luminescent dosimeter		Suitable dosimeter for occupationally exposed workers.
8	Personal dosimeter- Film badge		Suitable dosimeter for occupationally exposed workers.

No.	Types of monitors	Illustration	Application
9	Personal dosimeter- Neutron badge		Suitable dosimeter for occupationally exposed workers.
10	Dosimeter- Direct reading- quartz fiber electrometer		Used in addition to the dosimeter, where high dose rates are possible, such as in radiography.
11	Dosimeter- Direct reading- electronic dosimeters		Used in addition to the dosimeter, where high dose rates are possible, such as in radiography.

No.	Types of monitors	Illustration	Application
12	Surface contamination monitor		Indicates surface contamination in counts/s (or s−1) or counts/min and the instrument needs to be calibrated for the particular radiation being detected to enable the indicated reading to be converted into meaningful units such as Bq/ cm^2.
13	Portable contamination rate meter with beta probe and alpha–beta dual probe		Surface contamination monitors that incorporate a combination of separate alpha and beta detectors. Aimed at monitoring thin layers of NORM on surfaces. Care should be taken as most beta detectors are sensitive to gamma radiation- the presence of ambient gamma radiation that might originate from inside a vessel could in such cases be misinterpreted as contamination. 2^{nd} picture: NORM contamination within a vessel being measured using a surface contamination measuring instrument.

No.	Types of monitors	Illustration	Application
			
14	Cylindrical beta detector (found also as intrinsically safe)		Checking tubulars for internal NORM contamination.

Table 19: Types of monitors (IAEA, 2010)