GUIDELINES FOR

NATURALLY OCCURRING

RADIOACTIVE MATERIALS

March 2002

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APPEA

ABN 44 000 292 713

ISBN

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SUMMARY

Small quantities of solid naturally occurring radioactive materials (NORMs) have been generated by a few Australian petroleum production facilities. NORMs and the nuclear radiation they emit create occupational health and safety, environmental protection, waste disposal and management issues.

This Guideline provides guidance on NORM monitoring, management of occupational radiation exposures and decision-making regarding NORM waste disposal. A similar regulatory practice is recommended as the one used in the uranium mining and milling and heavy mineral sands industries.

The rationale behind this notion is based on the fact that petroleum industry NORMs and NORMs in the uranium mining and heavy mineral sands industries are in a similar category with respect to the content of a few natural radionuclides and their specific activity. Furthermore, the NORM waste in the petroleum/natural gas industry and in uranium mining and milling and heavy mineral sands processing is a byproduct of similar primary industry activities – extraction of minerals/oil/natural gas.

The Guideline provides the petroleum industry and Government regulatory authorities with a summary of technical background on:

- Natural radionuclides and nuclear radiation in the environment;
- Types of NORM, its radioactivity and factors conducive to its formation;
- Occurrence of NORM in oil and gas facilities;
- Measurement of NORM and trigger levels of concern;
- Potential effects of NORM in the receiving environment;
- Decision making on NORM disposal; and
- Precautions in handling NORM.

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1. INTRODUCTION

Whilst the petroleum industry in the USA (API, 1992) and in Europe (E&P Forum, 1988) has dealt with Naturally Occurring Radioactive Materials (NORMs) for a number of years, NORMs in the Australian offshore petroleum industry have been reported only recently (Kvasnicka, 1996a; Kvasnicka, 1998).

Both the Australian petroleum industry and the Government regulatory authorities have been addressing the following NORM issues:

- radiation exposures of workers;
- temporary NORM waste storage and management;
- radioactive waste storage and disposal;
- transport of the NORM waste; etc.

These issues have been regulated by various State, Territory and Commonwealth Government departments. Due to existing differences between Commonwealth, State and Territory radiation protection regulations, Government regulatory agencies have adopted a State specific regulatory approach, rather than a uniform and coherent one, to deal with the above NORM issues.

The purpose of this guideline is to provide a rational basis for responding to potential occupational and environmental radiation protection concerns associated with managing, handling, discharging and disposing of Naturally Occurring Radioactive Materials. The guideline further provides APPEA member companies and regulators with an understanding of occupational and environmental risks from NORMs generated in oil and gas producing facilities in Australia. The guideline also reviews methods for disposing of NORMs and provides risk-based guidance for selecting an appropriate disposal method.

2. NATURAL RADIONUCLIDES AND NUCLEAR RADIATION IN THE ENVIRONMENT

Considering that radiation exposures of petroleum industry personnel can be managed at very low levels, it is important to understand occupational exposures of petroleum industry personnel to nuclear radiation emitted by NORMs in perspective with population exposures to natural nuclear radiation in normal living environments. All human beings, animals and plants are exposed to natural nuclear radiation in normal living environments. On average, natural nuclear radiation exposures of members of the public are higher than occupational exposures in most industries where people are exposed to nuclear radiation.

Natural nuclear radiation is a product of the radioactive decay of natural radioactive atoms *(terrestrial nuclear radiation*) and is also produced by nuclear collisions of galactic cosmic radiation, as well as by nuclear collisions of solar cosmic radiation with the atoms of gases in the atmosphere *(secondary cosmic radiation*). Natural nuclear radiation is a natural part of our living environment. All living organisms including human beings are exposed to low levels of natural nuclear radiation during their daily lives.

2.1 Terrestrial nuclear radiation

Terrestrial nuclear radiation is mainly emitted by natural radioactive atoms of uranium, thorium, radium and other atoms that are present in all naturally occurring materials around us. Natural potassium is also slightly radioactive. Low concentrations of the above natural radioactive atoms are also in tissues of our bodies.

Natural radioactive atoms are present in materials like soil, rocks, bricks, tiles, etc. When radium in building material and subsoil decays it generates the radioactive gas radon. Radon gas diffuses indoors from brick walls, concrete slabs and subsoil and subsequently radon concentrations in some clay brick homes with low air ventilation can be high.

It could be concluded that terrestrial nuclear radiation irradiates us not only externally, in the form of gamma radiation emitted from soil, rocks and building material, but we are also irradiated internally. As low levels of natural radioactive atoms are also present in food we eat, air we breathe and water and other drinks we drink, a proportion of the radioactive atoms in our diet is incorporated into our body tissues and bones.

2.2 Secondary cosmic radiation

Secondary cosmic radiation is produced when galactic cosmic radiation collides with atoms of air (oxygen, nitrogen and hydrogen) in the upper layers of the atmosphere. The sun also emits cosmic radiation but this solar radiation has far less energy than galactic cosmic radiation. The energy of galactic cosmic radiation is also much higher than the energy of any terrestrial nuclear radiation emitted by sources such as uranium, radium and by any other radioactive materials.

When the galactic and secondary cosmic radiation penetrates through the atmosphere, it is slowed down and the majority of cosmic radiation stops in the atmosphere. The Earth's atmosphere is, therefore, an effective cosmic radiation shield. This means that the cosmic radiation intensity is much higher in the upper layers of the atmosphere than at sea level (the altitude effect).

2.3 Annual public radiation exposures

The average annual radiation dose due to exposures of members of the public to background natural radiation in normal living environments is about 2 millisievert (mSv). In addition, members of the public are on average exposed to about 0.6 mSv per year from artificial sources of nuclear radiation (mainly medical diagnostics exposures) (Table 1). Natural radiation exposures in subtropical northern Australia are lower than in the southern states because houses in northern Australia are better ventilated, which results in lower concentrations of radon gas in indoor air.

Radiation doses of the population exposed to the natural background nuclear radiation in normal living environments are not regulated. There is no regulatory radiation dose limit for natural background nuclear radiation exposures in normal living environments.

Table 1: Average annual radiation doses due to exposures of the general public to natural background nuclear radiation in normal living environments and to artificial sources of nuclear radiation

Sources of natural nuclear radiation	**Annual radiation dose**
Cosmic radiation at sea level	0.3 mSv
Natural radioactive atoms in soil, rocks, building material, etc.	0.3 mSv
Natural radioactive atoms in body tissues and bones	0.4 mSv
Radioactive radon gas in indoor air	1.0 mSv
All natural sources	*2.0 mSv*
Sources of artificial nuclear radiation	
Medical and dental x-rays	0.40 mSv
Nuclear medicine	0.10 mSv
Nuclear weapons fallout	0.04 mSv
Other sources	0.02 mSv
Nuclear power plant discharges	0.01 mSv
All artificial sources	*0.6 mSv*
All natural and artificial sources	***2.6 mSv***

Note: Natural radiation and medical radiation exposures summarised in this Table are not regulated ie annual radiation doses in this Table are not to be compared with the public annual dose limit of 1 mSv and/or with the occupational annual radiation dose limit of 20 mSv (section 8).

There are regions around the world where the concentrations of thorium, uranium and other natural radionuclides in soil and beach sand are exceeding many times average background levels. For example, in a Brazilian coastal town of Guarapari and along the Kerala coast in India, the personal annual doses of members of the public may exceed the occupational annual dose limit of 20 mSv because of high levels of uranium and thorium in the local geology (Bennett, 1990).

Elevated activities of natural radionuclides in some building materials increase the external doses in homes. Nevertheless, far more important are indoor doses from inhaled radon-222 gas. High radon gas concentrations in houses may also be caused by elevated radium-226 content in rocks and soil below the basement of houses from where radon diffuses indoors. Therefore, doses from inhalation of radon gas indoors may be high. The world wide average dose due to exposures to radon in homes is approximately 1 mSv per annum. However, in many homes indoor radon concentrations have been measured in excess of 1,000 Bq/m^3 and thus annual doses above 20 mSv are not uncommon (Ennemoser, et al., 1994).

2.4 Occupational Exposures to Natural Nuclear Radiation

Levels of exposure to cosmic radiation increase with altitude. For example, pilots and aircrew of commercial airlines exposed to cosmic radiation receive an annual cosmic radiation dose between 2 and 7 mSv (EC, 1996; Kvasnicka, 1997a). The average annual radiation exposure of uranium process plant workers is about 1 – 5 mSv (WMC, 1996; OSS, 1983-8). It has been demonstrated that petroleum industry personnel receive an average annual radiation dose of well below 1 mSv (Kvasnicka, 1998).

3. NORMS IN THE PETROLEUM INDUSTRY

NORMs are present in components of both petroleum production facilities and natural gas production facilities. NORMs can be associated with the presence of crude oil, produced water and natural gas. Petroleum industry NORMs are mainly scale, sludge and sand. In gas plant components, where only natural gas and/or its fractions are present, NORM occurs on internal walls in the form of thin films and/or coatings formed by the decay products of radon gas. Considering that some formation water is also present in natural gas, small quantities of NORM sludge can be present in gas plants as well.

NORMs occurring in oil installations mainly contain radium-226 and radium-228, the activity of which is usually in equilibrium with the activity of their decay products. In gas installations, NORM sludge also contains radium and the thin film radioactive coatings of internal walls of pipes and vessels mainly contain lead-210 and polonium-210.

3.1 Oil installations

Scales in pipes and vessels are the most common NORMs in the petroleum industry. Scales are solid minerals that precipitate from produced water which has high salinity and contains sulfates and/or carbonates plus calcium, barium and strontium. The most common scales consist of barium sulfate ($BaSO_4$), strontium sulfate ($SrSO_4$) or calcium carbonate ($CaCO_3$). Scale-forming material may also precipitate on sand and sludge particles and debris of scale may be mixed with sludge and sand inside vessels.

Scale formation is caused by a combination of the following events (E&P FORUM, 1988):

- Mixing of incompatible waters;
- pressure changes;
- temperature changes;
- impurities;
- additives;
- variation of flow rates;
- changes in water acidity;
- fluid expansion;
- gas evaporation; etc.

The most important scale formation processes are mixing of incompatible waters and temperature changes.

Under high temperature and pressure conditions in an oil reservoir, trace concentrations of barium, strontium, calcium and radium are leached out from reservoir sand and are present in a soluble form in the formation water. This water also contains sulfates, carbonates and other ions. Events that may cause precipitation of scale particles have been mentioned above. When scale precipitates from a large volume of formation/produced water, radium is concentrated within a small amount of solid scale such that the radium concentration in scale exceeds the radium concentration in the formation/produced water by several orders of magnitude. As uranium and thorium radionuclides are substantially less soluble in the formation water than radium, NORM scale contains practically no uranium and/or thorium.

It can be concluded that NORMs in petroleum production facilities mainly contain radium-226, radium-228 and their short-lived decay products. The half-life of radium-226 is 1,600 years and that of radium-228 is 5.8 years. Radon decay products are continuously generated in solid NORMs in petroleum production installations by the decay of radium. Therefore, scale, sludge and sand emit approximately the same amount of radiation during normal operation conditions as well as during shutdowns.

As the concentration of radium and radium decay products in formation and/or produced water is usually low, the water itself is not a source of external radiation exposures. Nevertheless, radium in discharges of the produced waters (especially from onshore facilities) may need to be considered depending on the levels of radium and on environmental considerations.

Both radium-226 and radium-228 decay series radionuclides are summarised in Tables 2 and 3. Radionuclides below radium-226 and radium-228 are generated by the radioactive decay of the original radionuclide of radium. The third column indicates the half-life of a given radionuclide and the type of radiation emitted by that radionuclide is in the last column.

Data in Tables 2 and 3 can explain some basic radiological differences between different types of NORMs:

a) As NORM scale, sludge and sand contain radium-226 and radium-228, they must also contain all other radionuclides of both decay series. Radioactivity of these NORMs decreases only slowly because of the long half-lives of radium-226 (1,602 years) and radium-228 (5.75 years).

b) Radon gas in natural gas generates short-lived decay products that can attach to the internal walls of pipes and vessels in gas installations and form thin film deposits. The build up of radon decay products is most likely to be first apparent at any gas filters, chokes and valves in the system. Short-lived radon decay products emit highly penetrative gamma radiation that is a source of occupational external radiation exposures in the vicinity of pipes and vessels with the above thin film deposit.

c) During shut downs, when the flow of gas is interrupted, short-lived radon daughters no longer deposit onto internal walls and, within several hours after the shut down, external gamma radiation is no longer emitted from pipes and vessels as the previously deposited gamma-emitting radon daughters have decayed.

d) During shut downs, only longer-lived lead-210, bithmut-210 and polonium-210 remain in thin film deposits which emit only weak gamma radiation and mainly beta and alpha radiation. These radionuclides are a source of internal radiation exposures if inhaled or ingested.

Table 2: Properties of the radium-226 decay series

Nuclide	Atomic No.	Half-life	Radiation
^{226}Ra	88	1602 y	α,γ
^{222}Rn	86	3.824 d	α
^{218}Po	84	3.05 m	α
^{214}Pb	82	26.8 m	β,γ
^{214}Bi	83	19.8 m	β,γ
^{214}Po	84	162 ms	α
^{210}Pb	82	22.3 y	β,γ
^{210}Bi	83	5.012 d	β
^{210}Po	84	138.4 d	α
^{206}Pb	82	stable	-

Table 3: Properties of the radium-228 decay series

Nuclide	Atomic No.	Half-life	Radiation
^{228}Ra	88	5.75 y	β
^{228}Ac	89	6.13 h	β,γ
^{228}Th	90	1.913 y	α,γ
^{224}Ra	88	3.64 d	α,γ
^{220}Rn	86	55.3 s	α
^{216}Po	84	0.15 s	α
^{212}Pb	82	10.64 h	β,γ
^{212}Bi	83	60.6 min	α,β,γ
^{212}Po	84	0.305 ms	α
^{208}Tl	81	3.07 min	β,γ
^{208}Pb	82	stable	-

3.2 Natural gas installations

A fraction of radon gas is released from reservoir sand during the decay of radium contained in sand. Radon then becomes a part of natural gas and is transported with natural gas to the gas plant. Considering that the half-life of radon-220 is short (55.3 s), all radon-220 decays before it reaches the gas plant.

When radon-222 decays, short-lived decay products are generatedwhich plate out on the internal walls of pipes and vessels. Radon gas is more concentrated in the propane and ethane circuits because it has a boiling point between that of propane and ethane. Therefore, the build up of radon daughters on internal walls of pipes, vessels etc. of propane and ethane circuits is substantially higher than in other parts of gas plants.

Radon decay products form thin dark grey/black films on internal walls and, because the short-lived radon decay products emit gamma radiation, external gamma radiation dose rates near gas plant components with radon decay product films and coatings can be high. The build up of radon decay products is most likely to be first apparent at any gas filters, chokes or valves in the system. During shut downs, radon gas is present in pipes and vessels of a gas plant in much lower concentrations in comparison with normal operation conditions and, thus, a negligible amount (activity) of short-lived radon decay products adheres onto internal walls. The external dose rate near pipes and vessels decreases rapidly after a shut down because of the decay of short-lived radon decay products.

Produced water associated with natural gas usually contains a very low concentration of radium, which is unlikely to cause an external exposure hazard. Nevertheless, radium in produced water may place constraints on discharges depending on radium concentrations as well as environmental, public health and regulatory considerations. Solid NORMs (mostly calcium carbonates and sulfates) usually accumulate in separators.

The main forms of NORMs in petroleum and natural gas production installations are summarized in Table 4.

Table 4: Main forms of NORM in petroleum and gas production installations (IAEA, 1999)

Type	Nuclides	Characteristics	Occurrence
Radium-scales	Radium-226, Radium-228 + decay products	Hard deposits of calcium, strontium, barium sulfates and carbonates	Wet parts of oil production installations; Well completions
Radium-sludge	Radium-226, Radium-228 + decay products	Sand, clay, paraffin, heavy metals	Separators; Skimmertanks
Lead-deposits	Lead-210 + decay products	Stable lead deposits	Wet parts of gas production installations; Well completions
Lead-films	Lead-210 + decay products	Very thin films	Oil and gas treatment and transport
Natural gas	Radon-222	Noble gas	Consumers domain
Produced water	Radium-226 + Radium-228 (and/or) Lead-210	More or less saline, large volumes in oil production	Each production facility

4. OCCURRENCE OF NORMS

The main types of NORMs in oil and gas installations are scale, sludge, sand and thin film deposits of radon decay products. Their occurrence depends on certain reservoir parameters and can be triggered by water flooding a reservoir.

4.1 Occurrence of NORM scale

Provided the formation water contains barium, strontium or calcium as well as sulfates and carbonates, scale can build up in well tubing where a considerable pressure and temperature drop occurs between the reservoir and the crude oil in the well tubing. Scale formation in well tubing can be predicted on the basis of concentrations of cations and anions in the formation water, reservoir temperature and pressure, temperature and pressure in the well tubing etc. (Oddo and Tomson, 1994).

It is important to understand that if scale forms, in the majority of cases it contains radium and its radium specific activity depends on levels of radium and thorium in reservoir sands. Generally, the specific radium activity in calcium carbonate scales is lower than the specific activity of barium sulfate scales.

The water chemistry of several wells of a reservoir can be substantially different (some wells may contain elevated concentrations of barium and strontium and low concentrations of sulfates whilst the formation water of other wells may be deficient in barium and strontium but contain elevated concentrations of sulfates). This happens when a part of the reservoir is flooded by sea water, which has an elevated concentration of sulfates, to increase the production pressure. Under such circumstances an intensive scale formation occurs when the two types of incompatible water mix in a production header.

Provided scale is found in the upstream sections of an oil producing facility (well tubing, production header, etc.), it is likely that NORMs would be present in remaining parts of the facility as well. Nevertheless, their production rate differs depending on the type of the primary scale formation process and several other factors.

Scales are brittle minerals and thus scale build up in pipes and vessels frequently cracks due to temperature contractions of pipes, movement of flexible hoses etc. Scale debris are being removed from pipe surfaces and are carried with crude oil and produced water. Coarse scale debris end up in separators and sand traps, while fines end up in slops tanks.

The most ‘difficult’ type of NORM from a management perspective is the practically insoluble barium(radium)sulfate scale that forms in pipes and vessels. Barium sulfate scales are usually more radioactive than carbonate scales. Scale build-up in pipes and vessels may also cause production complications (clogging pipes and valves and undesirable accumulation of large quantities of NORM solids in vessels and separators) (Kvasnicka, 1998).

The specific radium activity of radium in NORMs from two Australian offshore petroleum production facilities has been summarised in Table 5. The first facility had only NORMs based on barium sulfate whilst the second one had a NORM mixture of barium sulfate and calcium carbonate (Kvasnicka, 1992; Kvasnicka, 1997b).

The E&P Forum (1988) reported a wide range of radium activities in scale: northern North Sea up to 3,700 Bq/g (Becquerel per gram); mid North Sea up to 15,200 Bq/g; northern Europe up to 3,400 Bq/g; and southern Europe 0.37 Bq/g. In the US, scale was reported to have a specific radium activity in excess of 100 Bq/g (Bernhardt, at al., 1996).

Scale build up in components of gas plants is usually minor.

Table 5: NORMs in two Australian offshore petroleum production facilities

NORMs in two Australian offshore petroleum production facilities were present in three forms: scale, sludge and sand. Typical activities of radium in these materials are summarised.

	Specific activity (Bq/g)	
	Radium-226	Radium-228
Scale	250*	300*
	150**	240**
	*21***	*48***
Sludge	25*	30*
Sand	8.9*	9.6*

*Note: * The first facility had only barium sulfate based scale and NORMs.*
*** The second facility had a mixture of barium sulfate scale and calcium carbonate scale (in italics) (Kvasnicka, 1998; WRS, 1997).*

4.2 Occurrence of NORM sand

Small quantities of sand are carried in crude oil and coarse sand is trapped in sand traps located upstream from separators and in separators as well. In oil production facilities with scale build up, sand is highly contaminated with scale debris and radium content in this waste stream needs to be taken into account when disposing of such sands.

In facilities with high concentrations of calcium and carbonates, a rapid precipitation of coarse calcium carbonate particles may occur in those facility components with a positive temperature gradient. Such crystal precipitate usually accumulates in separators and a fine fraction increases the sludge production rate.

The specific radium activity of radium in NORMs (including sand) from two Australian offshore petroleum production facilities has been summarised in Table 5.

There is usually only a minor waste sand stream in natural gas plants.

4.3 Occurrence of NORM sludge

Sludge usually contains fine sand particles, corrosion particles, flakes of paint, bacteria growth and fines derived from scale. Sludge is usually accumulated in separator vessels and slops tanks of oil production facilities.

The specific radium activity of radium in NORMs (including sludge) from two Australian offshore petroleum production facilities has been summarised in Table 5.

In gas plants, sludge containing radium and solids accumulated in separators containing lead-210/polonium-210 must be periodically removed.

4.4 NORMs in gas production

The major radionuclide in natural gas is radon-222. The half-life of radon is 3.8 days and thus the radon specific activity in natural gas is only marginally lower in the gas plant than in the reservoir. When radon decays, a series of short-lived decay products is generated (Table 2 and 3). These decay products have an electrostatic charge and thus adhere within a short period of time either to the walls of pipes, vessels etc. or to any fine dust that might be present in natural gas. The build up of short-lived radon decay products causes a growth in the surface activity of radioactive lead-210 and polonium-210, the half-lives of which are 22.3 years and 138 days respectively.

During normal production, radon in natural gas continuously ‘feeds’ the activity of short-lived radon decay products (polonium-218, lead-214, bithmut-214 and polonium-218) onto the internal walls of pipes and other gas plant components. As the short-lived radon decay products emit high-energy gamma radiation, it is possible to detect elevated external gamma doses near external pipe and vessel surfaces. A few hours after the shut-down the external dose rate appears to be at a background level (the flux of ‘fresh’ radon decay products is diminished and already deposited short-lived radon decay products that emit gamma radiation decay).

The surface activity of polonium-210 on a gas plant component has been measured at 290 Bq/cm^2 (Summerlin, J. and Prichard, H. M., 1985). Such high surface activities would correspond to the specific activity of up-to 10^6 Bq/g. This implies that inhalation of a few milligrams of fine lead dust would cause the effective dose of 1 mSv (IAEA, 1996). Therefore, it is important to manage vessel entries and clean up operations during shut downs, taking into account radiation safety precautions. It needs to be pointed out that it is difficult to remove lead films from the internal surfaces of gas plant installations. After 12 minutes of abrasive brushing with a stiff wire brush, the surface alpha activity has been observed to decrease only by a factor of five times (Summerlin, J. and Prichard, H. M., 1985).

4.5 Radium in produced water

The specific activity of radium-228 and radium-226 in the produced water mainly depends on the concentration of uranium and thorium in reservoir sands. Under conditions of the high reservoir temperature (the reservoir temperature may exceed 150^{o}C) and high pressures, much more radium is leached out to the formation water from reservoir sands than to shallow aquifer drinking water. Mean radium concentrations in Norwegian offshore oil production installations were measured at 4 Bq/l and 2 Bq/l for radium-226 and radium-228 respectively (Lysebo and Strand, 1997). The specific radium-226 and radium-228 activities in the produced water of one Australian offshore petroleum production installation were measured at 17 Bq/l and 23 Bq/l respectively (Amdel, 1992).

4.6 NORMs in primary production and power generation industries

In order to put the radiological significance of petroleum industry NORMs into perspective, the radium content in NORMs generated in several different primary and power generation industry operations was mentioned (Table 6). For example, the radium activity of petroleum industry NORM scale is similar to the specific radium activity of uranium ore, monazite or xenotime. Petroleum industry NORM sludge and sand are in a category of NORM materials with phosphate rocks, phosphate fertilizer and fly ash (UNSCEAR, 1982).

This comparison is rather significant, especially if one takes into account that many million tones of uranium ore, heavy mineral sands, phosphate ore and fertiliser and fly ash are handled and significant volumes of naturally occurring low radioactive wastes derived in these industries are disposed of following radiologically, ecologically and economically sound and recognised disposal methods and procedures.

Table 6: Radium-228 and radium-226 activity concentrations in naturally occurring uranium ore, two components of heavy mineral sands, fly ash and a phosphate fertilizer.

Material/Grade	Radium-228 (Bq/g)	Radium-226(Bq/g)
Uranium ore (0.1 % U)	-	12
Uranium ore (1 % U)	120	-
Uranium ore (5 % U)	-	600
Monazite	200 - 290	1.2 - 37
Xenotime	61	49
Fly ash	0.56	0.56
Phosphate rocks	4.8	0.12
Oil industry scale *	48 - 300	21 - 250

*Note: Uranium tailings radium concentration is similar to that in the primary uranium ore. * Based on Australian industry experience (Kvasnicka, 1998; WRS, 1997).*

5. MEASUREMENT

The radiation exposure pathways in petroleum and gas production are similar to those in the uranium and heavy mineral sand mining and processing industry, ie workers can be exposed to:

- External gamma radiation exposures (external gamma radiation emitted mainly from NORM scale, sludge and sand in petroleum production facilities and from thin films and coatings of short-lived radon daughters in gas production facilities).
- Inhalation of resuspended long-lived airborne radionuclides in NORM dust (NORM dust can be inhaled during vessels entries, maintenance and decontamination operations that involve handling of components contaminated by NORMs, etc.).
- Inhalation of radon and radon decay products (radon and radon decay products can be inhaled during vessel entries and in areas where NORMs are temporarily stored).

Relevant occupational radiation health and safety measurements include:

a) Monitoring of personal external gamma radiation exposures.
b) Monitoring of inhaled activity of NORM dust.
c) Monitoring of inhaled activity of radon gas or the potential alpha activity concentration (PAEC) of radon decay products.
d) Monitoring of the surface contamination of skin, tools, protective equipment and material/components to be released from a facility.
e) Periodic external gamma surveys of facility components where build-up of NORMs occurs.

Personal external gamma radiation doses are monitored by thermoluminescent dosimeters (TLDs). A TLD badge is usually issued for a period of three months. The exposed badge is sent to a central laboratory for evaluation and the external personal dose for the three month wearing period is reported.

It ought to be mentioned that TLDs have a low sensitivity to the low levels of radioactivity in the petroleum and gas production industry, where low operational personal external doses around 1 mSv per year could be received. For example, in the uranium mining industry, personal external dose monitoring is not required provided the annual dose does not exceed 5 mSv.

The monitoring of personal radiation exposures during shut downs may be required when workers are involved in non-routine operations in areas highly contaminated by the NORM scale, inside vessels etc. This monitoring of non-routine personal external radiation exposures is usually carried out by pocket electronic dosimeters. Such dosimeters are useful because the personal dose is known at the end of a task and the level of personal exposure can be progressively checked during the task. It is also possible to use the external gamma survey meters to survey the external dose rate throughout a workplace (inside a vessel, during descaling, etc.) and establish a likely average dose rate for a task. This dose rate (μSv/hour) is then multiplied by the task duration (hour) to calculate the personal radiation dose (μSv) of personnel involved in the task.

It may be required to monitor radon or radon decay product concentrations inside vessels and tanks which contain NORM and have insufficient ventilation. Such monitoring is carried out using specialised and expensive monitoring equipment. The personal radiation dose due to inhalation of radon and radon decay products is calculated by taking into account the average radon/radon decay product concentration in vessel/tank air and the time of the confined space entry taken from the “Confined Space Entry Permit” form.

A personal radon exposure monitoring service is also available. A small badge that includes a special nuclear track etch film is issued to a person working in an environment with high radon concentration in air. After the task is completed, the badge is sent to a central laboratory, the film is evaluated and the personal radiation dose due to inhalation of radon is reported taking into account the task duration.

Provided NORM dust particles are released into air during a task, it may be required to monitor the alpha activity concentration of NORM dust particles in air and assess the personal radiation exposure due to inhalation of NORM dust. The monitoring of the alpha activity of NORM dust in air is carried out by personal or area air samplers coupled with a prescribed aerosol filter cassette. After the sampling, the filter with the collected NORM dust particles is removed from the cassette and the alpha activity of NORM dust on the filter is established by alpha counting the filter under an alpha counter. The personal dose due to inhalation of NORM dust is then calculated considering the task duration and the alpha counting result.

It is also required to keep the surface contamination of protective equipment, skin and tools of personnel working with NORMs below the skin surface contamination limit of 0.37 Bq/cm^2 after the task is completed. It is further required that the skin of personnel is below this same skin contamination limit before they eat and at the end of a shift. A hand held alpha surface contamination monitor is used to check the surface contamination.

The monitoring instruments, units of measurements and relevant derived levels/trigger levels or limits are summarized in Table 7 and 8.

Table 7: Radiation monitoring instruments with relevant units of measurements, derived levels or limits.

Radiation monitoring instruments used for the monitoring of personal external exposures, external gamma dose rates, surface contamination, the radon activity in air, the PAEC of radon daughters in air and the specific activity of radium, lead-210 and polonium-210 in solid and liquid samples are presented with relevant units of measurements, derived levels or limits.

Radiation Measurement	**Monitoring Instrument**	**Measured quality & Unit of Measurement**	**Derived Levels or Limits Trigger levels**	**Comment**
Personal exposure	Thermoluminescent dosimeter (TLD) Electronic pocked dosimeter	Effective dose / Radiation dose millisievert (mSv)	Public dose limit – 1 mSv/y[a] Occupational dose limit – 20 mSv/y[a]	TLD badges are issued for 3 months or for a job duration
External dose rate	Geiger Muller (GM) Counter Scintillation survey meter, etc.	Radiation dose rate or exposure rate microsievert per hour (μSv/h) or microroentgen per hour (μR/h)[b]	If the dose rate is 0.5 μSv/h the public dose limit can be reached in 2,000 hours and if the dose rate is 20 μSv/h the occupational dose limit would be reached in 50 hours	It is recommended to survey petroleum and gas production facilities periodically and during shut-downs
Surface contamination	Surface contamination monitor (Scintillation of Proportional Counter)	Surface activity Becquerel per cm^2 (Bq/cm^2)	0.37 Bq/cm^2 [c]	It is required that workers have their skin, cloth and tools below 0.37 Bq/cm^2 at the end of every shift [d]
Radon in air	Continuous radon monitor Passive radon monitor	Radon activity concentration Becquerel per m^3 (Bq/m^3)	1,000 Bq/m^3	Radon monitoring program is to be carried out if the radon activity concentration exceeds 1,000 Bq/m^3 [e]
Radon daughters in air	Continuous radon daughter monitor Semi-passive radon daughter monitor	PAEC of radon daughters microJoule per m^3 ($\mu J/m^3$)	If a worker is exposed to the PAEC of radon daughters of 0.36 $\mu J/m^3$ for 2,000 hours per year the annual dose of 1 mSv would be received (IAEA, 1996)	Vessel ventilation before and during vessel entries decreases the PAEC of radon daughter

Radiation Measurement	Monitoring Instrument	Measured quality & Unit of Measurement	Derived Levels or Limits Trigger levels	Comment
NORM dust in air	Air sampling and filter alpha counting	Alpha activity concentration in air Becquerel per litre (Bq/l)	Provided only equilibrium Radium-226 is present the inhalation of 910 alpha Becquerel is equivalent to 1 mSv. Provided only equilibrium Radium-228 is present inhalation of about 140 alpha Becquerel is equivalent to 1 mSv [f]	
Specific activity (solid NORMs)	Gamma spectroscopy Radiochemistry	Specific activity Becquerel per kilogram (Bq/kg)	Provided the specific radium activity exceeds 2,400 Bq/kg material should be regarded as NORMs [g]	Such an approach is agreed by the States/Territories that have a uranium mining industry
Specific activity in produced water	Radiochemistry Radium-226 by emanation	Activity concentration Becquerel per litre (Bq/l)		Produced water discharges into the sea have no radiological consequences because of dilution. Inland discharges have to consider radiation exposures of a Critical Group of Members of the Public

Note: [a] NHMRC, 1995;

[b] The conversion factor between exposure rate (μR/h) and external radiation dose rate (μSv/h) is approximately 0.006 (1 μR/h = 0.0061 μSv/h).

[c] There is no surface contamination limit in current relevant Australian regulations. Nevertheless, the skin contamination limit of 0.37 Bq/cm^2 (Code of Practice, 1980) has been used.

[d] It is further required that all material, equipment and facility components are declared as non contaminated provided their accessible surface have the surface contamination by alpha emitting radionuclides below 0.37 Bq/cm^2.

[e] According to ICRP 60 (ICRP, 1990), IAEA Safety Series No. 116 (IAEA, 1996) and the NHMRC 1995 Recommendations (NHMRC, 1995) the radon monitoring program should commence if the radon concentration in workplace exceeds 1,000 Bq/m^3. Provided workers are exposed to external gamma radiation, long-lived radioactive dust and radon/radon daughters in air exposures to all sources of radiation ought to be estimated to demonstrate if workers' exposures exceed the public limit of 1 mSv/y.

[f] *According to IAEA Safety Series No. 116 (IAEA, 1996) inhalation of dust particles which AMAD (Aerodynamic Mass Activity Diameter) of 5 μm was considered for inhaled scale particles.*
[g] *Regulations dealing with medical radioactive materials and radioactive sources should not be applicable in situations where naturally occurring radioactive materials are handled / disposed of.*

Table 8: Trigger indicators - decision making table based on activity levels and types of NORMs.

Material/NORM type	Specific Activity Trigger Level (Bq/g)	External Dose Rate (DR) Trigger Level (μSv/h)	Comment:
Lose scale, sludge, sand	< 2.4 (radium) and/or < 12 (equilibrium alpha activity)	if DR < 0.7 μSv/h*	Material is not NORM and may be disposed of in a land fill pending a land fill operator approval.
Lose scale, sludge, sand	-	if DR > 0.7 μSv/h*	NORM may be diluted pending an approval of a regulatory authority and disposed of in a land fill.
Pipework, valves, etc.	-	if DR < 0.5 μSv/h**	Scrap metal may be sent to a smelter.
Pipework, valves, etc.	-	if DR > 0.5 μSv/h**	Scrap metal ought to be decontaminated below 0.5 μSv/h before it is smelted or it is to be disposed of as NORM.

Note: It has been considered that provided the specific activity of radium is less than that of radium specific activity in the uranium waste rock is less 2.4 Bq/g (that of "Specific Material"; Code of Practice, 1982). Material below such specific radium activity is in the same category as the waste rock in the uranium mining industry.
** The external dose rate is measured at the surface of a pile of NORM which surface area is at least 1 x 1 m^2 and the thickness 0.3 m.*
*** Provided material containing radium is inside a pipe, which wall is 1 cm thick, the external dose rate at the surface of the pipe would be about 80% of the dose rate at the surface of unshielded material (HP&RHH, 1992).*

6. POTENTIAL EFFECTS OF NORM ON THE RECEIVING ENVIRONMENT

There are several possible scenarios for the disposal of petroleum industry NORMs:

a) Produced water discharge to sea from offshore petroleum and gas facilities.
b) Produced water discharge from onshore petroleum and gas facilities.
c) Discharge of NORM scale, sludge and sand to sea from offshore petroleum and gas facilities.
d) Onshore disposal of NORM scale, sludge and sand.

There are no radiation protection dose limits for fauna or flora. The current principle of environmental radiation protection for flora and fauna is based on the ICRP recommendation (ICRP, 1991). The ICRP postulated that if man is protected by certain radiological standards then biota are also protected. This implies that, provided public exposures to radiation caused by NORM discharges or by the NORM waste disposal are less than the 1 mSv/y public limit, then the radiation doses received by biota would also be acceptable.

This concept of environmental radiation protection is applicable to the petroleum industry NORMs because levels of radioactivity in petroleum industry NORMs are low, as are potential operational NORM discharge rates:

- Petroleum industry NORMs are Low Specific Activity (LSA) radioactive materials and their generation rate is low. Due to this fact, radiation exposures and the radiological impact on marine life due to discharges of small volumes of NORMs are likely to be negligible.
- Produced water discharges from onshore oil and gas facilities may elevate radionuclide content in creek and river sediments and may be a cause of potential contamination of drinking water.
- The radiological impact due to discharges of NORMs (offshore as well as onshore discharges) should be estimated for a critical group of the public considering site specific conditions.

NORMs released to the environment can give rise to human radiation doses through a variety of pathways and the potentially highest radiation exposures are estimated (considering all major exposure pathways) to be received by the “critical group of the public” (IAEA, 1986). The critical group should be identified or defined for every oil or gas production facility that releases NORMs to the environment.

The potential for bioaccumulation should be considered in assessing the likely dose for the critical group. In terms of offshore disposal to the sea, the discharge of LSA scale would result in only a marginal increase in radium in sand on the seabed due to dilution and dispersion. This would result in a low incremental radium concentration in bottom feeding marine fauna and subsequently in a negligible public radiation dose.

The low risk through bioaccumulation is illustrated by considering the following example: The public dose limit of 1 mSv would be received after ingestion of the activity of radium-226 and radium-228 of 3,600 Bq and 1,500 Bq respectively (IAEA, 1996). As the combined radium-226 and radium-228 activity concentration in barium sulfate scale is about 550 Bq/g (Table 6) some 4.2 g of scale would have to be ingested to receive the dose of 1 mSv. Even if it was assumed that the radium concentration in the flesh of bottom feeding fish is the same as those living close to a nuclear reactor (about 2 Bq/kg according to S. St-Pierre et al., 1999), an individual would have to consume about a tonne of fish meat in a year to receive the dose of 1 mSv. This is of course a highly conservative assessment where the radium concentration in river sediment and water near to a nuclear reactor is far higher than would be found near an oil or gas facility in the sea.

The IAEA (IAEA, 1988) recommended that provided the maximum personal annual personal radiation exposure is in order of 10 - 100 uSv, the associated radiation health risk is trivial and the practice could be exempted from regulatory control. This risk-based exemption concept also considers that since average annual natural background radiation exposures are about 2,000 uSv, a few percent increase in the annual radiation exposure can be regarded as trivial.

The IAEA (IAEA, 1988; IAEA, 1992) then suggested that principles of exemptions from regulatory control would be applicable to the disposal of very Low Level Radioactive (LLR) wastes at a municipal landfill, LLR effluents and also to recycling or reuse of contaminated steel.

7. DECISION MAKING ON NORM WASTE DISPOSAL

Disposal of NORM waste must satisfy relevant State/Territory and Commonwealth regulations. As petroleum industry NORMs are LSA radioactive materials and the byproduct of mineral extraction, their management and disposal in Australia would be consistent with the radiological management and disposal practice in the Australian uranium mining industry and the heavy mineral sands industry.

For example, the NORM waste disposal in uranium mining depends (amongst other factors) on the specific activity of NORM and on the amount of NORM to be disposed of. More radioactive NORM waste requires more stringent disposal methods than less radioactive wastes (IAEA, 1987a; IAEA, 1994). The IAEA (IAEA, 1987a) states that uranium tailings may have the average radium-226 concentration in the range of 10 – 1,000 Bq/g. This implies that petroleum industry NORMs with the specific activity of radium below this figure could be disposed of in a similar manner as uranium tailings.

The worldwide petroleum industry has developed a number of NORM waste disposal options, the application of which depends on the legislative framework of a given country. Several NORM waste disposal options identified by the American Petroleum Institute (API, 1992) and the Oil Industry International Exploration & Production Forum (E&P Forum, 1988) are briefly outlined below. The suitability of each option depends on the specific activity of waste material and the availability of a suitable site. Factors involved in site selection include the potential for disturbance, any potential for migration of contaminants, and accessibility by man and other animals.

The E&P Forum (1988) reported that in 62% of cases scale was discharged to the sea at the platform location, in 29% of cases scale was disposed of on land (disposal in a dedicated NORM disposal facility, deep well disposal) and in remaining cases scale and contaminated equipment were stockpiled at a controlled area on land.

7.1 Onshore disposal

A number of NORM waste disposal methods are used overseas. Some of the methods are briefly outlined below.

a) Landspreading

This option involves disposal by spreading sludge and scale on the surface of open lands in an area where NORM was not originally present above background levels. It has been proposed that sludge and scale waste with a radium specific activity up to 4.4 Bq/g could be spread on the land surface with a maximum thickness of 0.63 cm. There is no limit to the total area that could be covered (API, 1992) assuming suitable site characteristics.

b) Landspreading with dilution

This option involves mixing the NORM waste within soil using agricultural equipment in an area where NORM was not originally present above background levels. It has been proposed that sludge and scale wastes with a radium specific activity up to 9.6 Bq/g could be spread at a thickness of up to 2.5 cm for dilution with 17.8 cm of soil, yielding a total thickness of 20.3 cm (API, 1992).

c) Burial with unrestricted site use

This option involves burial of NORM with at least 4.6 m of cover which is level with the surrounding terrain, minimising erosion potential. It has been proposed that sludge, scale and equipment with scale wastes with radium specific activities up to 1, 4.8 and 16.8 Bq/g, respectively, could be buried with unrestricted site use below 4.6 m of cover (API, 1992).

Provided the NORM waste contains mainly radium-228, the capping thickness may be substantially thinner than in the case of NORMs containing radium-226. NORMs with radium-228 generate radon-220 gas, which has a very short half-life (55 seconds). Therefore, radon-220 would be completely contained within a disposal site by less than 1 cm thick wet clay capping.

The South Australian and the Northern Territory regulatory authorities have permitted uranium tailings disposal in this manner (Code of Practice, 1982). Uranium tailings are NORM waste of a similar nature to scale and sludge and uranium tailings have a similar specific radium activity. Thus, the uranium tailings disposal method could be used for the disposal of petroleum industry NORMs. Up to 3 m thick waste rock/clay/soil capping is usually constructed above uranium tailings to ensure a negligible flux of radon gas from the capping surface (IAEA, 1992).

d) Commercial oil industry waste facility

Disposal in a commercial oil industry waste facility has been allowed where NORM waste represents less than 7% of the total waste volume. Sludge, scale and equipment with scale wastes with radium specific activities of up to 15, 67 and 229 Bq/g respectively, have been buried in a commercial oil industry waste facility with 4.6 m of cover (API, 1992). There are no such petroleum industry NORM waste disposal facilities in Australia.

e) Commercial NORM waste facility

A NORM waste disposal site is one that is designed to contain NORM for long periods and is deeded to the State for the permanent monitoring and restricted future use after closure. Sludge, scale and equipment with scale wastes with radium specific activities of up to 37, 167 and 2,520 Bq/g, respectively, have been placed in a commercial NORM disposal facility (API, 1992).

f) Commercial low-level radioactive waste facility

A low-level radioactive waste disposal site is defined and licensed under a responsible Government regulatory authority with numerous protective features and restrictions. Sludge, scale and equipment with scale wastes with radium specific activities of up to 1,850, 1,850 and 3,700 Bq/g respectively, have been placed in a low level radioactive waste facility (API, 1992).

Construction of NORM waste disposal facilities as mentioned under d), e) and f) must comply with the principles of the disposal of low specific activity radioactive waste, as outlined by the IAEA. In addition, specialised legislation would be required to establish such disposal facilities.

In Western Australia (WA), the only Australian Low-Level Radioactive (LLR) Waste Disposal Facility is operated by the Department of Environmental Protection (WA EPA) at Mount Walton East. According to enabling legislation, this facility can't accept any LLR waste from interstate. Any WA based petroleum companies must apply to the WA EPA for a disposal permit and the Government charges a fee for the disposal. Disposal of LLR waste is carried out when enough of this waste is available (Hutchinson and Toussaint, 1998; Kvasnicka, 1996b).

g) Plugged and abandoned well

Well abandonment operations provide an opportunity to dispose of NORM wastes. Sludge, scale and tubular goods containing NORM scale with radium specific activities up to 3,700 Bq/g have been placed in wells during plugging and abandonment operations. This method is not frequently used because suitable wells are not readily available.

h) Well injection and hydraulic fracturing

Sludge and scale wastes could be injected or fractured into formations which are isolated geologically and mechanically from drinking water reservoirs. Sludge and scale with radium specific activities up to 3,700 Bq/g could be injected or hydraulically fractured.

7.2 Offshore disposal

Options g) and h) are also used offshore. The option frequently used offshore (especially in the North Sea) is a direct discharge of scale into the sea under suitable sea current conditions. For example, the UK legislation makes provision for the discharge of scale into the sea (SDDRSA, 1960).

i) Discharge of scale into sea

This option requires that scale debris are ground to a suitable size to aid dispersion (typically a maximum particle size of 1 mm) and disposed of to the sea either from offshore installations or from onshore facilities with an ocean outfall (E&P Forum, 1988). It can be demonstrated that the radiological impact due to discharged scale on the sea environment is negligible because:

- Scale is low specific activity radioactive material, ie its radiological impact is limited due to the low levels of radiation it emits;
- Scale particles are dispersed due to currents and wave action and therefore there is a low surface density of scale particles on the sea bed;
- Scale particles discharged into warm sea water would subsequently be dissolved in sea water.

The International Atomic Energy Agency (IAEA) published release rate limits for a sea disposal site for a number of radionuclides, in order to minimise a radiological impact on the marine environment and members of the general public eating fish and other marine species. In the case of radium-226 the annual release rate limit is 410,000 GBq (IAEA, 1986). In the UK, the authorised annual discharges of scale from production platforms are between 5 and 30 GBq of radium (E&P Forum, 1988).

8. PRECAUTIONS IN HANDLING NORM

Scale and some other NORMs are low specific activity (LSA) radioactive materials. Because scale contains radium and its short-lived decay products, scale and other NORMs can (depending on the radium specific activity) generate intensive gamma radiation fields that are a source of personal external gamma radiation exposures. If NORM particles and/or radon gas with its decay products in air are inhaled, a person would receive internal radiation exposures. In order to manage personal radiation exposures a NORM Radiation Management Plan ought to be established. This plan is to ensure that personal radiation exposures are maintained not only below the relevant annual radiation exposure limit, but as low as reasonably achievable (ALARA).

8.1 Australian radiation protection standard and practice

The National Health and Medical Research Council (NHMRC) recommended an occupational effective dose limit of 20 mSv (milliSievert) per year, averaged over a period of 5 consecutive years, as well as an effective dose limit in a single year of 50 mSv. Additionally, an annual public effective dose limit of 1 mSv was recommended (NHMRC, 1995). The same dose limits were also recommended by the International Commission on Radiological Protection (ICRP) (ICRP, 1991).

When solid materials on petroleum and gas production facilities are in the category of NORMs, it is required that a relevant Government regulatory authority is notified about the situation and it may be necessary for the facility to be licensed (NHMRC, 1995; Code of Practice, 1987).

It needs to be mentioned that there is no uniform view in State, Territory and Commonwealth regulations on the radium specific threshold activity in NORMs below which materials would be classified as "not radioactive".

It is also necessary to carry out radiation surveys and assessments to estimate the highest average personal radiation exposure of the most exposed group of facility personnel during normal operations. If the maximum annual radiation dose exceeds the annual public dose limit of 1 mSv and/or if there is a potential to receive elevated radiation exposures, then specific precautions for handling NORM must be put in place. The precautions will depend on the above-mentioned maximum annual dose and on potential radiation exposures (Code of Practice, 1987). If the maximum personal annual exposure is below 5 mSv, no personal radiation monitoring may be required and radiation exposures of exposed work categories are estimated through the results of regular radiation surveys.

8.2 Personal exposures due to NORM radiation in petroleum and gas production

Natural radionuclides in NORMs emit alpha, beta and gamma radiation and thus NORMs can be a source of both external and internal radiation exposure.

During routine operations, workers are exposed to external gamma radiation. The external gamma radiation passes through the steel walls of pipes and vessels and the dose rate at the surface of oil production pipes and vessels could be in order of tens of microSievert per hour.

During shutdowns and maintenance periods, workers may also be exposed to inhaled radon gas and NORM dust and to external gamma radiation (radon gas isotopes are in bold in Tables 2 and 3). The external gamma radiation dose rate inside separators is higher than at external walls because external gamma radiation inside the separator is not shielded by its steel walls (Kvasnicka, 1996a).

Considering that the specific activity of radium in barium(radium)sulfate scale can be in excess of 500 Bq/g (Kvasnicka, J., 1996a), only a hundred milligrams of inhaled scale dust could cause a radiation dose in excess of the annual public dose limit of 1,000 μSv (1 mSv). Even though only a small fraction of radon gas is released from scale (Kvasnicka, 1996a; Rood, A. S. et al., 1998), the radon gas concentrations in non-ventilated vessels with scale, sludge or sand could cause elevated radiation exposures. Potential inhalation of NORM dust and radon gas makes the management of radiation exposures of workers during shutdowns different from the management of radiation exposures during routine operations.

8.3 Management of routine operation exposures

Routine operations are those day-to-day operations that do not include any vessel entries, dismantling of facility components, handling of LLR waste, etc. Considering that no personnel would come in direct contact with NORMs during routine operations, it is only necessary to manage external radiation exposures. The most important components of the management of routine radiation exposures are as follows:

- Training of facility personnel in radiation protection.
- External radiation surveys of areas of the facility where NORMs have been detected (Code of Practice, 1987).
- Assessment of the average annual radiation dose of the most exposed group of employees (Code of Practice, 1987).
- Identification of the facility components contaminated with NORMs.

It has been demonstrated that provided the above management principles of radiation exposures are implemented, annual radiation exposures can be maintained below the public limit of 1 mSv/y (1,000 μSv/y) (Kvasnicka, 1996a). Under such low exposure conditions it is not required to carry out personal external dose monitoring by thermoluminescent badges (TLD badges) (Code of Practice, 1998; NHMRC, 1995; IAEA, 1996).

8.4 Management of shutdown, maintenance and other non-routine operation exposures

Any activity of facility personnel which is not in a category of routine operations and/or for which there is the potential to receive elevated personal radiation exposures, requires special management. The most important aspects of NORM management include:

- Radiation safety induction of staff personnel and contractors.
- Radiation surveys of the workplace before the job begins.
- Job planning, which should consider relevant work procedures/instructions.
- Personal monitoring may be considered depending on the task, personal protective equipment, radiation field, etc.
- Vessel ventilation to minimize the build up of radon gas.
- Keeping NORMs wet during the task to minimize generation of dust.
- Personal protective equipment (rubber gloves and boots, disposable overalls, face masks, etc.).

The petroleum industry has in place an advanced safety management system to control a spectrum of occupational hazards. NORM Work Procedures and Instructions to control personal radiation exposures are based on similar philosophies as those used in Work Procedures to control other hazards in the industry.

It is also important that the staff of petroleum production facilities are trained to carry out basic radiation protection monitoring and assessments. This contributes to a better understanding of radiation protection issues by staff and to more effective NORM management.

Work Procedures and Instructions should emphasise that “As Low As Reasonably Achievable” (ALARA) principles of radiation protection should be adhered to during all operations where workers could be exposed to higher doses of nuclear radiation emitted by NORMs. Work planning and the conduct of all work should include general aspects of ALARA (see the ALARA check list below) to ensure that doses received by all personnel are low.

8.5 ALARA Checklist

The ALARA checklist includes the most important tasks, which are observed by the Facility Superintendent, supervisors and all personnel who handle NORMs and work in areas where exposed NORMs are present. It also sets a general concept of radiation protection for operations which involve the handling of NORMs. The ALARA checklist for the management of radiation exposures in the offshore petroleum industry includes:

- Prior to the commencement of work, the work area, pipework and all components shall be checked for radiation levels.
- Based on the measured radiation levels, the radiation safety specialist or a suitably trained and instructed member of the facility shall assess the work situation and shall recommend the appropriate personal protection measures to be applied.
- Prior to the commencement of work, all personnel engaged in the task shall be informed of the potential hazards and the safe work practices.
- The area where NORMs are to be handled is to be marked and only a necessary number of personnel shall be present within this area at all times.
- Any person shall spend only a necessary amount of time within a marked area.
- All personnel shall be instructed about locations with the highest dose rates so they can avoid unnecessary exposures.
- The physical handling of NORMs shall be kept to a minimum.
- All vessels shall be sufficiently ventilated prior and during vessel entries and NORMs shall be kept wet.
- All personnel involved in handling NORMs shall be equipped with appropriate personal protective equipment.
- External personal doses of the most exposed personnel shall be monitored by electronic radiation monitors provided.
- All personnel involved in handling NORMs shall observe good personal hygiene practice.
- NORMs and material contaminated by NORMs which are classified as radioactive material shall be contained and labeled.

9. COMMENTS ON NORMS REGULATION

Occupational health and safety issues in the offshore petroleum industry are regulated by the Commonwealth *Petroleum (Submerged Lands) Act 1967*. This Act does not address NORM issues in required detail. The onshore petroleum industry is regulated by State/Territory governments, which have special legislation for the regulation of conventional occupational health and safety issues in the petroleum industry. This legislation has not been developed to deal specifically with petroleum industry NORMs. As a consequence of this, petroleum industry NORM issues are dealt with using the legislation originally developed for sealed radioactive sources and/or radioactive materials used in hospitals and research.

The rationale behind this notion is based on the fact that petroleum industry NORMs and NORMs in the uranium mining and heavy mineral sands industries are in a similar category with respect to the content of natural radionuclides and their specific activity. Furthermore, the NORM waste in the petroleum/natural gas industry and in uranium mining and milling and heavy mineral sands processing is a byproduct of similar primary industry activities, namely the extraction of minerals.

During normal operations of petroleum and natural gas-producing facilities, NORMs are mostly contained within pipes and vessels. Therefore, the radiation safety management in the petroleum industry is more straightforward than in the uranium mining and heavy mineral sands industries.

The petroleum industry generates significantly less radioactivity and much smaller amounts of solid NORMs than the above-mentioned industries. It can be implied that the NORM waste management and the NORM waste disposal in the petroleum industry should be even more straightforward than in uranium mining and milling and heavy mineral sands processing.

10. GLOSSARY OF TERMS AND ABBREVIATIONS

Absorbed dose: Absorbed dose is the energy of radiation absorbed per unit mass. The unit of the absorbed dose is the Gray (Gy).

Activity: In nuclear physics and radiation protection, activity has been used to quantify an amount of radionuclides in a radioactive source, a radioactive sample or radioactive material. The activity unit is Becquerel, Bq. If the activity of a radioactive source or radioactive material is 1 Bq, one radionuclide decays per second (for example the activity of 1 microgram of radium-226 is 37,000 Bq ie in 1 microgram of radium-226 37,000 radium atoms decay every second).

ALARA: As Low As Reasonably Achievable (ALARA) is a principle of radiation protection according to which the level of personal exposures and the number of exposed personnel should be kept ALARA. This implies that the radiation protection should be optimised.

Alpha radiation (particle): Alpha particle (α) is the nucleus of helium that contains two protons and two neutrons. Alpha particles have a very low capability of penetrating matter because they are relatively large and positively charged.

Background radiation: In this context the background radiation is mainly the cosmic radiation and the terrestrial gamma radiation emitted by naturally occurring radionuclides in naturally occurring materials (soil, rocks, building material, etc.).

Beta radiation (particle): Beta particle (β) is a fast moving electron originating in a nucleus that decays. Emission of beta radiation from the nucleus is accompanied by emission of gamma radiation. Beta particles have a low capability of penetrating matter. Beta particle penetrates through matter further than alpha particles because they are smaller and carry only half of electrical charge.

Becquerel (Bq): Becquerel is the unit of activity of radioactive materials. One Becquerel is equivalent to one radioactive decay per second.

1	μBq	=	0.000001 Bq	(μ = micro)
1	mBq	=	0.001 Bq	(m = milli)
1	Bq	=	1 Bq	
1	kBq	=	1000 Bq	(k = kilo)
1	MBq	=	1000000 Bq	(M = Mega)
1	GBq	=	1000000000Bq	(G = Giga)

Collective dose: Collective dose is the sum of personal radiation doses of all exposed individuals.

Effective dose: The effective dose is the sum of the weighted equivalent doses in all tissues and organs of the human body. The effective dose unit is the Sievert (Sv).

Equivalent dose: Equivalent dose is in this context the radiation dose. The unit for effective dose (radiation dose) is Sievert (Sv).

Exempt specific activity: The exempt specific activity is the specific activity of a given radionuclide in any material below which a radioactive substance is exempt from registration or licensing and requirements of radiation protection regulations. For example IAEA Safety Series No. 115 recommended the exempt specific activity for radium-226 and radium-228 as 10,000 Bq/kg. The concept of the exempt specific activity is usually defined in regulations.

Gamma radiation: Gamma radiation is electromagnetic radiation similar to radio or microwave radiation. Nevertheless, the energy of gamma radiation is much higher. As the gamma radiation is not electrically charged, it penetrates through matter much further then alpha and beta radiation.

Gray (Gy): Gray is the special name for the unit of absorbed dose. One gray is equal to the absorbed energy of one joule per kilogram.

Half-life: Is the time during which half of the atoms of a particular radioactive substance (source) decay.

IAEA: International Atomic Energy Agency (IAEA) is a body under the United Nations Organisation involved in developing international radiation protection standards.

ICRP: International Commission on Radiological Protection (ICRP) is an independent international body involved in developing radiation protection recommendations.

Ionisation: Ionisation of molecules and atoms of matter by nuclear radiation is the process during which electrons are ejected from the molecule/atom and positively charged ions are created.

LSA radioactive material: Low Specific Activity (LSA) radioactive material is such material which specific activity is limited by its nature. For example, uranium ore contains natural uranium forming a given uranium-bearing mineral in which uranium is a part of a molecule of the mineral. This means that the amount of uranium (uranium activity) in one kilogram of the mineral can't exceed its given chemical content.

NORM: Is naturally occurring radioactive material. In the petroleum and gas production the most common NORMs are scale, sludge, radioactive sand, lead deposits, very thin films of radon decay products, etc.

Occupational dose limit: The annual dose limit for radiation workers is 20 mSv.

Public dose limit: The annual dose limit for members of the public exposed to nuclear radiation is 1 mSv (smaller radiation dose unit is microSievert, μSv, 1 mSv = 1000 μSv).

Radiation dose: Radiation dose is the energy of radiation absorbed by 1 kg of irradiated material, tissue, etc. corrected for biological effectiveness of radiation. The radiation dose unit is Sievert (Sv).

Radiation exposure: Radiation exposure is the process of being exposed to ionising radiation.

Radioactive contamination: Radioactive contamination is the contamination of any material, surface or environment or of an individual by radioactive substances. The surface contamination unit is Bq/m^2.

Radiation health risk: As radiation exposures of human beings may increase a rate of cancer development, radiation dose has been linked with the fatal cancer risk. Millisievert, mSv, is a radiation dose unit. A linear relationship has been assumed between the radiation dose and the fatal cancer risk. Thus a constant cancer risk conversion factor of 0.00004 per 1 millisievert has been used in radiation protection for adult workers. This means that if 25,000 workers receive the radiation dose of 1 mSv, 1 in this group may develop a fatal cancer (ie the risk factor is 1 in 25,000).

Radioactive substance: Radioactive substance is any substance that contains one or more radionuclides, the activity or concentration of which may be significant from radiation protection point of view. Threshold activity levels are usually defined by national regulations. For example, the Code of Practice for the Safe Transport of Radioactive Substances (1990) defines radioactive material as any material having a specific activity greater than 70,000 Bq/kg.

Radionuclide: Is an unstable element that decays spontaneously, emitting radiation.

Secondary cosmic radiation Secondary cosmic radiation is produced when galactic cosmic radiation collides with atoms of air (oxygen, nitrogen and hydrogen) in upper layers of the atmosphere. The sun also emits cosmic radiation but this radiation has much lower energy than galactic cosmic radiation and thus generates less secondary cosmic radiation in the Earth's atmosphere than the galactic cosmic radiation.

Sievert (Sv): Sievert is the special name of the unit of equivalent dose (radiation dose) or effective dose. Sievert is a large unit and thus smaller units are used in radiation protection:

1 mSv = 0.001 Sv (m = milli)
1 μSv = 0.001 mSv = 0.000001 Sv (μ = micro)

Specific activity: Specific activity is the activity per one kilogram of any substance. The specific activity unit is Bq/kg.

Terrestrial radiation Terrestrial nuclear radiation is mainly emitted by natural radioactive atoms of *uranium, thorium, radium* and other atoms that are present in all naturally occurring materials around us. Also natural *potassium* is slightly radioactive. Low concentrations of the above natural radioactive atoms are also present in tissues of our bodies.

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