APPENDIX 10

Normally Occurring Radioactive Material (NORM)

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A10.1 Introduction

Radiation is part of the natural environment; it is estimated that approximately 80% of all human exposure comes from naturally occurring or background radiation. Certain extractive industries have the potential to increase the risk of radiation exposure to the environment and humans, by concentrating the quantities of naturally occurring radiation beyond normal background levels. This material is termed ‘naturally occurring radioactive material’ (NORM); this is to distinguish the radiation material from that which has been technically enhanced by mankind (e.g. nuclear fuel).

There are essentially two requirements for the formation of NORM in the oil and gas industry:

- The formation waters must have the appropriate chemical make up and concentration of dissolved compounds from the reservoir rock for the potential formation of scale precipitates. Formation fluids should contain appropriate concentrations of Group II (periodic table) elements: Calcium (Ca); Strontium (St); Barium (Ba); and the naturally occurring radioactive isotopes of Radium (Ra) - Radium-226 ($^{226}\text{Ra}$), Radium-228 ($^{228}\text{Ra}$) and their daughter products (see Table 1 below).

- The physical and chemical conditions should promote the precipitation of scales. As the formation fluids reach the surface, changes in pressure and temperature result in the precipitation of sulphate and carbonate products which were previously dissolved in the formation fluids. This is referred to as scale or sludge.

It is the co-precipitation of naturally occurring radium isotopes (and other naturally occurring radionuclides) with the sulphate and carbonate scales that results in the formation of NORM i.e. scales or sludges with higher than background levels of radioactivity. Not all scale or sludge resulting from oil and gas activities contains NORM – it is a feature of the composition of reservoir fluids and associated physical and chemical conditions resulting from the production of oil and gas.

Table A10.1 Main Radionuclides and their characteristics, associated with NORM in the Oil and Gas Industry

<table>
<thead>
<tr>
<th>Radionuclides</th>
<th>Half-life</th>
<th>Mode of Decay</th>
<th>Main decay product(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{226}\text{Radium} – \text{(Ra)}$</td>
<td>1600 yr</td>
<td>Alpha ($\alpha$)</td>
<td>$^{222}\text{Rn}$ (noble gas)</td>
</tr>
<tr>
<td>$^{222}\text{Radon} – \text{(Rn)}$</td>
<td>3.8235 dy</td>
<td>Alpha ($\alpha$)</td>
<td>Short lived progeny $^{(1)}$</td>
</tr>
<tr>
<td>$^{210}\text{Lead} – \text{(Pb)}$</td>
<td>22.30 yr</td>
<td>Beta ($\beta$)</td>
<td>$^{210}\text{Po}$</td>
</tr>
<tr>
<td>$^{210}\text{Polonium} – \text{(Po)}$</td>
<td>138.40 dy</td>
<td>Alpha ($\alpha$)</td>
<td>$^{206}\text{Pb}$ (stable)</td>
</tr>
<tr>
<td>$^{228}\text{Radium} – \text{(Ra)}$</td>
<td>5.75 yr</td>
<td>Beta ($\beta$)</td>
<td>$^{228}\text{Th}$</td>
</tr>
<tr>
<td>$^{228}\text{Thoron} – \text{(Th)}$</td>
<td>1.9116 yr</td>
<td>Alpha ($\alpha$)</td>
<td>$^{224}\text{Ra}$</td>
</tr>
<tr>
<td>$^{224}\text{Radium} – \text{(Ra)}$</td>
<td>3.66 dy</td>
<td>Alpha ($\alpha$)</td>
<td>Short lived progeny $^{(1)}$</td>
</tr>
</tbody>
</table>

1) Progeny - Decay products or (daughters) of $^{222}\text{Rn}$ are called the ‘radon progeny’ (formerly ‘radon daughters’), because the half-life of these daughters are very short, resulting in the production of $^{210}\text{Pb}$.
Typically, scale or sludge collects in areas of the production system where there is a drop in flow, such as bends in pipe-work and in process vessels. Liquid and solid waste streams that have the potential to contain NORM include:

- Produced water
- Sludges and scales resulting from maintenance and shut down activities (cleaning of pipework and process vessels)
- Wastes arising from NORM cleaning and decontamination activities

A10.2 Occurrence & Concentration of NORM in Oil and Gas Operations

Scale formation is a complex multiphase process that depends upon a number of factors (including concentration, pressure and temperature changes, presence of particles to facilitate crystal growth, breakthrough of injected (high sulphate containing seawater) into production wells, and compatibility of mixed fluids from formations having different chemical compositions). This complexity makes it difficult to predict NORM concentration over a project lifetime. Some fields have no NORM, whilst others may have significant levels of NORM. Generally when production first begins NORM is absent, but as production continues the produced water being extracted to the surface increases in salinity, indicating the co-production of brine and the dissolution of Group II elements from the reservoir rock, especially radium, and with it the potential start of NORM depositing on equipment.

Industry experience has shown that scaling is encountered more frequently on oil producing installations than in gas producing facilities. This is because more water (into which Group II elements dissolve) is associated with oil producing facilities compared with gas facilities.

A10.2.1 Probability of NORM formation in ACG Reservoirs

NORM scale tends to be formed from sulphate rather than carbonate products. Radium sulphate (radioactive) generally only precipitates in association with barium and strontium sulphates (non-radioactive), and it is these sulphates that are most commonly present in NORM containing scale.

A water analysis from the Chirag well A6 has been used to determine the scaling potential as a consequence of pressure and temperature changes. The study also included the consequences of mixing with Caspian seawater. The study found that calcium carbonate scaling is likely both offshore and onshore. However, sulphate scales (most commonly associated with radiation) are unlikely, even when there is seawater mixing. A further analysis of scaling potential has been made using water from East Azeri. Here significant barium is present in the formation waters. Whilst serious barite scaling is unlikely, some deposition in the production wells is likely on breakthrough of Caspian seawater.

Analysis of the produced water from Chirag Platform (conducted in 2004) shows there to be little propensity for NORM to occur since no measurable levels of radioactive elements (such as radium) were detected. However, in order to ensure that the installations are fully prepared to deal with NORM issues, BP procedures require an ongoing monitoring plan.

A10.2.2 Mitigation of NORM formation - Scale Inhibitor

In order to mitigate against the formation of scale in production installations, all facilities will be equipped with the ability to inject scale inhibitor at the production wellhead. The scale inhibitor works in the process stream by interacting with scale crystals to prevent crystal growth.
A10.2.3 Monitoring System

Experience from the international oil extraction industry has shown that if NORM is found, it is generally contained within process piping and equipment, particularly in equipment that is in contact with produced water. BP’s procedure requires operations to monitor for NORM. The standard procedure for monitoring adopted by BP is to ensure whenever areas of the process system are opened which have the potential to contain NORM a risk assessment is conducted to consider the likelihood that NORM may be encountered. The risk assessment will consider the history of the plant and any previous monitoring results. If it is considered that there is a possibility that NORM may be encountered, then monitoring procedures are put into place.

To date monitoring shows no radioactivity above background levels.

A10.3 NORM Management if detected

If surface contamination is found, then BP’s NORM handling procedures are followed. These procedures require that an assessment be made to determine if the area is to be classified as either supervised or controlled (see below) and appropriate barriers are put up to control access to the area. Personnel working in the area are monitored on entering and leaving the area and any contamination that is encountered is contained within the area.

Definition of radioactive worksite designation:

i) Supervised Area

A supervised area is defined as a workplace in which one or more of the following conditions prevail:

   a) The effective dose rate\(^1\) exceeds 2.5 µSv/hr
   b) The surface contamination exceeds 2 Bq/cm\(^2\)
   c) The air concentration exceeds 0.003 Bq/m\(^2\)

Generally, the public and ordinary members of the work-force should be excluded from a supervised area and the area should be demarcated with signs advising that it is a Supervised area and what type of radiation hazard exits within the area.

ii) Controlled Area

A controlled area is a workplace in which an individual could be exposed to an annual radiation dose greater than 6 millisieverts (mSv). This annual dose is translated into the following criteria, which are designed to ensure that the annual dose rate is not exceeded.

   a) The effective dose rate exceeds 7.5 µSv/hour
   b) The surface contamination exceeds 7 Bq/cm\(^2\)
   c) The air concentration exceeds 0.01 Bq/m\(^2\)
   d) The effective dose rate exceeds 2.5 µSv/hr and the surface contamination exceeds 2 Bq/cm\(^2\).

As with a supervised area, a controlled area must be clearly marked as such and entry to the area is restricted. Generally only classified workers should enter a controlled area. Classified workers are personnel who have been trained to work specifically with radioactive substances. In addition, a classified worker is medically screened annually and carries a personal dose rate meter at all times when performing work involving radioactive sources. Personnel entering both supervised and controlled areas will be equipped with the appropriate personal protective equipment (PPE).

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1 Effective dose rate refers to the degree or level of radiation in an area while air concentration refers to the amount of airborne radioactive material in that area.
A10.4 NORM Decontamination & Waste Management

The requirement to clean or decontaminate equipment that has scale or sludge containing radioactive materials is highly dependent on the nature of the NORM.

i) Leave in Situ

NORM may be found as a very thin, tight adhered film of scale on the insides of process piping or equipment. In such cases the NORM may be left in situ and sealed up again after the work activity is completed. Since NORM is principally composed of alpha and beta particles, leaving NORM in situ does not pose a radiological hazard to personnel working on the facility since the radioactivity is attenuated by the presence of the steel walls of pipe-work etc. In such circumstances the NORM scale may remain in place until the plant or equipment is decommissioned, at which time, the scale is should be removed for disposal.

ii) Remove and Dispose

In some cases the nature of scale or sludge in terms of volume or thickness of deposits may cause interference with the operation of the installation. Such circumstances would include where sludge or sand has accumulated in equipment such as in a separator. Where this has occurred the presence of the sand or sludge may result in the equipment losing efficiency and therefore there is a requirement to remove the material.

In circumstances where the material is removed it will require to be disposed. Options for final disposal include capture and transfer to an onshore waste disposal facility, and disposal into the sea along with platform drainage/washings. Any disposal route for NORM containing scale will be pre-approved with the MENR and appropriate government departments.

In line with BP waste management system, should NORM waste occur, it will be securely contained to avoid any spillage or leakage and will be clearly labelled and a waste transfer audit trail maintained. Disposal of material in this way is documented and recorded.