Guidelines for the management of Naturally Occurring Radioactive Material (NORM) in the oil & gas industry

Report No. 412
September 2008
Global experience

The International Association of Oil & Gas Producers has access to a wealth of technical knowledge and experience with its members operating around the world in many different terrains. We collate and distil this valuable knowledge for the industry to use as guidelines for good practice by individual members.

Consistent high quality database and guidelines

Our overall aim is to ensure a consistent approach to training, management and best practice throughout the world.

The oil and gas exploration and production industry recognises the need to develop consistent databases and records in certain fields. The OGP’s members are encouraged to use the guidelines as a starting point for their operations or to supplement their own policies and regulations which may apply locally.

Internationally recognised source of industry information

Many of our guidelines have been recognised and used by international authorities and safety and environmental bodies. Requests come from governments and non-government organisations around the world as well as from non-member companies.

Disclaimer

Whilst every effort has been made to ensure the accuracy of the information contained in this publication, neither the OGP nor any of its members past present or future warrants its accuracy or will, regardless of its or their negligence, assume liability for any foreseeable or unforeseeable use made thereof, which liability is hereby excluded. Consequently, such use is at the recipient’s own risk on the basis that any use by the recipient constitutes agreement to the terms of this disclaimer. The recipient is obliged to inform any subsequent recipient of such terms.

This document may provide guidance supplemental to the requirements of local legislation. Nothing herein, however, is intended to replace, amend, supersede or otherwise depart from such requirements. In the event of any conflict or contradiction between the provisions of this document and local legislation, applicable laws shall prevail.

Copyright notice

The contents of these pages are © The International Association of Oil and Gas Producers. Permission is given to reproduce this report in whole or in part provided (i) that the copyright of OGP and (ii) the source are acknowledged. All other rights are reserved. Any other use requires the prior written permission of the OGP.

These Terms and Conditions shall be governed by and construed in accordance with the laws of England and Wales. Disputes arising here from shall be exclusively subject to the jurisdiction of the courts of England and Wales.
Guidelines for the management of Naturally Occurring Radioactive Material (NORM) in the oil & gas industry

Report No: 412
September 2008
Table of contents

1 Introduction ........................................................................................................................................ 1
  1.1 The Origins of Naturally Occurring Radioactive Material (NORM) .................................................. 1
  1.2 NORM in Scale .................................................................................................................................. 6
  1.3 NORM in Sludge and Scrapings .......................................................................................................... 7
  1.4 NORM in Gas Processing Facilities ...................................................................................................... 8
  1.5 NORM in Seawater Injection Systems ................................................................................................. 8
  1.6 Health Hazards of NORM .................................................................................................................... 8
  1.7 Environmental Problems Associated with NORM .............................................................................. 10
2 NORM Management Process Cycle .................................................................................................... 11
3 NORM Monitoring ................................................................................................................................ 13
  3.1 Baseline surveys ................................................................................................................................. 13
  3.2 Pre-shutdown surveys .......................................................................................................................... 13
  3.3 Operational assessments ...................................................................................................................... 13
  3.4 Legacy contamination surveys ........................................................................................................... 14
4 NORM Action Limits .............................................................................................................................. 16
5 Training and Awareness .......................................................................................................................... 17
6 Contamination Control ............................................................................................................................ 18
7 Control of NORM Contaminated Waste ................................................................................................. 20
  7.1 NORM disposal options ....................................................................................................................... 21
8 Control of NORM Contaminated Equipment ........................................................................................... 23
9 Decontamination ..................................................................................................................................... 25
  9.1 Operating criteria ................................................................................................................................ 25
  9.2 Required operating areas ...................................................................................................................... 25
  9.3 Control of equipment ............................................................................................................................ 26
  9.4 Inspection of equipment ....................................................................................................................... 27
  9.5 Monitoring of equipment ...................................................................................................................... 27
10 Workers Protection Requirements ....................................................................................................... 29
11 Confined Space Entry .............................................................................................................................. 30
12 Transport of NORM Contaminated Equipment ...................................................................................... 31
13 Documentation ....................................................................................................................................... 33
  Glossary of Terms .................................................................................................................................. 34
  References ................................................................................................................................................ 36
Further reading ......................................................................................................................................... 36
1 Introduction

Naturally occurring radionuclides are present at varying concentrations in the Earth’s crust and can be concentrated and enhanced by processes associated with the recovery of oil and gas. This “enhanced” NORM, often known as TENORM (Technologically-Enhanced Naturally Occurring Radioactive Materials) can be created when industrial activity increases the concentrations of radioactive materials or when the material is redistributed as a result of human intervention or some industrial processes, TENORM also can be the by-product or waste product of oil, gas and geothermal energy production. Sludge, drilling mud, and pipe scales are examples of materials that can contain elevated levels of NORM, and the radioactive materials may be moved from site to site as equipment and materials are reused.

Uncontrolled activities associated with enhanced levels of NORM can contaminate the environment and pose a risk to human health. These risks can be alleviated by the adoption of controls to identify where NORM is present; and by the control of NORM-contaminated equipment and waste while protecting workers. The general principles of radiation protection are primarily implemented by means of good protective measures at the workplaces. Hence, exposure control and adequate dosimetry are the most critical components of a health and safety programme.

There are various national and international regulations and guidelines on radiation protection in general and NORM in particular. These are not specific to the oil & gas industry and there are variations in the methods of control adopted. This document has been developed after research, review and thorough consideration of readily available NORM regulations and guidelines, to determine best practice for managing NORM in oil and gas producing facilities. Similarly, there is no universal medical surveillance programme for low-level radiation exposures. Medical surveillance is typically triggered by an exceedance of a defined action level. An action level is a scientifically derived value used for the purpose of limiting exposure. Action levels often vary from country to country so that the reader must understand the applicable regulations in a given locale.

This document acts as a road map and establishes uniform approaches on NORM management that makes the implementation of tasks easy to manage. The guidance does not seek to obstruct or impede normal operations but to describe controls that are adapted to working practices. The guidelines are flexible and accommodate regulatory variations under which individual OGP member companies may be required to operate.

The guidance acts as a single point of reference, is user-friendly and utilises flowcharts to guide the reader through different NORM management activities. It guides the user through the various components of an effective NORM management process.

It must be stressed, however, that these guidelines provide a framework. Users should realise that management of NORM requires the consultation and engagement of a number of stakeholders, notably the approval of the regulatory authorities.

1.1 The origins of Naturally Occurring Radioactive Material (NORM)

Radioactive materials such as Uranium and Thorium were incorporated in the Earth’s crust when it was formed; these normally exist at trace (parts per million – ppm) concentrations in rock formations. Decay of these unstable radioactive elements produces other radionuclides that, under certain conditions (dependent upon pressure, temperature, acidity etc) in the subsurface environment are mobile and can be transported from the reservoir to the surface with the oil & gas products being recovered.

During the production process, NORM flows with the oil, gas and water mixture and accumulates in scale, sludge and scrapings. It can also form a thin film on the interior surfaces of gas processing equipment and vessels. The level of NORM accumulation can vary substantially from one facility to another depending on geological formation, operational and other factors. To determine whether or not a facility has NORM contamination, NORM survey, sampling and analysis needs to be conducted. Figure 1.1 indicates where NORM may accumulate, eg at wellheads in the form of scale; at
Gas/Oil Separation Plants (GOSP) in the form of sludge; and at gas plants the form of thin films as the result of radon gas decay.

Table 1.1 Mean and range of Thorium and Uranium concentration in sedimentary rock (Reference 1)

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

There are three types of radiation emitted by NORM, namely:

- Alpha (α)
- Beta (β)
- Gamma (γ)

Alpha particles are helium nuclei that are heavy and doubly (positively) charged which causes them to lose their energy very quickly in matter. They can be stopped by a sheet of paper or the surface layer of your skin. Alpha particles are considered hazardous to a person’s health only if a radioactive source of alpha emitting particles is inhaled or ingested.

Beta particles are much smaller and only have one (negative) charge, which causes them to interact more slowly with material. They are effectively stopped by thin layers of metal or plastic and are again considered hazardous only if a beta emitter source is ingested or inhaled.

Gamma emitters are associated with alpha, beta decay and are a form of high energy electromagnetic radiation that interacts lightly with matter. Gamma rays are best shielded by thick layers of lead or other dense materials and are considered as an external hazard to living tissues (ie the human body). Figure 1.2 details the penetrating power of ionising radiation emitted from NORM radionuclides.
Figure 1.1 The origins of NORM, indicating where NORM may accumulate in the recovery process.

Table 1.2 Activity concentration of $^{238}$U, $^{226}$Ra, $^{210}$Pb and $^{232}$Th, $^{228}$Ra, $^{224}$Ra in production water (Reference 1)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Reported Range (Bq/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U</td>
<td>0.0003 – 0.1</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>0.002 – 1,200</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>0.05 – 190</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>0.0003 – 0.001</td>
</tr>
<tr>
<td>$^{228}$Ra</td>
<td>0.3 – 180</td>
</tr>
<tr>
<td>$^{224}$Ra</td>
<td>0.5 – 40</td>
</tr>
</tbody>
</table>

Table 1.3 Activity concentration of $^{238}$U, $^{226}$Ra, $^{210}$Po and $^{232}$Th in crude oil (Reference 1)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Reported Range (Bq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U</td>
<td>0.00000001 – 0.01</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>0.0001 – 0.04</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>0 – 0.01</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>0.000003 – 0.002</td>
</tr>
</tbody>
</table>
**NORM Decay Series**

The NORM nuclides of primary concern in oil production are Radium-226 and Radium-228. These decay into various radioactive progeny, before becoming stable lead. Radium-226 belongs to the Uranium-238 decay series and Radium-228 to the Thorium-232 decay series.

The two principal radioactive decay series (Uranium-238 and Thorium-232) associated with NORM in the oil & gas industry are detailed in Figures 1.3 & 1.4. These figures show the radionuclides of concern, their radioactive half-lives, decay mechanism, and the manner in which they are mobilised.
Figure 1.3  Uranium-238 decay series (Reference 3)

- **a) Naturally occurring radionuclides**
  - Transport with reservoir
  - $^{238}\text{U}$ 10$^9$y
  - $^{236}\text{Th}$
  - $^{234}\text{Pa}$
  - $^{234}\text{U}$
  - $^{230}\text{Th}$
  - $^{232}\text{Th}$

- **b) Leaching**
  - Transport with water
  - $^{226}\text{Ra}$ 1600y
  - $^{222}\text{Rn}$ 4d

- **c) Emanation/dissolution**
  - Transport with gas/oil/water
  - $^{218}\text{Po}$
  - $^{218}\text{Po}$
  - $^{214}\text{Pb}$
  - $^{214}\text{Bi}$
  - $^{214}\text{Po}$
  - $^{210}\text{Po}$ 22y
  - $^{210}\text{Bi}$

- **d) Mechanism**
  - Transport via water (gas/oil) carrier lead compounds
  - $^{210}\text{Po}$ 138d
  - $^{206}\text{Pb}$ stable
  - $^{211}\text{Po}$
  - $^{211}\text{Bi}$

- **e) Mechanism**
  - Transport via NGL/condensate
  - $^{206}\text{Pb}$ stable
1.2 NORM in scale

The main types of scale encountered in oil & gas facilities are sulphate scale such as BaSO₄, SrSO₄ and carbonate scale such as CaCO₃. Radium is chemically similar to barium (Ba), strontium (Sr) and calcium (Ca), hence radium co-precipitates with Sr, Ba or Ca scale forming radium sulphate, radium carbonate and – in some cases – radium silicate.

The mixing of seawater, which is rich in sulphate, with the formation water, which is rich in brine, increases the scaling tendency. Also the sudden change in pressure and temperature or even acidity of the formation water, as it is brought to the surface, contributes to scale build-up. The build-up of scale on the interior of a pipe is shown in Figure 1.5. This phenomenon has significant implications for the production of oil; in this case the capacity of the pipe to transfer oil would be reduced significantly.

Table 1.4 Activity concentration of ²³⁸U, ²²⁶Ra, ²¹⁰Pb, ²³²Th and ²²⁸Ra in hard scales (Reference 1)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Reported Range (Bq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>²³⁸U</td>
<td>0.001 – 0.5</td>
</tr>
<tr>
<td>²²⁶Ra</td>
<td>0.1 – 15,000</td>
</tr>
<tr>
<td>²¹⁰Pb</td>
<td>0.02 – 75</td>
</tr>
<tr>
<td>²¹⁰Po</td>
<td>0.02 – 1.5</td>
</tr>
<tr>
<td>²³²Th</td>
<td>0.001 – 0.002</td>
</tr>
<tr>
<td>²²⁸Ra</td>
<td>0.05 – 2,800</td>
</tr>
</tbody>
</table>
Figure 1.5: Scale build-up on internal pipe surface

Table 1.5 Activity concentration of $^{238}$U, $^{226}$Ra, $^{210}$Pb, $^{232}$Th and $^{228}$Ra in soft/medium hard scales (Reference 1)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Reported Range (Bq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U</td>
<td>0.001 – 0.05</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>0.8 – 400</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>0.05 – 2,000</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>0.001 – 0.07</td>
</tr>
<tr>
<td>$^{228}$Ra</td>
<td>0.05 – 300</td>
</tr>
</tbody>
</table>

1.3 NORM in sludge and scrapings

Radioactive molecules containing radium which were not incorporated into scale can be found in sludge, produced sands and produced waters. Other radionuclides such as Lead-210 and Polonium-210 can also be found in pipelines scrapings as well as sludge accumulating in tank bottoms, gas/oil separators, dehydration vessels, liquid natural gas (LNG) storage tanks and in waste pits as well as in crude oil pipeline scrapings.

Table 1.6 Activity concentration of $^{238}$U, $^{226}$Ra, $^{210}$Pb, $^{210}$Po, $^{232}$Th and $^{228}$Ra in sludges (Reference 1)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Reported Range (Bq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U</td>
<td>0.005 – 0.01</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>0.05 – 800</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>0.1 – 1,300</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>0.004 – 160</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>0.002 – 0.01</td>
</tr>
<tr>
<td>$^{228}$Ra</td>
<td>0.5 – 50</td>
</tr>
</tbody>
</table>

Table 1.7 Activity concentration of $^{226}$Ra, $^{210}$Pb and $^{228}$Ra in scrapings (Reference 1)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Reported Range (Bq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{226}$Ra</td>
<td>0.01 – 75</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>0.05 – 50</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>0.1 – 4</td>
</tr>
<tr>
<td>$^{228}$Ra</td>
<td>0.01 – 10</td>
</tr>
</tbody>
</table>
1.4 NORM in gas processing facilities

Radon is a radioactive gas, which is present in varying degrees in natural gas in oil & gas formations. In the absence of natural gas, radon dissolves in the (light) hydrocarbon and aqueous phase. When produced with the oil and gas, radon will usually follow the gas stream. If the natural gas is fractionated, a disproportionately high percentage of radon can concentrate in the propane streams and to a lesser degree in the ethane streams.

Radon-222 produces, through natural decay, several radioactive nuclides (also known as radon progeny). Most radon progeny are short-lived, with the exception of Lead-210 and Polonium-210, which have relatively long half-lives of 22.6 years and 138 days respectively. Most of the radon decay products (90-99%) are attached to ambient aerosols, airborne particulates or surfaces. This can result in forming thin radioactive films on the inner surfaces of gas processing equipment such as scrubbers, compressors, reflux pumps, control valves and product lines.

Table 1.8 Activity concentration of $^{222}$Rn, $^{210}$Pb and $^{210}$Po in natural gas (Reference 1)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Reported Range (Bq/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{222}$Rn</td>
<td>5 – 200,000</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>0.005 – 0.02</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>0.002 – 0.08</td>
</tr>
</tbody>
</table>

Table 1.9 Activity concentration of $^{210}$Pb and $^{210}$Po in NGL/hydrocarbon condensate (Reference 1)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Reported Range (Bq/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{222}$Rn (NGL)</td>
<td>0.01 – 1,500</td>
</tr>
<tr>
<td>$^{222}$Rn (C3 -liq)</td>
<td>0.01 – 4,200</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>0.3 – 230</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>0.3 – 100</td>
</tr>
</tbody>
</table>

1.5 NORM in seawater injection systems

Uranium exists in seawater in part per billion (µg/l) concentrations. The use of seawater for recovery of oil from a reservoir can potentially introduce an additional enhanced NORM scenario. In an anaerobic environment (such as in a geological formation), sulphate-reducing bacteria have been shown to enhance the uptake of uranium which is deposited in bio-fouling deposits$^4,5$. In many seawater injection systems this may not pose a significant hazard, however, systems which utilise large quantities of seawater may encounter levels of uranium in bio-fouling which present a risk to workers and a problem for waste disposal. Concentrations of uranium up to ~2% by weight have been identified in seawater injection systems$^4,5$.

1.6 Health hazards of NORM

There are two ways in which personnel can be exposed to NORM, namely:

- Irradiation – external exposure where the source remains outside the body
- Contamination – internal exposure where radioactive material is taken into the body via inhalation, ingestion or absorption

There is a large body of scientific research and literature on the health effects of ionizing radiation exposure. The health effects associated with exposure to ionising irradiation vary depending on the total amount of energy absorbed, the time period, the dose rate and the particular organ exposed. A key consideration related to NORM is that exposures are generally quite low and below established...
regulatory action levels. In some situations, exposure to low-level ionising radiation may not result in any adverse health effects; hence the basis for developing regulatory health-based action levels.

Exposure to NORM will not result in acute and severe effects similar to those effects associated with exposure to high radiation levels from man-made sources. Chronic exposure to NORM above exposure limits for the general public or following inadequate safety precautions are typically delayed effects such as the development of certain forms of cancer. A variety of cancers has been associated with exposure to ionising radiation including leukaemia, and cancers of the lung, stomach, oesophagus, bone, thyroid, and the brain and nervous system. It is important to understand that the potential health effects are strongly dose-related. In addition, based on extensive scientific study over many decades, radiation exposure is not associated with all forms of cancer.

Medical surveillance for low-level radiation exposures is typically triggered by exceedance of an established regulatory action level. However, medical surveillance is an imperfect and non-specific tool. It is difficult to find medical tests that detect meaningful abnormal changes in a timely fashion. Most medical tests do not have high sensitivity or specificity, i.e., the ability to correctly identify who has a problem (sensitivity=true positive) and who does not have a problem (specificity=true negative). All medical tests have various levels of sensitivity (false positive) and specificity (false negative). There is no perfect set of tests for every potential health concern. Therefore, while medical surveillance is a standard strategy that is often used, it must be emphasised that source control, exposure monitoring, worker education and safe operating practices are the most important strategies for preventing significant worker exposures.

Potential NORM exposure scenarios are detailed in Figure 1.6.

**Figure 1.6** NORM exposure scenarios (Reference 6)

NORM materials may become an inhalation risk when the material is dislodged by mechanical forces, such as wire brushing, pipe rattling etc.
Table 1.10  Observed external radiation levels at the outside of processing facilities (Reference 1)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Radiation Level# (µSv/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crude oil processing/treating</strong></td>
<td></td>
</tr>
<tr>
<td>• down hole tubing, safety valves (internal)</td>
<td>up to 300</td>
</tr>
<tr>
<td>• well heads, production manifolds</td>
<td>0.1 – 2.5</td>
</tr>
<tr>
<td>• production lines</td>
<td>0.3 – 4</td>
</tr>
<tr>
<td>• separator scale (internal)</td>
<td>up to 200</td>
</tr>
<tr>
<td>• separator scale (external)</td>
<td>up to 15</td>
</tr>
<tr>
<td>• water outlets</td>
<td>0.2 – 0.5</td>
</tr>
<tr>
<td><strong>Associated/natural gas processing/treating</strong></td>
<td></td>
</tr>
<tr>
<td>• downhole tubing</td>
<td>0.1 – 2.2</td>
</tr>
<tr>
<td>• piping, filters, storage tanks, reflux lines</td>
<td>up to 80</td>
</tr>
<tr>
<td>• sludge pits, brine disposal/injection wells,brine storage tanks</td>
<td>up to 50</td>
</tr>
<tr>
<td><strong>NGL processing</strong></td>
<td></td>
</tr>
<tr>
<td>• filters</td>
<td>up to 90</td>
</tr>
<tr>
<td>• NGL pump</td>
<td>up to 200</td>
</tr>
<tr>
<td>• C\textsubscript{3} storage tanks</td>
<td>up to 60</td>
</tr>
<tr>
<td>• NGL/C\textsubscript{3} shipping pumps, C\textsubscript{3} reflux pumps, elbows, flanges</td>
<td>0.1 – 2.8</td>
</tr>
</tbody>
</table>

1.7 Environmental problems associated with NORM

Handling, storage, transportation and the use of NORM contaminated equipment or waste media without controls can lead to the spread of NORM contamination, and result in contamination of areas of land, resulting in potential exposure of the public.
2 NORM management process cycle

To ensure that all aspects of NORM management are highlighted, structured and managed, the following process cycle has been developed. The process cycle indicates where action and controls may be required to ensure adequate protection of workers, public and the environment in a practical and cost effective manner. The process cycle is detailed in Figure 2.1.

It is important that NORM management is planned and carried out following consultation and engagement of stakeholders. Specifically, the approval of the regulatory authorities will be required. NORM management is not an activity that companies can undertake independently, given the contentious nature of radioactivity and radioactive material.

A strategy for NORM management in the process cycle is essential, if management is to be successful. Key areas to be considered are:

- NORM monitoring
- Control of NORM contaminated waste
- Control of NORM contaminated equipment
- Worker protection and training
- Development of NORM management guidelines
- Compliance monitoring.

The flowcharts provided in this document are generic, high-level charts and require many tasks, documents and systems to enable them to function effectively; they indicate where main controls and documentation are required. A general plan for NORM management which would fit with the above process cycle is shown in Figure 2.2.

Figure 2.1 NORM management process cycle

© 2008 OGP
Figure 2.2  NORM management generic plan

1. NORM survey
2. NORM detected?
   - Yes
     - Workers protection issue?
       - Yes
         - Conduct risk assessment
         - Document work procedures/instructions
         - Record sample analysis data
         - Document operation
         - Document risk assessment
       - No
         - NORM waste issue
         - Take representative samples for radiometric analysis
         - Document plan
         - Record storage/disposal information
   - No
     - Normal operation
     - Normal disposal route
     - Approved NORM storage/disposal
     - Document risk assessment
     - Implement the plan/carry out operation
     - Plan the operation, including contingency planning
     - Develop work procedures/instructions
     - Record sample analysis data
     - Document operation
     - Document procedures/instructions
     - Document plan
     - Record storage/disposal information

- Normal operation
- Hazard exists
- Controlled hazard
- Safe disposal options
- Documentation/data
3 NORM monitoring

Monitoring is required to ascertain whether NORM is present in a medium. It can utilise direct measurement instruments which can be taken to the onshore or offshore fields to measure the levels of radiation emitted. Alternatively, samples can be collected and sent to a laboratory for radiometric analysis. In practice, a monitoring programme will usually make use of all available monitoring methods and techniques based on specific requirements of individual organisation. Various components of a monitoring programme may include:

- Baseline surveys
- Pre-shut-down surveys
- Operational assessments
- Legacy contamination surveys.

3.1 Baseline surveys

The objective is to establish a baseline of the spread and level of NORM accumulation in facilities. This information is essential in determining which category of workers needs protection and type of contamination control procedure. Baseline surveys also yield important information about NORM waste streams that is essential input toward developing NORM waste disposal solutions.

The following are examples of where baseline surveys could be considered:

- Vessels in oil/gas separation facilities
- Wellheads.

3.2 Pre-shutdown surveys

The objective is to determine the locations of NORM accumulation in facilities where NORM contamination is suspected. One example would be gas/oil separation facilities; where a survey should be undertaken prior to a shutdown. If a positive indication is shown by gamma radiation detectors, then the presence of NORM inside vessels/tanks is clearly indicated. This confirms the need for establishing worker protection and contamination control measures. It also indicates that there may be NORM waste which requires to be handled in a controlled manner.

3.3 Operational assessments

The objective is to enable field organisations to identify NORM contamination promptly during routine operational scenarios. In operating facilities, situations arise where workers might need to conduct intrusive work, such as clean up or maintenance, on potentially NORM contaminated equipment or entry into potentially contaminated vessels. In such situations, field personnel should be capable of conducting NORM assessments using portable and easy-to-use instruments to determine the presence of NORM contamination.

The following are examples of operational components where NORM may be detected:

- Down-hole tubing, safety valves, etc
- Long piping runs
- Well heads
- Production manifolds
- Flow-lines (to gas/oil separators)
- Separators (high, intermediate, and low pressure)
- Dehydrators
- Desalinators

© 2008 OGP
• Valves
• Gas/oil separator baffle plates
• Oil storage tanks.

3.4 Legacy contamination surveys

‘Legacy contamination’ is contamination which results from operations before the implementation of a NORM management strategy. Areas with potential legacy NORM contamination include, but are not limited to, land disposal sites, evaporation ponds, disposal pits and areas used for equipment storage, cleaning, and maintenance where NORM contamination was potentially accumulated over time.

The requirements for an effective NORM survey as stated below are detailed in Figure 3.1. Personnel who are required to monitor levels of radiation and contamination associated with NORM should be trained in the use of the instrumentation and the interpretation of the readings/measurements (see Training & Awareness). There are many factors which affect the efficiency of a radiation detector and personnel who are required to monitoring NORM levels should be aware of these. For example, surface coatings of water or oil/grease would attenuate any NORM contamination present on the surface and give a lower than anticipated indication on the detector. Many surfaces may be difficult to directly monitor due to their surface condition or geometry and therefore both direct (probe measurement) and indirect (smear/swab) means of survey are required. The probe must also be held very close to the surface to ensure optimum detection efficiency for the emitted radiation as both alpha and beta particles have relatively short range in air and gamma ray intensity will decrease in line with the inverse square law away from the source of activity. Training requirements for those required to use radiation detectors to monitor levels of NORM are detailed in section 6 of this document.

In practice, it is unlikely that alpha and/or beta particles will be unsupported and not have associated gamma rays. However for the purposes of hand held instruments, surveyors need to have detectors which will respond to alpha/beta particles and gamma rays. Unfortunately, there is no detector that measures all three types of radiation, therefore a minimum of two different detectors is required to characterise the NORM present in facilities adequately.

Suitable handheld radiation detectors for use in the assessment of NORM contamination are:

Alpha/beta, an uncompensated Geiger-Muller tube (pancake type detector): this will respond to alpha, beta and gamma however when used in the field its measurements should be used as an indicator rather than a quantifiable measurement, due to many factors which will affect the detector’s ability to respond.

Gamma, a sodium-iodide (NaI) scintillation detector: this provides a very quick response and is sensitive at low energy ?-emissions, such as those associated with NORM decay.

Other types of instruments can be used, but it is important to be aware of the limitations of each detection system.

The majority of radiation detectors are not intrinsically safe and their use in operational facilities will require the use of a ‘hot work’ permit or its equivalent. There are now some intrinsically safe detectors.
Figure 3.1: Schematic of NORM survey requirements

Table 3.1 Suitable radiation detector types for Alpha, Beta and Gamma emissions from NORM

<table>
<thead>
<tr>
<th>Radiation type</th>
<th>Instrument type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>Uncompensated GM tube</td>
<td>Probe must be as close to the surface as possible without touching it, alpha only has a short range in air and will be attenuated on wet surfaces. In NORM radionuclides alpha usually always has an associated gamma emission.</td>
</tr>
<tr>
<td>Beta</td>
<td>Uncompensated GM tube</td>
<td>As above, although beta has a slightly greater range in air.</td>
</tr>
<tr>
<td>Gamma (screening)</td>
<td>Sodium iodide</td>
<td>Very sensitive gamma detector which will give a very quick indication if enhanced gamma levels are present. It can potentially over-estimate gamma dose-rates so should not be used to quantify – only detect.</td>
</tr>
<tr>
<td>Gamma (measurement)</td>
<td>Compensated GM tube</td>
<td>Slower responding instrument, which will however give a more accurate indication of gamma dose-rate.</td>
</tr>
</tbody>
</table>
4 NORM action limits

The action limits for the disposal/control of NORM waste material may be stipulated in National regulations. However, in the absence of National Regulations, the following limits can be utilised and these will provide for compliance with current international practice:

- Materials and waste media such as sludge/scale containing NORM at levels below those listed in Table 4.1 shall be exempted from the requirements of this procedure.
- Soil shall not have a Radium-226 contamination above 0.185 Bq per gram (5 pCi per gram) above background averaged over any 10 square metres or unless risk assessment demonstrates an acceptable level of risk.
- Equipment, vessels, and clothing shall be considered ‘NORM contaminated’ if internal or external surface contamination measures double the radiation background level.

Table 4.1 NORM exemption levels

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Exemption level (Bq/g)</th>
<th>Exemption level (pCi/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{226}$Ra</td>
<td>1.1</td>
<td>30</td>
</tr>
<tr>
<td>$^{228}$Ra</td>
<td>1.1</td>
<td>30</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>5.5</td>
<td>150</td>
</tr>
<tr>
<td>Uranium (nat)</td>
<td>3.0</td>
<td>80</td>
</tr>
</tbody>
</table>
5 Training and awareness

Training and awareness are major components of a NORM management system. Workers need to be made aware of the hazards associated with NORM, the controls that are required for their protection and the methods for preventing environmental contamination.

Training should focus on operational personnel who are potentially exposed to NORM and directly involved in maintenance operations. Key personnel should be identified and provided with training that will permit them to ensure that the work they do pays due regard to the hazards of NORM and prevents the spread of NORM contamination.

Workers awareness can be enhanced through NORM awareness sessions.

A formally structured training programme provides training in the following areas:
- Workers’ course
- Surveyors’ course
- Supervisors’ course/Radiation Safety Officers’ course.

Figure 5.1 details the training identification, formulation and review process, together with core knowledge and documentation requirements.

Figure 5.1 Training development process and core knowledge topics
6 NORM contamination control procedures

The following are basic control procedures that should be practised when handling NORM contaminated equipment, tubulars, vessels, pipes or machinery:

- Establish a boundary around the work area. The boundary should be as small as possible, but large enough to allow for personnel and equipment access from the work area and to allow for all work to be accomplished in a safe manner. Containers or plastic bags should be provided for discarded protective clothing and contaminated trash at the exit of the work area.
- Only essential personnel should be allowed in the work areas where potential NORM contamination exists.
- Prior to maintenance of contaminated equipment or opening inspection hatches, sludge traps or pig receivers, sufficient ground cover shall be placed below the item in the work area. The ground cover should be made of a plastic, waterproof type material capable of withstanding the work activities involved without tearing or ripping. Alternatively, a suitable drip-tray or catch-pan may be used. The ground cover should be sized to provide for the containment of leakage and waste and to allow ample room for related peripheral work.
- Post the boundary with radiation warning signs “Caution: NORM Material”; (with radiation trefoil)
- Hold a safety meeting for all personnel performing work. Radiological items which should be addressed during the meeting are, but are not limited to, protective clothing and respiratory protection requirements, radiation and contamination levels, maintenance activities which may cause radioactive material to become airborne, requirements for waste generated, heat stress, action to be taken in the case of emergencies.
- Commence maintenance activity; any dry material that is NORM-contaminated should be wetted down to prevent the generation of airborne radioactive materials. Dry material should be wetted periodically throughout the maintenance work.
- Openings of equipment or pipes that have internal NORM contamination should be sealed or wrapped by plastic or other suitable materials.
- Obsolete NORM-contaminated pipes or equipment should be clearly labelled as “NORM Contaminated Materials” and removed to a designated area. The area should be labelled as “Containing Radioactive Materials” and restricted for the general public.
- All contaminated waste generated during maintenance should be drummed or put into containers and marked or labelled. Representative samples should be collected from the waste and analysed for radioactivity.
- Upon completion of maintenance, personnel should remove their protective clothing before leaving the work area.
- All material, equipment and tools not placed in containers or drummed should be surveyed for both loose contamination and exposure rate levels upon exit from the work area. A reading greater than background levels is positive indication of contamination, and should be handled as such.
- Upon job completion, the accessible areas of the work area should be surveyed for loose contamination. Any loose surface contamination found should be promptly cleaned up and drummed.
- Once the work area has been verified free of loose surface contamination, the boundary and postings may be taken down.

A schematic diagram of a potential contamination control system for the removal of a valve is shown in Figure 6.1. The diagram indicates what controls are required, eg a physical barrier (red line) to prevent unauthorised access, plastic sheeting/ground cover to catch any NORM contamination and prevent contamination of work area, separate entrance and exit to prevent spread of contamination etc.
Figure 6.1 NORM contamination control requirements

Valve removed and sealed for cleaning

γ

β

α

β

α

γ

Valve removed and sealed for cleaning

Ground cover

Special drain

Washing facility & towels

Used PPE†

New PPE

† PPE: Personnel Protective Equipment
7 Control of NORM contaminated waste

Before NORM can be managed effectively, it is necessary to know where it is being produced. This requires an assessment of all process that identify potential NORM contamination.

NORM waste disposal must adhere to applicable regulations pertaining to the disposal of radioactive waste.

In many cases short-term or interim storage may be required before final disposal of NORM waste. Where NORM waste is required to be stored, it should be kept in suitable container which should comply with the following requirements. The container;

- Should be in good condition with no visible indications of internal or external corrosion, and be made of a durable material such that it provides adequate containment of the NORM waste during the storage period.
- Should be made of or lined with materials that will not react with or be incompatible with the NORM waste so that the ability of the container is not impaired or compromised.
- Should be resistant to degradation by Ultra Violet radiation.
- Should be closed and sealed during storage, and practical to open and re-seal when it is necessary to add or remove waste.
- Should not be opened, handled, or stored in a manner that may rupture the container or cause it to leak.
- Should be resistant to normally expected range of temperature in storage environment.
- Should be resistant to water ingress.
- Should be stored in a dry environment to prevent corrosion.
- Should be physically robust to prevent damage during transport.
- The storage location should be hard surfaced and bunded to prevent contamination of ground/surface waters and the creation of contaminated land from any potential leaks/spills as a result of incidents during storage period.

Areas where containers of NORM waste are stored should be inspected on a regular basis. Containers should be inspected for signs of leakage, overall deterioration and proper labelling. Records of these inspections should be documented and properly maintained.

Where NORM waste is disposed of, records shall be maintained of the disposal activities. These should include but not limited to:

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

The objective is to establish safe, practical and cost effective permanent disposal protocols for NORM waste that provide adequate protection to both human health and the environment.

A permanent disposal protocol should be designed to prevent contamination of natural resources such as underground water, or contamination of soil that could in future become residential or agricultural areas even although the area is currently remote or uninhabited.

Methods of NORM disposal currently used in the oil & gas industry are:

- Land based management
- Salt cavern disposal
- Offshore discharge
- Land fill
- Underground injection

The preliminary selection criteria may include:

- Risk
- Technical feasibility
- Cost
- General acceptance (regulatory and public)

<table>
<thead>
<tr>
<th>Table 7.2 Description of disposal methods (Reference 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disposal Method</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>Land spreading</td>
</tr>
<tr>
<td>Land spreading with dilution (land farming)</td>
</tr>
<tr>
<td>Non-retrieved line (surface) pipe</td>
</tr>
<tr>
<td>Burial with unrestricted site use</td>
</tr>
<tr>
<td>Commercial oil industry waste facility</td>
</tr>
<tr>
<td>Commercial NORM waste facility</td>
</tr>
<tr>
<td>Commercial low level radioactive waste facility</td>
</tr>
<tr>
<td>Plugged and abandoned well</td>
</tr>
<tr>
<td>Well injection and hydraulic fracturing</td>
</tr>
<tr>
<td>Equipment release to smelter</td>
</tr>
</tbody>
</table>

Once potential disposal options are identified as a result of preliminary selection then a full assessment in terms of risk and cost can be undertaken. Risk assessment has shown that the lowest residual risk methods for NORM disposal may be underground injection and 'class one' landfill.

A typical process for the control of NORM waste during shutdown operations is detailed in Figure 7.1.
Figure 7.1  Control of NORM waste during shutdown operations

- Pre T&I survey

- Enhanced gamma dose rate?
  - Yes
    - Assume NORM contaminated until proved otherwise
    - Provide information on NORM status to operations
    - Workers protection & contamination control measures
    - Representative samples
    - Normal disposal for hydrocarbon waste
  - No
    - NORM above action levels?
      - Yes
        - Transportation in controlled manner
        - Interim storage
      - No
        - Final NORM disposal

Legend:
- Hazard exists
- Controlled hazard
- Safe disposal options
NORM contaminated equipment must be handled, transported, stored, maintained or disposed in a controlled manner. Protocols are required to ensure that equipment is not released or handled without controls to protect the worker and prevent contamination of the environment. Therefore, it is critical to understand and control how and where NORM materials can be transported. For example, drilling pipe that contains low-level NORM scale can be unrecognized and transported to a variety of secondary pipe reprocessing facilities with subsequent, inadvertent exposure and spread of NORM.

The following should be considered the minimum requirements for the control of NORM-contaminated equipment. Equipment should:

- Be decontaminated prior to release for unrestricted use
- Be stored only in designated storage areas
- Be tagged or clearly marked as NORM contaminated.
- Be handled only by employees trained in NORM hazards and is using PPE
- Not be sent for maintenance/repair to workshops without informing the workshop that the component is contaminated with NORM.
- Be disposed of only in an approved NORM disposal facility.
- Be decontaminated only in an approved NORM decontamination facility or according to an approved decontamination protocol. Once verified as free from NORM contamination, the equipment may be:
  - Re-used
  - Sent for repair to a workshop prior to being re-used
  - Sold or disposed of as scrap
- Be stored in areas which are exclusively used for the storage of NORM-contaminated equipment.

In addition:

- All open sections of equipment, i.e. flange or pipe ends, etc. should be adequately covered by heavy-gauge UV-stabilized plastic or other suitable materials to ensure that NORM material does not leak from the item.
- Routine checks on all stored NORM-contaminated equipment should be undertaken to ensure that the integrity of the protective measures is adequate. Routine checks should be carried out at least on a quarterly basis.
- Detailed and verifiable records should be maintained of all stored NORM contaminated equipment.

A typical process for the control of NORM contaminated equipment is detailed in Figure 8.1.
Figure 8.1: Control of NORM contaminated equipment

1. Routine facility operations
2. Potentially NORM contaminated equipment
   - Can equipment be screened in situ?
     - Yes: Screen equipment for NORM
     - No: Assume NORM contaminated
3. Assume NORM contaminated?
   - Yes: Contain to prevent spread of NORM contamination
   - No: Transportation
4. Transportation
   - NORM contaminated?
     - Yes: Dedicated NORM storage facility
     - No: Normal operation
5. Normal operation
   - Can equipment be screened in situ?
     - Yes: Screen equipment for NORM
     - No: Assume NORM contaminated
6. Assume NORM contaminated?
   - Yes: Contain to prevent spread of NORM contamination
   - No: Transportation
7. Transportation
   - NORM contaminated?
     - Yes: Dedicated NORM storage facility
     - No: Normal operation
8. Normal operation
   - Equipment verified free of NORM contamination
9. Decontamination facility
10. Safe disposal options

Legend:
- Normal operation
- Hazard exists
- Controlled hazard
- Safe disposal options
9 Decontamination

Decontamination of equipment which is NORM-contaminated should be undertaken in a controlled manner to ensure worker protection, prevent the spread of NORM contamination, and to minimise the waste arising from the decontamination process. Simple mechanical/abrasive ie high pressure water jetting (HPWJ) in conjunction with other mechanical/abrasive methods has been proven to be the most cost effective and successful. When such methods are used, consideration needs to be given to the following:

- Changing facilities for workers
- Operating areas to carry out work
- Handling/receiving areas
- Strip down areas
- Water jetting areas
- Liquid re-circulation system
- Ventilation system
- Control of equipment (administration system)
- Inspection of equipment
- Monitoring of equipment
- Safety related systems.

Where possible, decontamination systems should be automated, as there are significant industrial safety hazards associated with hand-jetting activities. Injuries associated with hand-jetting operations can be difficult to treat successfully. A well-defined safe system of work is required which will consider the associated industrial hazards and as a minimum include Kevlar type PPE (boots, aprons, gloves etc).

Mobile decontamination units have been used successfully. These utilise modified ISO-containers to provide containment for HPWJ operations, and are fitted with drainage systems which direct water used in the HPWJ operation through a series of filters and back to the water jetting system, so the waster is continually re-circulated. The basic design criteria for a NORM decontamination facility may include the following:

9.1 Operating criteria

The function of a NORM decontamination facility should be to decontaminate NORM contaminated components. The acceptance criteria for successful decontamination should be:

1. All equipment must be visually clear of scale.
2. All equipment must be free of detectable radioactive contamination, as per Section 4 (ie less than double background).

9.2 Required operating areas

Main change room
This will allow access to the radiologically-controlled areas where NORM decontamination will take place.
Handling area
This will be for:

1. checking the inventory/material being sent for decontamination
2. carrying out radiation surveys of decontaminated equipment
3. providing a segregation system to keep incoming "dirty" items separate for outgoing “clean items”
4. a quarantine area for items that require further decontamination.

Strip down area
To allow the strip down of components such as valves, wellheads and other components.

Burning bay to allow for oxy-propane cutting, grinding etc of equipment
This is an area where airborne NORM contamination is may occur and therefore requires total containment with a HEPA filtered extract ventilation system. Local extract ventilation (ie elephant trunks) will also be available in the area to control/ remove dust/contamination at source. Workers will be required to wear respiratory protective equipment (RPE) in this area; therefore the supply of breathing air for RPE is required. The floor and surfaces shall be of an impermeable non-flammable surface capable of withstanding heavy loads.

Water jetting area
This is an area where airborne NORM contamination may occur and therefore requires total containment with a ‘HEPA’-filtered extract ventilation system. In this area, workers will be required to wear respiratory protective equipment (RPE) in this area; therefore the supply of breathing air for RPE is required. The floor and surfaces should be of an impermeable non-flammable surface capable of withstanding heavy loads, and the impact of HPWJ.

Liquid recirculation system
All process liquid used in decontamination operations should be filtered and re-used. There should be no connection to any external drainage system. The following elements will be required in the system:

1. Primary supply tank
2. Filter bank
3. Settling tank.

The system needs to separate NORM-contaminated sediment and oily waste material from the process water.

Water from the HPWJ area will be circulated back to the system by an enclosed and doubly contained drainage system.

A leak detection system should be included in the water circulation system.

The settling tank should be able to be readily accessible and able to have any sediment removed/decanted into waste containers. The system shall have capacity to allow the transfer of water from the settling tank to another holding tank to allow sediment removal.

9.3 Control of equipment
An administrative system is required to control and track the progress of all equipment and components entering the decontamination facility.
9.4 Inspection of equipment

Inspection of all equipment and components should be carried out on receipt. The status of the equipment should be logged and any damage not logged on the documentation should immediately be brought to the proponent’s attention and the component shall be quarantined pending further instruction from the proponent.

9.5 Monitoring of equipment

Monitoring of equipment for clearance should only be carried out by trained operators. All monitoring equipment should be fully operational and within its calibration period. A check on the operational status of all radiological monitoring equipment should be maintained. An administrative system should be implemented to identify items which are NORM-contaminated from those that have been cleaned.

Figure 9.1: NORM decontamination operations

Personal decontamination should be carried out in a manner which restricts radiation exposure by minimising potential for the inhalation, ingestion and absorption of radioactive materials.

Areas of land which become NORM contaminated should be remediated such that NORM levels are at or below the criterion described in Section 4.

Land which is NORM-contaminated as a result of oil and gas–related operations, such as an evaporation pond or land farm, should be remediated prior to release for unrestricted use. Remediation is the systematic removal of NORM contamination from the area in a controlled manner, with the contaminated soil/material becoming part of the NORM waste stream. Land remediation requires clear release criteria to be established. A general schematic for land remediation is detailed in Figure 9.2. Prior to any remediation operations careful analysis of the overall risks shall be completed to ensure that there is benefit to be gained by carrying out the operation.
Figure 9.2 Remediation of NORM contaminated land.

1. Establish radiological surveillance programmes
2. Establish release criteria
3. Perform radiological surveys
4. Enhanced NORM detected?
   - No
   - Yes, Collect representative samples
5. Enhanced NORM detected?
   - No
   - Yes, Assess radiological risks
6. Above release criteria?
   - No
   - Yes, No action required
7. Immediate remediation?
   - No
   - Yes, Establish controls to minimise exposure until land remediated
8. End of operational life
9. Final disposal of NORM waste
10. Interim storage of waste
11. Packaging, containment and transportation of waste
12. Remediate land
13. Verification monitoring
14. Enhanced NORM detected?
   - No
   - Yes, Release of land from control
15. Development land remediation & mapping programme

Legend:
- Normal operation
- Hazard exists
- Controlled hazard
- Safe disposal options
10 Worker protection requirement

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

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

Personnel should adhere to applicable regulations and guidelines for confined space entry. In addition, before entering vessels/tanks or other confined spaces known or suspected to be NORM-contaminated, the workers’ protection measures mentioned in the previous section should be implemented.

Furthermore, before entering tanks or vessels in gas plants, especially in propane and methane streams, vessels/tanks should be emptied and ventilated, through forced ventilation, for at least four hours prior to entry for cleaning or maintenance. Ventilation will force any trapped radon gas out of the vessel, while the delayed entry will allow adequate time for the decay of short-lived radon daughters (progeny). It should be noted that radon is not the most significant hazard associated with confined space entry and all other loss prevention checks must also be completed. Radon does not present an acute hazard to health, and the requirement to vent the tank for 4 hours is a means of minimising potential dose uptake, and as such should be included as part of the full safety job risk assessment.

All personnel and equipment exiting a vessel should be subjected to a NORM contamination survey. Personnel or equipment found to be contaminated should be segregated and decontaminated.
12 Transport of NORM contaminated equipment

NORM materials and/or NORM-contaminated components should be transported in ‘exclusive-use’ vehicles. No other cargo should be carried in the transportation vehicle.

Boats operating offshore and used to transport NORM contaminated material or equipment, should utilise standard transport containers appropriately segregated and marked to house the contaminated items. NORM-contaminated items that cannot be stored in standard transport containers should be protected in such a manner as to ensure no leak/spillage of NORM material during transport.

Before dispatch of any NORM materials/components, the receiving organisation should be notified.

The operator of the vehicle (or boat) should be provided with a written contingency plan detailing the actions to be taken in the event of a reasonably foreseeable emergency.

The NORM transportation vehicle (or boat) operator should be aware and capable of implementing the contingency arrangements to be taken in the event of an accident.

The vehicle carrying NORM material or NORM-contaminated equipment should bear appropriate transports placard and signage as required by the International Atomic Energy Agency (IAEA).

Organisations should maintain records of all NORM transportation. These records should include the following:

- NORM material description (contaminated equipment, scale, sludge, scrapings, etc)
- Volume/quantity of NORM material transported
- Method of transportation
- Destination
- Organisation/facility where the NORM waste was generated
- Any other relevant information.

The regulations involving the transportation of radioactive material are complex and therefore advice should be sought from a corporate expert on transportation particularly should cross-border transportation be required.
Figure 12.1: Handling, storage and transportation of potentially NORM-contaminated equipment/waste

1. Potentially contaminated equipment/waste
   - Yes: Screen/sample NORM
   - No: Routine operation

2. Routine operation
   - Yes: Worker's protection & contamination control procedure
   - No: Enhanced levels of NORM

3. Enhanced levels of NORM
   - Yes: Workers protection & contamination control procedure
   - No: NORM transport procedure

4. NORM transport procedure
   - Yes: Adhere to NORM material transportation procedure
   - No: Equipment requires transportation?

5. Equipment requires transportation?
   - Yes: Adhere to NORM material transportation procedure
   - No: Equipment requires storage?

6. Equipment requires storage?
   - Yes: Adhere to NORM storage procedure
   - No: Controlled hazard

7. Controlled hazard
   - Yes: Safe disposal options
   - No: Documentation/data
13 Documentation

As a minimum, the support documentation for a NORM management system should include:

- Organisational responsibilities
- NORM monitoring requirements
- Workers’ protection and training requirements
- Requirements to control NORM-contaminated equipment
- Requirements to prevent or minimise workplace contamination.
Glossary of terms

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

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

**Carbonate**
A compound containing the acid radical of the carbonic acid (CO$_3$ group). Bases react with carbonic acid to form carbonates, e.g. CaCO$_3$ calcium carbonate.

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

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

**NOR**
Naturally Occurring Radionuclide, relating to those radionuclides which are present at trace concentrations in the Earth.

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

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

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

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

**Curie (Ci)**
The old unit of radioactivity, has been replaced by the Becquerel (Bq). One Ci is equal to 3.7\(\times\)10\(^{10}\)Bq. One Bq is equal to 27 pCi.

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

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

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

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

### Unit conversions

<table>
<thead>
<tr>
<th>Activity</th>
<th>Becquerel (Bq)</th>
<th>Equivalent dose</th>
<th>Sievert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curie (Ci)</td>
<td></td>
<td>Rem (r)</td>
<td></td>
</tr>
<tr>
<td>27 pCi</td>
<td>1 Bq</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 nCi</td>
<td>37 Bq</td>
<td>100 μr</td>
<td>1 μSv</td>
</tr>
<tr>
<td>27 nCi</td>
<td>1 kBq</td>
<td>1 mr</td>
<td>10 μSv</td>
</tr>
<tr>
<td>1 μCi</td>
<td>37 kBq</td>
<td>10 mr</td>
<td>100 μSv</td>
</tr>
<tr>
<td>27 μCi</td>
<td>1 MBq</td>
<td>100 mr</td>
<td>1 mSv</td>
</tr>
<tr>
<td>1 mCi</td>
<td>37 MBq</td>
<td>1 r</td>
<td>10 mSv</td>
</tr>
<tr>
<td>27 mCi</td>
<td>1 GBq</td>
<td>5 r</td>
<td>50 mSv</td>
</tr>
<tr>
<td>1 Ci</td>
<td>37 GBq</td>
<td>100 r</td>
<td>1 Sv</td>
</tr>
</tbody>
</table>

### Unit prefixes

<table>
<thead>
<tr>
<th>Fractions</th>
<th>Multiples</th>
</tr>
</thead>
<tbody>
<tr>
<td>10(^{-3})</td>
<td>milli</td>
</tr>
<tr>
<td>10(^{-6})</td>
<td>micro</td>
</tr>
<tr>
<td>10(^{-9})</td>
<td>nano</td>
</tr>
<tr>
<td>10(^{-12})</td>
<td>pico</td>
</tr>
<tr>
<td>10(^{-15})</td>
<td>femto</td>
</tr>
<tr>
<td>10(^{-18})</td>
<td>atto</td>
</tr>
</tbody>
</table>
References


Further reading

IAEA, Regulatory and management approach for the control of environmental residues containing naturally occurring radioactive material (NORM), IAEA-TECDOC-1484 (2004).


King Abdulaziz City for Science and Technology (KACST), Basic Regulations for Protection Against Ionizing Radiation, 1997.


TEXAS REGULATIONS FOR CONTROL OF RADIATION, Part 46 - Licensing of Naturally Occurring Radioactive Material (NORM).


What is OGP?

The International Association of Oil & Gas Producers encompasses the world’s leading private and state-owned oil & gas companies, their national and regional associations, and major upstream contractors and suppliers.

Vision

• To work on behalf of the world’s oil and gas producing companies to promote responsible and profitable operations

Mission

• To represent the interests of oil and gas producing companies to international regulators and legislative bodies
• To liaise with other industry associations globally and provide a forum for sharing experiences, debating emerging issues and establishing common ground to promote cooperation, consistency and effectiveness
• To facilitate continuous improvement in HSE, CSR, engineering and operations

Objectives

• To improve understanding of our industry by being visible, accessible and a reliable source of information
• To represent and advocate industry views by developing effective proposals
• To improve the collection, analysis and dissemination of data on HSE performance
• To develop and disseminate best practice in HSE, engineering and operations
• To promote CSR awareness and best practice