

Managing naturally occurring radioactive material and mercury in petroleum and gas sites

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Resources Safety & Health Queensland

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1.0 Summary

Resources Safety and Health Queensland's (RSHQ) Petroleum and Gas Inspectorate regulates safety in the petroleum and fuel gas industry in Queensland under the *Petroleum and Gas (Production and Safety) Act 2004*.

The demand for natural gas in Queensland is met from large reserves of coal seam gas and relatively small conventional gas reserves.

This guideline was developed to help operators of petroleum and pipeline facilities in Queensland to achieve an acceptable level of safety and health risk to people during operations where there is the potential for occupational exposures to naturally occurring radioactive material (NORM) and mercury (Hg).

NORM and Hg contamination are an inevitable by-product of petroleum exploration and production. NORM and Hg can accumulate in petroleum and gas infrastructure.

The Act requires the operator of an operating plant to develop a safety management system (SMS) for the operating plant to ensure that risks are managed to 'as low as reasonably practicable' (ALARP).

Any company working in the petroleum industry should have a comprehensive SMS to address all aspects of managing NORM and Hg. Where a risk assessment indicates significant potential for exposure to NORM and Hg, they should be managed together.

All pipeline and associated processing infrastructure residues should be treated as containing NORM and Hg until the status can be confirmed by measurement.

NORM and Hg in Queensland's gas industry

Data from companies operating in Queensland's gas industry indicates that NORM and Hg contaminant concentrations within infrastructure show considerable variation.

Worker exposure to these contaminants is typically infrequent, as activities that involve potential exposure to NORM and Hg are typically related to process unit shutdowns and openings.

Workplace monitoring undertaken by gas companies during identified high-potential exposure activities found that NORM and Hg vapour exposures were significantly below exposure limits set in the *Radiation Safety Act 1999* and the Environmental Protection Regulation 2019 respectively.

Pigging and other open-pipe activities can create potential for substantial contact with NORM and Hg vapour concentrations in piping and vessel contaminants, as well as pipeline contaminants.

The presence of Lead-210 (Pb-210) has been found in pigging residue samples from pipelines, with radioactive activity concentrations occasionally exceeding thresholds above which material is regulated as a radioactive substance under the *Radiation Safey Act 1999*.

Similarly, pigging residue samples from pipelines have contained Hg at levels that would classify them as category 2 regulated waste or higher. Such levels can trigger the need for a hazardous substances management plan under the Environmental Protection Regulation 2019.

Inhalation is the primary route of exposure for NORM and Hg. Hg can also be absorbed through the skin. Skin contamination can result in ingestion of both substances. This means good housekeeping, personal hygiene, and appropriate personal protective equipment (PPE) selection and use are critical for controlling exposure.

2.0 Preface

2.1 Queensland petroleum industry

Conventional natural gas is found and produced with other petroleum products, such as oil. Demand for natural gas in Queensland is met from large reserves of coal seam gas (CSG), currently from the Bowen and Surat basins, and relatively small conventional gas reserves. There are significant differences in the way the gas is extracted and the location of the reserves in Queensland. Although the location and production methods are different, natural gas produced from conventional gas fields and coal seam gas fields is the same product. Find out more about Queensland's gas industry at Business Queensland.

The petroleum and gas industry in Queensland is dominated by production of CSG (> 90%) and liquid natural gas (LNG). Best practice information from the petroleum industry is mostly based on experience with conventional oil and gas fields. This guidance is targeted to the Queensland petroleum and gas industry, including coal seam gas.

2.2 Obligations under Queensland legislation

Obligations relating to safety and health in the petroleum and gas industry in Queensland are detailed in:

- Chapter 9 of the *Petroleum and Gas (Production and Safety) Act 2004*
- Petroleum and Gas (Safety) Regulation 2018.

These obligations aim to protect the safety and health of persons at facilities and ensure that the risk of injury or illness to any person resulting from operations is at an acceptable level.

Neither the Act nor the Regulation refer specifically to NORM or hazardous substances. Obligations relating to NORM are detailed in the *Radiation Safety Act 1999* and the Radiation Safety Regulation 2021.

For a risk to a person to be at an acceptable level, operations at a facility must be carried out so that the level of risk from the operation is not only within safety norms, but also as low as is reasonably practicable (ALARP).

The *Petroleum and Gas (Production and Safety) Act 2004* requires the operator of an operating plant to make or adopt a safety management system (SMS) that complies with section 675, or section 705C if the plant is used to explore for, extract, produce or release petroleum within coal seams.

The SMS must:

- contain all information relevant to the gas system and the activity being undertaken
- identify relevant hazards, assess and manage risks
- identify exclusion zones, emergency equipment and evacuation routes
- detail operating procedures for the activity including emergency management
- specify any roles, responsibilities and training requirements.

The SMS must be specific to the operating plant and each stage of the plant, including commissioning, operation, maintenance, modification and decommissioning.

As part of an effective SMS, there are certain statutory positions and obligations that must be fulfilled, including an executive safety manager, an operator and a site safety manager.

Where a CSG operating plant is associated with coal mining, the requirements of the *Coal Mining Safety and Health Act 1999* and the Coal Mining Safety and Health Regulation 2017 may apply on site. Section 29 of the *Coal Mining Safety and Health Act 1999* requires that the risk of injury or illness to any person resulting from coal mining operations be at an acceptable level and ALARP. Section 62 of the *Coal Mining Safety and Health Act 1999* requires a safety and health management system to also be in place to effectively manage risk.

In certain circumstances, the Queensland *Work Health and Safety Act 2011* and the Work Health and Safety Regulation 2011 may apply to a gas industry site. There is an approved *Model Code of Practice: Managing risks of hazardous chemicals in the workplace*, which can be used for management of Hg. Under the *Work Health and Safety Act 2011*, a person conducting a business or undertaking has the primary duty to ensure, so far as is reasonably practicable, that the health and safety of workers and other persons are not put at risk from work carried out.

2.3 Alignment with radiation protection requirements

This guideline aligns, where appropriate, with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) system of radiation protection, including RPS9 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing.

The code of practice establishes requirements for radiation protection in mining and mineral processing industries to manage the protection of human health and the environment from the harmful effects of radiation exposures arising from the radioactive waste resulting from these activities.

This guideline also draws on information in the Guideline for management of Naturally Occurring Radioactive Material in metalliferous mines, which aligns with RPS9. Additionally, this guideline also draws on information in the ARPANSA RPS15 Safety Guide for the Management of Naturally Occurring Radioactive Material. RPS15 provides information on the best practice management of NORM to aid in assessing the need for radiation protection measures. It includes a detailed annex for the petroleum and gas industry.

Transport of NORM from a petroleum or gas facility must comply with the *Radiation Safety Act 1999* and Radiation Safety Regulation 2021, which require compliance with the ARPANSA Code for the Safe Transport of Radioactive Material.

This guideline will assist in achieving compliance with the *Petroleum and Gas (Production and Safety) Act 2004* and the Petroleum and Gas (Safety) Regulation 2018 as well as the *Radiation Safety Act 1999* and the Radiation Safety Regulation 2021, in so far as the safe management on naturally occurring material is concerned.

3.0 Purpose

NORM and Hg may pose a risk to workers' health. Like any other hazard at a petroleum or pipeline facility, these hazards and associated risks must be managed.

This guideline will assist operators to understand their obligations in developing and implementing a SMS by providing guidance for a risk management approach and the minimum requirements for a NORM and Hg management plan for inclusion in the overall SMS for a petroleum or gas facility.

This guideline applies to all operations associated with processing and transporting (in pipelines) petroleum and gas.

4.0 Origin of NORM and Hg in infrastructure

In the petroleum and gas industry, there are elevated levels of pollutants[1], such as Hg, NORM contamination and the heavy hydrocarbons within which NORM is comingled. Individual hazards should not be considered in isolation. Risk assessments and measures to mitigate risks should consider all hazards.

NORM is ubiquitous in the environment. It is widespread in sand, clay, soil, rock, as well as many ores, minerals, commodities, products, by-products, recycled residues, and even in our devices. The radioactivity of coal depends on the type of coal and its location. The radionuclides identified in petroleum and gas streams belong to the decay chains of naturally occurring primordial radionuclides uranium 238 (U-238) and thorium 232 (Th-232).

Hg occurs naturally in soil and rock, including the formations that comprise petroleum reservoirs and coal seams. Mercury sulphide (HgS) is the most common form of Hg in nature. In its various forms it can cycle between the atmosphere, water bodies and sediments. It is a trace contaminant found in hydrocarbon reservoir fluids and coal globally, with concentrations varying by region. Research notes that Hg concentrations are highest in regions of high volcanic activity, including Northern and Eastern Australia (Crafts and Williams 2020). Processing plants that use raw materials with higher levels of Hg as feedstocks, may see increased levels of elemental Hg, as opposed to HgS. When mixed with hydrocarbons, elemental Hg behaves very differently from how it does in air. It tends to show an apparent vapour pressure similar to light hydrocarbons, such as propane and butane. In natural gas, Hg is present mostly in its elemental form.

The petroleum industry uses pipelines to transport petroleum and gas to processing plants and then to market. Gas processing facilities are typically large, purpose-built plants supported by extensive infrastructure and designed to operate for decades. Gas processing consists of several steps to produce a sale gas (pipeline quality) from the raw natural gas.

Any operation in which material is extracted from the earth and processed can potentially concentrate NORM and Hg in product, by-product or waste (residue) streams. NORM and Hg contamination is an inevitable by-product of petroleum exploration and production.

NORM can accumulate at various locations during petroleum and gas production. Components including wellheads, separation vessels, pumps, pipelines, and other processing equipment can become contaminated, and NORM can accumulate in the form of sludge, scale, scrapings, and other waste media. NORM bearing substances are commonly identified during maintenance operations on gas pipelines in Australia.

Hg may also accumulate slowly over time in process equipment and may be present in various waste streams or internal metal surfaces in some equipment from years of accumulation. This is relevant for areas with poor ventilation or circulation. Hg is adsorbed onto steel surfaces and porous scale deposits in gas transmission.

[1] Process fluids can also contain benzene, toluene, ethyl benzene and xylenes. Hydrogen sulphide is said to be not an issue in the Australian industry.

5.0 NORM and Hg hazards

5.1 NORM

NORM is an ionising radiation hazard that poses a potential long-term cumulative chronic risk if a person is exposed to it on a regular basis. It can have impacts for both worker health and public safety and is regulated under the *Radiation Safety Act 1999* and the Radiation Safety Regulation 2021.

There are 3 common types of ionising radiation—alpha, beta and gamma.

Occupational exposure to NORM typically occurs due to:

- gamma radiation (high-energy electromagnetic rays) from deposits inside equipment exposing workers outside the equipment
- disruption of NORM deposits during maintenance work on equipment that has been taken offline.

Irradiation from NORM can be from internal or external sources.

Internal sources[2] are where the material emitting radiation is located inside the human body. This occurs mainly due to inhalation or ingestion of material containing radionuclides such as dust particles or mist.

External sources are when the material emitting radiation is located outside the human body. This occurs in proximity to the source and decreases with distance, dropping to ambient background levels at a sufficient distance, usually a few metres, from the material or contaminated equipment.

5.2 Hg

Hg is a recognised toxin and is harmful to workers and the environment. Hg can contaminate most areas of the production plant through physical adsorption, potentially impacting process system safety[3] and creating hazardous wastes through operating life and decommissioning.

Liquid (elemental) Hg vaporises readily at room temperature. Inhalation of Hg vapour is the primary route of entry to the human body. However, the metal and its compounds can be absorbed through the skin. In cases of insufficient personal hygiene, ingestion may also be a route of exposure.

Exposure to Hg can result in adverse human health effects ranging from acute to chronic. It accumulates mainly in the brain and kidneys. The main target organ is the central nervous system (including the brain), although kidney damage may also occur with some Hg salts. Some people may develop sensitivity to Hg where their skin reacts even to the vapour, causing contact dermatitis. Hg also tends to accumulate in foetal tissues and in breast

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[2] Alpha radiation has the greatest effect for internal exposures.

[3] Liquid mercury in contact with aluminium can induce serious and rapid failures. If mercury is present in the liquid form (e.g. during process interruptions or plant shut down) it can cause catastrophic damage in aluminium heat exchangers in an LNG plant (Coade & Coldham, 2006).

milk, with possible adverse consequences for foetal and child growth. Recent data indicates that Hg can affect both male and female reproduction, and lead to children with abnormal cognitive and physical functioning (Firth & Capil, 2024).

6.0 Risk management

NORM and Hg exposure should be managed to avoid, or at least minimise, potential impacts on workers and the environment. This guideline focuses on the potential impacts of NORM and Hg exposure in the petroleum industry on worker health.

A systematic risk management approach is recommended:

1. Identify hazards and find out what could cause harm.
2. Assess risks, if necessary (this step may not be required if dealing with a known risk with known controls).
3. Follow the hierarchy of controls to eliminate risks as far as reasonably practicable or implement the most effective control measures that are reasonably practicable in the circumstances.
4. Review control measures to ensure they are working as planned and remain effective over time.

6.1 Hazard identification and risk analysis

The amount of NORM or Hg in a plant's streams and products is related to the NORM and Hg content of the plant's feedstock. Each plant should be aware of the NORM and Hg level of its incoming feedstock.

According to ARPANSA's RPS9, significant radiation exposures can arise from precipitates, scales or sludges from ponds that may accumulate in recovery of petroleum or natural gas. This can lead to individual radiation doses greater than the limit for members of the public and radiological control measures may be required.

NORM in the petroleum industry poses a controllable risk to workers, particularly during maintenance, waste transport, processing and decommissioning. The nature of the hazard depends on the concentration and type of radionuclides in the NORM. For example, Pb-210 deposits and films, as a beta emitter, is only a concern when pipe internals become exposed, however Ra-226 deposits and films can pose more significant problems. For the naturally occurring radionuclides, the most common modes of entry to the body are via inhalation and ingestion. Internal radiation can be a risk if no controls are established during shutdowns or during periods where systems are open. Internal exposures can be minimised with good ventilation and hygiene practices.

While contaminated plant or equipment may expose workers to external radiation from closed systems during normal operation, external exposure due to NORM in the petroleum industry is generally low enough that workers remain under the annual dose limit without additional protective measures.

The International Association of Oil and Gas Producers Managing Naturally Occurring Radioactive Material (NORM) in the oil and gas industry report (IOGP, 2016) states that even for the highest radon 222 (Rn-222) concentrations in natural gas, no external radiation at the outside of transmission lines can be measured.

The presence of Pb-210 as the parent radionuclide has been determined in pigging residue samples from petroleum and gas pipelines, with activity concentrations occasionally exceeding thresholds, above which material is regulated under the *Radiation Safety Act 1999* to address its effect on workers and the environment. While radium 226 (Ra-226) is not present naturally as a gas, if any moisture is present within gas pipelines it is possible that Ra-226 (and isotypes in its decay chain) could also be present as a dissolved particulate within any moisture.

Because of the low vapour pressure of Hg compounds, airborne exposures will most likely be highest during confined space entry or when the contaminated equipment is heated, for example during welding. In addition, workers could have skin contact with elemental Hg and Hg salts during opening or entry of equipment or handling contaminated parts.

According to the International Petroleum Industry Environmental Conservation Association Mercury management in petroleum refining good practice guide (IPIECA 2014), workers in Hg adsorption process units could potentially have an elevated risk of skin exposure during adsorber change-out, draining equipment in preparation for opening, draining low points in vessels or piping and other tasks involving opening. Workers could be exposed to Hg through inhalation of Hg vapours and dermal absorption of Hg during maintenance work, inspection activities and decontamination during shutdowns.

Activities that involve potential exposure to NORM or Hg are typically related to process unit shutdowns and openings.

To determine if the level of risk is within acceptable safety limits and ALARP, operators must consider:

- the likelihood of injury or illness to a person from the risk
- the probable severity of the injury or illness
- whether or not the risk is avoidable by reasonable means.

The Simplified Occupational Hygiene Risk Management Strategies guidebook (Firth et al 2020) provides tools to conduct risk management for occupational health hazards.

Risk assessment for NORM and Hg should include and consider where appropriate:

- radionuclides (for NORM), chemical form (for Hg), and their quantities
- the nature of proposed operations and activities
- routes of exposure (external radiation exposure, inhalation of dusts containing long-lived alpha and beta radiations, radon or Hg vapour, and ingestion due to poor hygiene)
- qualifications and competencies of people for assessing and quantifying the risks associated with NORM and/or Hg
- what controls might be used
- worker's exposure data, which can be measured by sampling the work environment
  - for NORM – collecting personal dust or measuring external radiation levels using personal radiation dosimeter
  - for Hg—collection of personal dust, mist or vapour[4]
- changes to plant, processes or substances
- extant legislation and changes to legislation
- new knowledge about NORM and/or Hg hazards or controls.

The approach to developing a risk management plan begins with characterising the exposure situation, comparing personal exposure to the radiation exposure limit or Hg workplace exposure limit (WEL). Wipe sampling can be used to identify where there are significant levels of NORM or Hg contamination.

[4] Several methods are available for monitoring mercury in the workplace, all of which rely on the fact that mercury can be trapped and measured as a vapour. Refer to 'Risk monitoring' section. Detail is provided in Firth & Capil (2024).

6.2 Exposure limits for NORM

Radiation protection in the field of NORM is achieved by controlling the exposure of people and the environment to low doses of radiation.

Assessing and managing risks associated with exposures to NORM in the petroleum industry can be complex but must start with analysing the material to identify the amount of radioactivity it contains. NORM levels are typically expressed in Becquerels (Bq), which indicates the level of radioactivity generally. While not an exposure limit for the purposes of defining the potential for human health impact, the activity concentration (in Bq/g) can assist in quantifying the extent of the hazard, and the extent to which the radioactive material is regulated under the *Radiation Safety Act 1999*. For example, if the concentrations of radioisotopes in the material are sufficiently high, licensing provisions may be triggered. Whereas if the concentrations are below that trigger level, as in the case for most circumstances, the regulatory requirements are limited to ensuring exposures are appropriately managed.

In Queensland, under the *Radiation Safety Act 1999*, all material is considered radioactive material because all material contains a small concentration of radioisotopes. Radioactive material is considered a radioactive substance if the concentration is above a certain level as prescribed in the legislation. For example, a material containing Pb-210 is considered a radioactive substance if the concentration of Pb-210 and its decay progeny exceeds 100 Bq/g.

Under the *Radiation Safety Act 1999*, the occupational exposure limit (effective dose) is 20 mSv/year averaged over 5 years, with a further provision that the effective dose not exceed 50 mSv in any single year. For members of the public, the exposure limit is 1 mSv/year. In addition, when a pregnancy is declared, the exposure limit for members of the public applies for the embryo or foetus.

The risks posed by exposure to radioactivity are linked to the amount of energy exposed tissues absorb. The amount of absorbed energy alone is insufficient to determine the risk, and any risk assessment must consider how much biological damage is expected from the absorbed dose. Different types of radiation have different damaging properties and different tissues have different susceptibility to damage. Taking these factors into consideration provides the effective dose, measured in sieverts per year (Sv/year). The effective dose cannot be directly measured. It is necessary to use methods and quantities that enable a conservative estimation of the effective dose.

For more detailed information on the health effects of ionising radiation, refer to the ARPANSA RPS F-1 Fundamentals for Protection Against Ionising Radiation. It explains how radiation protection, safety and security can work individually and collectively to manage radiation risks. If further information is required, please contact the Radiation Health Unit, Queensland Health.

6.3 Exposure limits for Hg

As with NORM, assessing and managing risks associated with exposures to Hg in the petroleum industry can be complex but must start with measuring contamination. While not an exposure limit for the purposes of defining the potential for human health impact, the definitions for regulated waste in mg Hg/kg for a substance can be used to define the substance as being hazardous. Likewise, µg Hg/L for a liquid can be used to define the liquid as being hazardous.

Commercial or industrial wastes containing certain hazardous properties are classified as regulated waste in the Queensland Environmental Protection Regulation 2019 and are subject to more stringent management requirements than other waste, due to their potential of higher risk to the environment or human health. Hg and Hg compounds are classified as category 1 regulated waste (highest risk). At less than 80 mg Hg/kg contamination, a solid waste is not regulated, but at 80 to 320 mg Hg/kg it is considered category 2 regulated waste and at greater than 320 mg Hg/kg it is considered category 1 regulated waste. At greater than or equal to 6 µg Hg/L, a liquid is classified as being category 1 regulated waste.

To determine human health hazard, the WEL for airborne Hg must be used. The WEL for Hg vapour and inorganic Hg compounds is 0.025 mg/m^3, expressed as a time-weighted average (TWA). Hg and its compounds also have a notation for skin absorption. The Environmental Protection Regulation 2019 outlines that personal exposures must not exceed the WEL value.

In addition, inorganic Hg is a scheduled hazardous substance. Health surveillance may be required if the risk from exposure to Hg is found to be significant, and any affected workers should immediately be removed from further exposure. The preferred indicator of elemental Hg absorption is its concentration in urine. A urine concentration of 35 µg Hg/g creatinine,[5] from a sample taken pre-shift, can be used as the biological exposure indicator (BEI) level. Levels above the BEI level can indicate that PPE is ineffective, or it is not being used effectively. The Safe Work Australia *Health monitoring guide for mercury (inorganic)* provides detailed information for registered medical practitioners to carry out or supervise health monitoring for workers potentially exposed to Hg.

6.4 Complying with exposure limits

A comparison of workplace exposures with an applicable exposure limit can be used to help ensure worker risk is minimised, and within regulatory limits. Compliance monitoring requires the use of personal monitoring data. A statistically valid exposure dataset needs to be collected (refer to Section 6.7 Risk monitoring6.7) then be statistically evaluated against the applicable exposure limit. The Australian Institute of Occupational Hygienists *Occupational hygiene monitoring and compliance strategies* guidebook provides tools to conduct compliance monitoring.

Available data from Queensland based petroleum companies indicates that Hg contamination levels are highly variable, ranging from less than 0.05 to 1,200 mg/kg for solids, with an average concentration of 112 mg/kg, meeting the criteria for at least a category 2 regulated waste (refer to Section 6.3

[5] Other biological exposure levels (standard equivalents) that have been published range from 20 to 30 µg/g creatinine.

Exposure limits for Hg). However, data from a small group of Queensland-based petroleum companies determined employee exposure to Hg was well below the shift-adjusted WEL.

It is important to note that while regulatory requirements specify exposure standards to protect worker health, there is also a requirement that workplace exposures are ALARP. If monitoring indicates exposure is below the acceptable limit, efforts should continue to reduce the worker's exposure to ALARP.

Given the variability that typifies NORM and Hg contamination of gas distribution infrastructure, all pipeline and associated processing infrastructure residues should be treated as containing NORM and Hg.

6.5 Approach for assessing and managing occupational exposures

Assessing and managing risks associated with exposures to NORM and Hg can be complex but must start with measurements of contamination. The approach to assessing risk must be established by an appropriately competent person, like an occupational hygienist.

To determine if a facility is accumulating NORM or Hg, a survey with sampling and analysis needs to be conducted. Locations where NORM or Hg may potentially accumulate should be the focus of the sampling program.

Health risks from exposure to low levels of contaminant NORM or Hg are generally minimal, but activities like pigging and other open pipe activities create potential for substantial interaction with concentrations of pipeline contaminants.

Activities that potentially expose workers to NORM include:

- filter inspection and replacement
- pigging operations (receiving, cleaning and maintenance)
- confined space entry tank internal inspections
- equipment servicing and decommissioning (including vacuum trailers, valves, regulators flanges and pipes)
- venting and blowdown
- storage and handling of process related wastes.

Consideration should be given to sections of equipment with scale accumulation, namely process pumps and valves, tank bottoms, sharp bends in flowlines, manifolds and spools.

Where the potential dose may exceed 1 mSv/year, a comprehensive risk assessment should be carried out and controls implemented according to the level of risk.

Activities that potentially expose workers to Hg include:

- pigging activities
- internal inspections
- hot tapping trunk or primary mains
- filter cartridge changing.

Where it is likely potential exposure may exceed 0.0125 mg Hg/m^3, a comprehensive risk assessment should be carried out and controls implemented according to the level of risk.

6.6 Risk reduction

Control strategies for potential inhalation or ingestion exposure risks to NORM are no different, in principle, from control approaches occupational hygienists recommend for control of exposure to other hazardous materials, like Hg. Where management of NORM and Hg is expected to form part of oil and gas production and transport operation, a SMS is required to monitor and control the risk in an appropriate and proportional manner that complies with legislation.

Individuals with legislated obligations to manage risk at a petroleum or pipeline facility must apply hazard controls using the hierarchy of controls.

The hierarchy of controls must be applied ensuring worker exposure to NORM and Hg does not exceed the limit and is ALARP:

1. Eliminate the hazard so far as is reasonably practicable.
2. Substitute with a lesser hazard if possible.
3. Use engineering controls to isolate people from the hazard.
4. Administrative or institutional controls (like training) to change the way people work.
5. Protect workers with PPE.

The following sections describe some of the controls that should be considered for risk reduction for NORM[6] and Hg.[7]

Inhalation is a primary route of entry to the body for both NORM and Hg, but the potential for skin absorption of Hg and the potential for ingestion due to skin contamination for both make housekeeping, proper personal hygiene practices, as well as PPE selection and use imperative.

6.6.1 Elimination and substitution

NORM is an inevitable by-product of petroleum and gas activities, meaning elimination and substitution are not feasible control measures.

An approach to minimise potential Hg accumulation is to have an approved 'mercury operating envelope' where petroleum facilities can apply acceptance criteria to limit the intake of Hg into their processes. For example, *the mercury content of incoming crudes to the facility will be less than 10 wt ppb, on a month-average basis, and no individual crude should exceed 100 wt ppb.* The envelope should be subject to a change management process, so

[6] The ARPANSA (2008) '*Safety Guide for the Management of Naturally Occurring Radioactive Material (NORM)*' Annex 1 and the IOGP (2016) Report 412 '*Managing Naturally Occurring Radioactive Material (NORM) in the oil and gas industry*' were primary reference sources.

[7] The IPIECA (2014) Good Practice Guide '*Mercury management in petroleum refining*' was a primary reference source.

deviations outside of the envelope are made only after considering the potential impact on workers, equipment, and other considerations.

6.6.2 Facility design

When designing facilities, operators should consider the impact of Hg accumulation and should identify the Hg removal technologies required to reduce safety, health and environmental risks to ALARP. All widely used Hg removal technologies are based on the adsorption mechanism and designed to treat single phase flow only. Adsorption occurs in vessels or beds where the stream being treated passes through it and the impurities (Hg) are removed to very low outlet levels.

Gas stream Hg removal units are commonly installed prior to cryogenic applications such as LNG facilities or hydrocarbon processing facilities that remove light compounds like ethane, propane and butane.

In addition, facilities should be designed to prevent bends in equipment and avoid temperature drops. Flushing facilities for cleaning the internal components of installations should also be implemented.

6.6.3 Ventilation

Effective extraction ventilation will reduce exposure to alpha/beta emitters and Hg vapour through inhalation. Exhaust systems or ventilation, both local and general, should be used to capture or disperse NORM dust or Hg vapour for work inside NORM or Hg contaminated vessels, and on NORM or Hg contaminated equipment. Local exhaust ventilation is required where general dilution ventilation is not effective.

The ventilation where a person may be present must be of a sufficient volume, velocity and quality to achieve a healthy atmosphere.

6.6.4 Maintenance

Maintenance personnel are most likely to encounter NORM or Hg contaminated plant or equipment, making risk assessment of and exposure control for maintenance activities a primary consideration. If a breakdown of operating plant or a particular maintenance procedure could cause an unacceptable level of risk from NORM or Hg, the plant's servicing and maintenance must be based on a preventive strategy. The use of a purpose-designed and purpose-built cleaning facility for removing NORM or Hg contamination from petroleum industry equipment is recommended.[8] Otherwise, contaminated equipment should be removed from service and cleaned using enclosed equipment, such as a glass bead blaster. Bead blasting should take place inside a ventilated cabinet, with the contaminated air exhausted cleaned by HEPA filters before release.

[8] Such facilities exist in petroleum producing areas outside Australia, but no such facility is yet available in Australia.

6.6.5 Separation of workers from NORM and/or Hg

Distance directly affects exposure to gamma radiation. A critical control is to ensure that only essential personnel are allowed in work areas where NORM or Hg are potentially present. It is important to designate clean areas and exclusion zones. Surface wipe sampling should be done to assess and manage contamination outside of the working area, particularly for crib areas.

6.6.6 Procedures and work practices

A risk assessment will identify if written procedures and standard work instructions are required to manage the risk of NORM or Hg exposure.

Under normal operating conditions, the greatest risk associated with NORM or Hg exists for people working near contamination for extended periods, like during decontamination. Procedural controls apply to virtually all work potentially involving NORM or Hg contaminated items. However, work procedures and practices are only effective if consistently applied and followed.

These procedures might include:

- working definitions of 'NORM contaminated' or 'Hg contaminated' to determine when NORM or Hg procedures apply and for designating safe work areas
- a classification of tasks on NORM or Hg contaminated equipment based on their potential for generating NORM dust or Hg vapour
- options for conducting tasks using methods that generate minimum airborne dust or Hg vapour, based on hygiene standards, rules and practices
- application of the site permit-to-work system
- monitoring and sampling to detect and measure NORM and Hg concentration[9]
- system flushing for Hg vapour
- classification for PPE by NORM or Hg task
- methods for containing NORM and Hg, preventing the spread of contamination, and for collecting, storing, and labelling waste
- steps to safety remove or dispose of NORM or Hg contaminated equipment from site.

The IOGP Managing Naturally Occurring Radioactive Material (NORM) in the oil and gas industry report provides detailed control procedures for managing NORM.

There should be no eating, drinking or smoking in these areas under any circumstances. Workers should wash thoroughly with generous amounts of soap and water after working with contaminated equipment, before eating, drinking, or smoking and at the end of the workday.

[9] It is important that monitoring equipment is suitably calibrated.

6.6.7 Education, training and competency

There is an obligation to train workers so that they are competent performing duties where there are risks from NORM or Hg. This includes appropriate induction training with periodic assessment of their knowledge of risk management for NORM and Hg, as well as any other relevant training with periodic assessment. Workers should obtain relevant competencies for their role and work location.

Induction training for workers who may be exposed to NORM or Hg should include, but is not limited to, the following topics:

- basic principles and terminology of radiation and basic chemistry of Hg
- the hazards and risks associated with exposure to NORM radiation and Hg vapour or Hg-containing materials (for example reviewing of safety data sheets)
- procedures to identify NORM and Hg and the associated challenges
- routes of entry and typical exposure controls with emphasis on proper personal hygiene practices and PPE selection and use
- the role of monitoring and measurement of dose or exposure limits
- locations where exposure to NORM and Hg may occur plus the meaning of warning signs and labels
- special precautions to minimise exposure, techniques for spill prevention, proper procedures for spill clean-up
- overview of NORM and Hg management plans
- relevant legislation.

A competent person, such as an occupational hygienist, should be appointed to supervise a radiation and Hg monitoring programs.

Training and competency requirements for supervisors and workers should be developed and documented. This should include requirements to have a more detailed understanding of NORM and Hg, the risk controls relevant to their work and the ability to recognise substandard conditions or practices relevant to the potential for NORM and Hg exposure.

6.6.8 Personal protective equipment

PPE is the lowest order control in the hierarchy of control and relies heavily on worker compliance and enforcement through supervision to be effective. Failure to wear suitable and correctly fitted PPE when required can result in a worker being directly exposed to hazards associated with NORM or Hg. Every effort should be made to reduce NORM and Hg vapour to levels that do not require the use of respiratory protection.

PPE requirements must be embedded in the SMS.

PPE controls should focus on:

- preventing skin contamination (for example impermeable gloves made of neoprene, PVC, nitrile, or nitrile rubber for NORM and nitrile only for Hg)
- preventing accumulation of NORM and Hg on clothing worn outside the immediate work area (for example ‘Tyvek’ style coveralls or chemical suits)
- achieving effective respiratory protection against airborne NORM dust or Hg vapour.

In the case of NORM exposure, respiratory protection will reduce the risk from alpha and beta emitters but will not impact the risk from gamma shine.

A respiratory protection program should be implemented where other higher controls are inadequate, noting such programs are limited by individual compliance, despite the availability of standards and best practices.

Achieving effective respiratory protection against any hazardous dust requires significant effort through a formal respiratory protection program with elements including the selection, cleaning and maintenance of respirators, training of respirator wearers, and the individual fit testing of respirators for each wearer, as per AS/NZS 1715:2009 and its 2023 ruling.[10]

The IPIECA Mercury management in petroleum refining guide suggests a tiered approach to the use of PPE, as demonstrated in Figure 1.

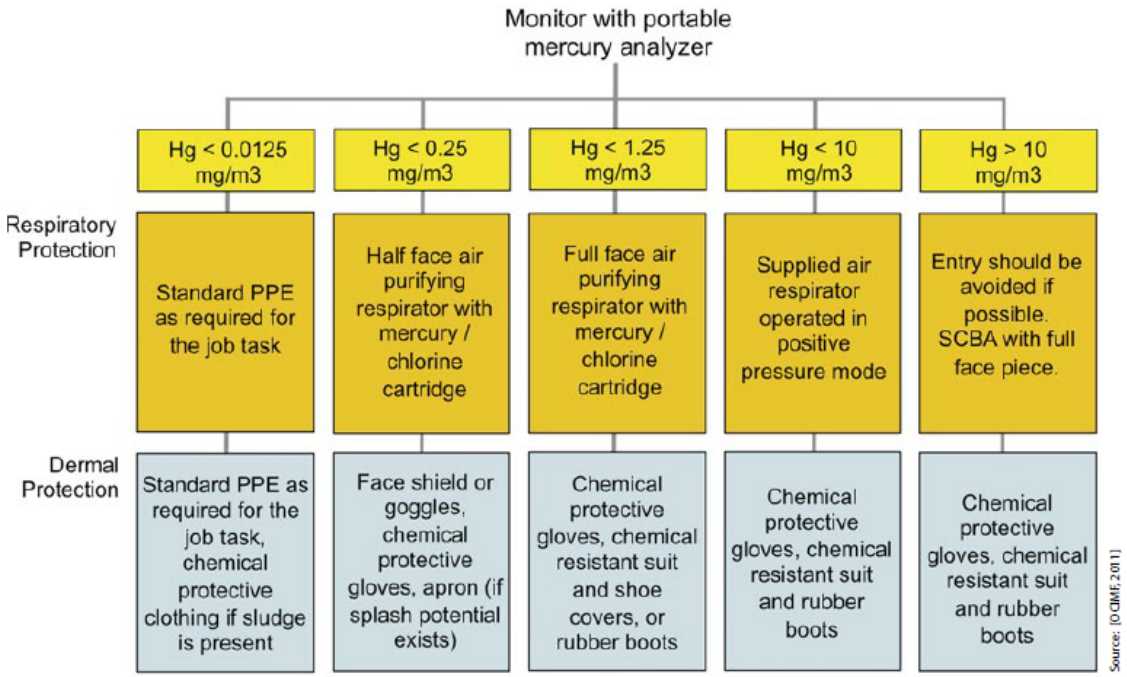


Figure 1: Tiered approach to the use of PPE for protection against Hg exposure (from IPIECA, 2014)

6.7 Risk monitoring

Risk monitoring is the process of monitoring and reviewing all parts of a control strategy. This can be a periodic or unplanned activity.

The aims of risk monitoring are to:

- review implementation of controls
- ensure controls are working as designed and intended
- incorporate new research, trends, or industry data into risk management processes
- obtain additional information to improve the risk analysis process.

Any change to plant, processes or feedstocks requires reassessment of the risk of exposure for workers. Change management practices and procedures should require reassessment of potential for worker exposure when

[10] The 2023 ruling provides further clarification around AS/NZS 1715 requirements for tight-fitting respirators and facial hair. According to Resp-Fit, in summary, there are no exceptions regarding facial hair and any tight-fitting respirator (negative or positive pressure) to comply with AS/NZS 1715. It also confirms that a positive pressure facepiece is to be fit tested in negative pressure to isolate the fit performance of the facepiece and the wearer.

there has been change to plant, processes or feedstocks. Risk monitoring programs should be documented and state the exposure assessment goals and strategy.

Ensuring exposure control using adequate and ongoing dosimetry is a critical component of a health and safety program to protect workers. Monitoring should be performed when a hazard has the potential to exceed exposure limits, or if the level of risk from the hazard may vary.

The approach to implementing a risk monitoring program should be established by an appropriately qualified person, such as an occupational hygienist. Results of any monitoring should be communicated to either individuals or work groups as appropriate in a timely manner.

NORM

Risk monitoring for NORM may include, but is not limited to:

- the use of personal dose monitors
- personal exposure dust and mist monitoring
- radiation exposure measurements
- surface contamination monitoring using for example surface wipe sampling
- ensuring there is compliance with work procedures and work practices.

The NORM concentration that can be measured with the aid of a user-friendly measuring apparatus in (on-site) production laboratories is Rn-222 in natural gas. The rest of the NORM activity concentrations in petroleum industry products can only be measured by specialised laboratories.

Mercury

Risk assessments for Hg should consider the locations where it might be detected. As a first step, a direct reading instrument should be used to monitor Hg levels. An example of a risk-based monitoring approach is provided in Figure 2.

Instantaneous elemental Hg readings in mg/m^3 concentrations may be measured with real-time instruments such as the Lumex RA-915+, NICEMP 1A or Jerome® 431. Other analysers may also be suitable. TWA personnel exposures may be collected using adsorbent tubes, diffusion badges or filters for inorganic Hg followed by laboratory analysis. Surface wipe sampling can be done to assess contamination.

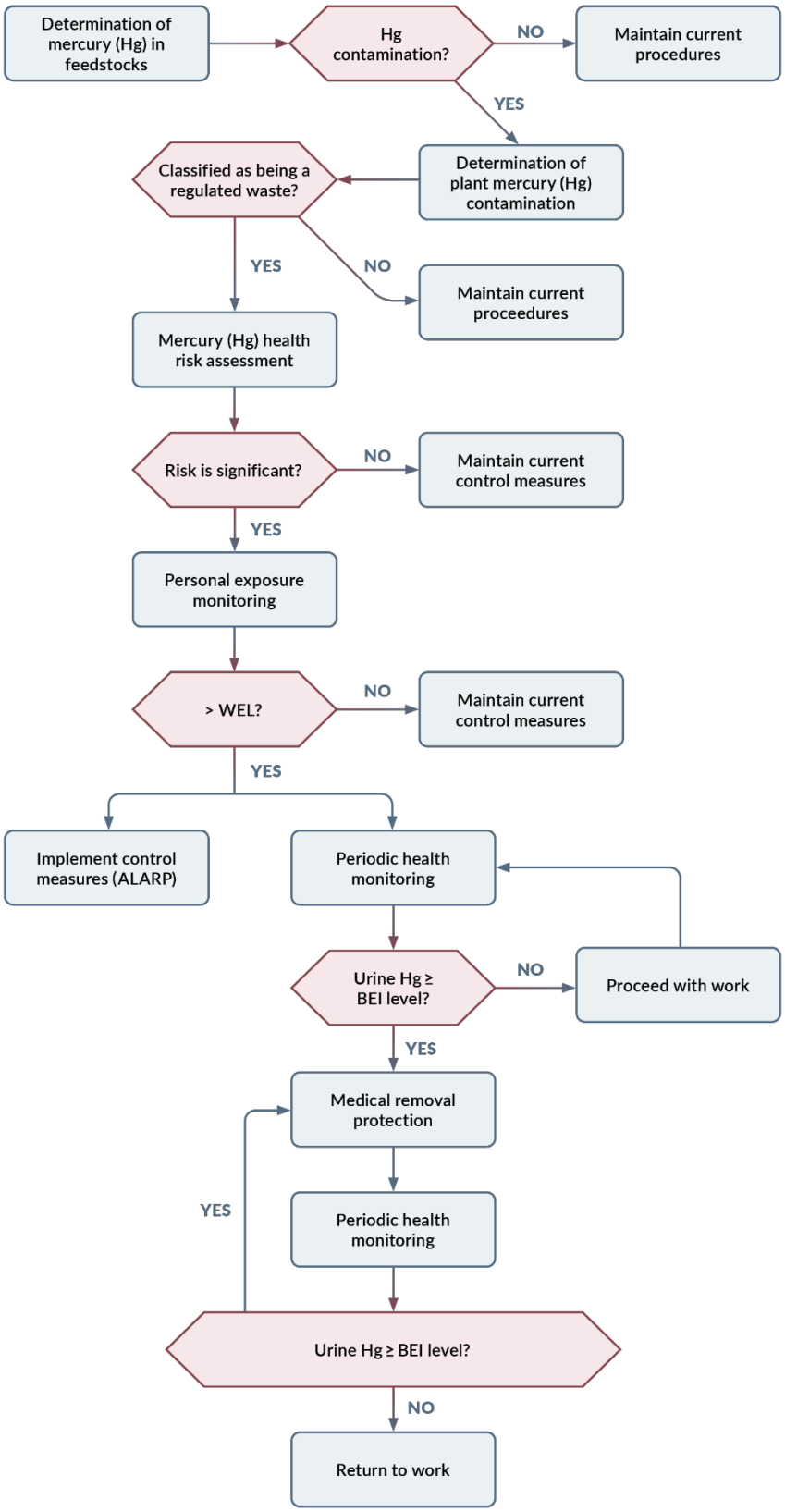


Figure 2: Example of a risk-based Hg monitoring approach (adapted from IPIECA, 2014)

6.8 Records

Records may include worker category exposure results, fixed monitoring, wipe results, and monitoring reports.

Plant operators should lodge prescribed incidents with RSHQ's Petroleum and Gas Inspectorate. The SMS and all resulting records must be kept for 7 years and made available for inspection at the operating plant when requested.

Copies of risk assessments must be available at the facility site for the duration that the hazard exists. Risk assessments must include:

- the names of the people involved in the risk assessment and their respective positions in the management structure
- a description of the hazard
- the method for assessing the likelihood and consequence of the risk
- the controls proposed to reduce the risk.

Risk assessments should also include the names of the persons responsible for implementing the controls.

7.0 NORM or Hg management plan

Where NORM and Hg exposure is found to be at an unacceptable level of risk, a management plan must be developed.

Management plans should:

- align with the goals and objectives of the facility's SMS
- be established using the facility's risk management practices and procedures
- address all relevant activities and processes at the facility
- be integrated and compatible with the facility's SMS
- be documented and auditable.

A current copy of the management plan should be available to workers. An indicative NORM management plan is provided in Figure 3.

A management plan should include sections such as:

- a purpose—describing the plant NORM and/or Hg contamination with an indication of potential worker exposure levels and how the management plan fits within the SMS.
- a scope of facility activities—providing a brief overview summarising the key processes done on site, including waste management, and a process flow chart and list of the principal equipment involved
- organisational arrangements for managing NORM and/or Hg—including the company organisation chart and management structure showing responsibilities and competencies for NORM and/or Hg exposure management
- workforce arrangements—including number of workers and roles, roster arrangements, hours of work and the likely annual working hours (to estimate dose)
- routes and risk of exposure.
- monitoring program—including written procedures and SWIs for the monitoring program that includes operating and maintenance of the monitoring equipment and a list of the monitoring equipment
- exposure assessment—including an explanation of how the results of the monitoring program are used in the assessment/measurement of workers' doses
- exposure controls
- education, training and competency—including a copy of the site's training matrix showing what competencies workers require and hold
- monitoring reports—including the procedure for responding and investigating unacceptable variances from a worker's expected exposure level and/or dose estimate
- management of waste—including details of the handling, storage and disposal methods of NORM and/or Hg contaminated waste on site
- review and audit—including procedures for periodic review, audit and continuous
- improvement of the management plan.

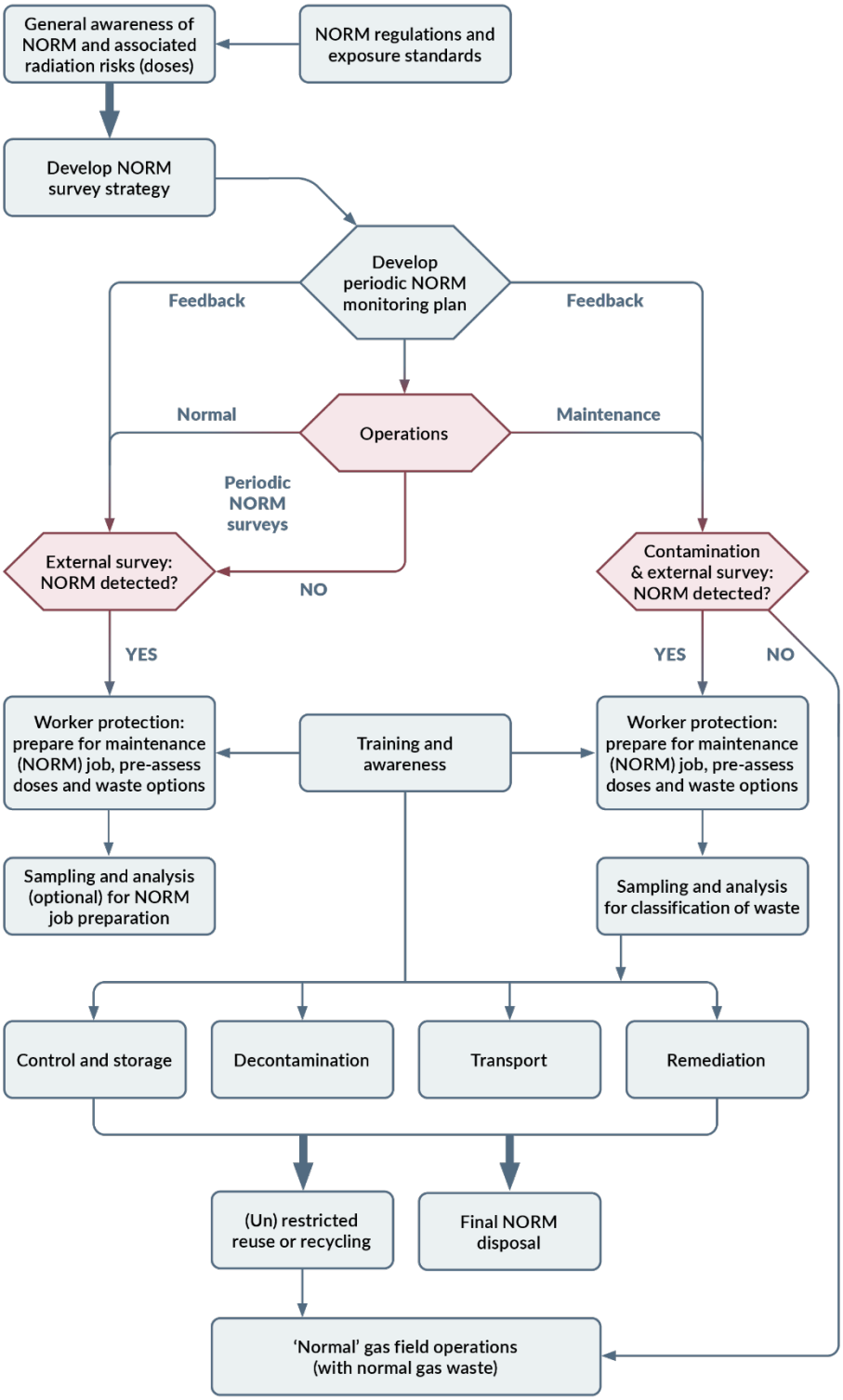


Figure 3: Indicative NORM management plan (adapted from IOGP, 2016)

8.0 Review and audit

Operators of petroleum and gas facilities are required to review and audit the effectiveness of the facility's SMS to ensure risk to persons from operations is at an acceptable level. This includes NORM and Hg management plans.

Further guidance about how to review the effectiveness of the management system is provided in RSHQ's QGN09 Reviewing the effectiveness of safety and health management systems.

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10.0 Glossary

Activity (Bq/kg or Bq/L)	Number of atomic disintegrations per second per kilogram of substance or litre of liquid
ALARP	As low as reasonably practicable
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency—the Australian Government's primary authority on radiation protection and nuclear safety
Alpha radiation	A charged helium nucleus from decay of a radionuclide that imparts potentially harmful energy to humans and may cause injury or illness. Alpha particles have limited travel, but are relatively long-lived and potentially cause most harm when inside the body, e.g. when inhaled or ingested
Becquerel (Bq)	The derived International System of Units of radioactivity equal to one disintegration per second—the measure of activity
Beta radiation	Beta particles are high-energy, high-speed electrons or positrons emitted by certain types of radioactive nuclei
BEI	Biological exposure indicator
CSG	Coal seam gas
Effective dose	A measure of dose, which considers both the type of radiation involved, and the radiological sensitivities/susceptibilities of the organs and tissues irradiated. The unit of effective dose is Sievert (Sv)
Gamma radiation	Electromagnetic radiation of extremely high frequency and energy per photon. Gamma rays can be produced by the decay of atomic nuclei from high to lower energy states (gamma decay)
Gamma shine	A term used to describe the personal exposure received from an area source emitting gamma radiation
Guideline	A document outlining non-mandatory legal requirements, but which are best practices
Hazard	A thing or a situation with potential to cause injury or illness to a person
Ionising radiation	Any radiation, as a stream of alpha/beta particles or gamma rays, that produces ionisation as it passes through a medium
IOPG	International Association of Oil and Gas Producers is the petroleum industry's global forum in which members identify and share best practices to achieve improvements in health, safety, the environment, security, social responsibility, engineering and operations
IPIECA	International Petroleum Industry Environmental Conservation Association - is the global oil and gas association for advancing environmental and social performance across the energy transition
LNG	Liquid natural gas
NORM	Naturally occurring radioactive materials
Petroleum	(a) a substance consisting of hydrocarbons that occur naturally in the earth's crust; or

	(b) a substance necessarily extracted or produced as a by-product of extracting or producing a hydrocarbon mentioned in paragraph (a); or (c) a fluid that is extracted or produced from coal or oil shale by a chemical or thermal process or that is a by-product of that process; and consists of, or includes, hydrocarbons; or (d) another substance prescribed under a regulation, consisting of, or including, hydrocarbons; or (e) a gas, that occurs naturally in the earth's crust, as prescribed under a regulation
PPE	Personal protective equipment
Radionuclides	A nuclide that is radioactive
Radon	A radioactive gaseous element. It is a product of ore radioactive decay
Risk	Means the risk of injury or illness to a person arising out of a hazard, measured in terms of consequences and likelihood
RPS9	The Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (ARPANSA, 2005)
RPS15	The Safety Guide for the Management of Naturally Occurring Radioactive Material (NORM) (ARPANSA, 2008)
RSHQ	Resources Safety and Health Queensland
SEG	Similar Exposure Group—groups of workers having the same general exposure profile because of the similarity and frequency of the tasks they perform, the materials and processes with which they work, and the similarity of the way they perform the tasks
Sievert (Sv)	A unit of health risk from any ionising radiation. The risk arising from 1 Sv is the same no matter what kind of radiation causes it
SMS	A comprehensive and integrated system for managing health and safety risks
TLD	Thermoluminescent Dosimeter is a badge used for the measurement of an individual's exposure to ionising radiation, such as gamma radiation
TWA	Time Weighted Average is the maximum average airborne concentration of a substance when calculated over a specific timeframe. Under the model WHS laws, this is an 8-hour working day, for a 5-day working week. With respect to a TWA, during periods of daily exposure to an airborne contaminant, exposure above this value is permitted for short periods, if they are compensated for by equivalent exposures below the exposure standard during the working day
WEL	Workplace Exposure Limit—Under the model WHS laws, a WEL for a particular chemical sets out the airborne concentration limit of that substance or mixture that must not be exceeded

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