Government of **Western Australia**
Department of **Mines and Petroleum**

Department of Mines and Petroleum

Environmental Risk Assessment of Chemicals used in WA Petroleum Activities Guideline




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Please consult www.dmp.wa.gov.au to ensure this version is current.

This Guideline has been developed in consultation with the Department of Water, Department of Health, Office of the Environmental Protection Authority and the Department of Environment Regulation (formerly Department of Environment and Conservation).

Government of Western Australia
Department of Mines and Petroleum
Mineral House, 100 Plain Street
East Perth, Western Australia 6006

Tel: +61 8 9222 3333
Fax: +61 8 9222 3862
Email: dmp@dmp.wa.gov.au

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1. Purpose

This Guideline outlines the environmental risk assessment process required by the Department of Mines and Petroleum (DMP) in relation to products and chemicals being used 'down-hole' in petroleum and geothermal activities. It ensures that all potential environmental risks and impacts associated with their use have been systematically identified, analysed and that adequate risk management measures have been considered.

Operators are required to undertake environmental risk assessment as part of preparing their Environment Plan (EP), which includes chemicals in a general sense. A more detailed environmental risk assessment for specific products and chemicals may be warranted where their use presents moderate to high risks to the environment. In these instances, information should be submitted to DMP in the EP in conjunction with chemical disclosure information.

This Guideline is not intended to be prescriptive – noting that environmental risk assessment of products and chemicals depends on many variables both intrinsic and extrinsic to a petroleum or geothermal activity. On this basis DMP will assess chemical hazards and potential environment risks and impacts on a case-by-case basis.

2. Scope

This Guidance supports the DMP "Guidelines for the Preparation and Submission of an Environment Plan 2012" (DMP, 2012a), and will assist petroleum operators of onshore and offshore (in State waters) projects in undertaking environmental risk assessment of products and chemicals being used down-hole. This Guidance also complements DMP's chemical disclosure requirements in DMP's "Chemical Disclosure Guideline" (DMP, 2013).

Risk assessment is part of the risk management process of estimating the potential impact of a hazard to people, communities or environments under a specific set of conditions and over a given time frame. This Guidance provides an emphasis on hazard analysis and risk assessment for products and chemicals proposed for use in petroleum and geothermal activities.

As part of its assessment of an Environment Plan (EP), DMP has responsibility to assess whether the use of specific products and chemicals down-hole in petroleum activities pose an unacceptable risk of impact to the environment. In turn, Operators are encouraged to use this Guidance to undertake their own environmental risk assessment of products and chemicals where risks are deemed moderate to high.

The context of the term "environment" is important in relation to risk management. As defined in regulation 4 of the petroleum environment regulations, environmental risk management applies to:

- "ecosystems and their constituent parts, including people and communities; and
- natural and physical resources [including water]; and
- the qualities and characteristics of locations, places and areas; and
- the heritage value of places; and
- includes the social, economic and cultural features of the [above-mentioned]".

This definition includes people and communities and therefore encompasses human health and places where people reside, sometimes referred to as 'sensitive receptors'. It does not relate to occupational health and safety which is covered under separate Western Australian legislation and regulations. It should be duly noted that further detailed guidance on human 'environmental health' risk assessment is provided in the "Environmental Health Risk Assessment" guidelines (Department of Health and Ageing, 2012).

Chemicals refer to any material that has a constant composition and distinct properties. Most chemicals used in the petroleum industry are found as ingredients within products. Products refer to a manufactured commercial good (with a marketed trade name) that contains chemicals, substances or mixtures thereof.

Chemicals used down-hole may be:

- organic or inorganic;
- solids, liquids or gases;
- naturally or synthetically produced;
- present as either a pure chemical or as a mixture.

Substances refer to solids and solid mixtures that have relatively uniform properties, including sands, muds, cements, proppants, ceramics and plant material.

3. Regulatory context

Regulation 14 of the:

- Petroleum and Geothermal Energy Resources (Environment) Regulations 2012;
- Petroleum (Submerged Lands)(Environment) Regulations 2012; and the
- Petroleum Pipeline (Environment) Regulations 2012,

outlines risk requirements of environmental assessment that should be considered by the Operator and presented within their EP.

These requirements are directly applicable to environmental risks and impacts associated with the use of products and chemicals, including:

- details of all environmental impacts and risks associated [relevant to products and chemicals use];
- an evaluation of those impacts and risks [relevant to product and chemicals used];
- a description of the risk assessment process used;
- defining objectives, policies, processes, practices and actions undertaken to mitigate impacts and risks [relevant to products and chemicals used]; and
- defining environmental performance standards and measurement criteria [relevant to chemicals].

Post approval, it should be noted that any changes to the type, quantity or use of products or chemicals may require a review of an EP or a bridging EP if new or increased environmental impacts or risks are identified:

- If increased additional or modified environmental impacts or risks are identified, then regulation 8 requires that operations cease. In this instance, a new or revised EP (including a revised chemical disclosure) must be submitted and approved by DMP before the activity can continue; or
- If minor additional or modified impacts or risks are identified, operations may be allowed to continue while the EP (including a revised chemical disclosure) is updated and submitted to DMP.

Notwithstanding the above, and in accordance with a Memorandum of Understanding, DMP may refer proposed petroleum activities that have potentially significant environmental impacts and risks to the Environmental Protection Authority for environmental impact assessment under the Environmental Protection Act 1986.

While out of scope in this Guidance, overlaps are recognised in relation to workplace risk management of hazardous chemicals, including the Occupational Health and Safety Regulations 1996 (WA) and the Dangerous Goods Safety Regulations 2007 (WA).

Consideration should also be given to regulatory requirements for using new chemicals in Australia. The National Industrial Chemical Notification and Assessment Scheme (NICNAS), a Commonwealth statutory scheme assessing industrial chemicals for their health, environmental effects and safe use, must be notified under the Industrial Chemicals (Notification and Assessment) Act 1989. NICNAS assesses the risks to occupational health and safety, public health and the environment using well established, internationally accepted methodology. It should be noted that NICNAS is currently reviewing the risks associated with some chemicals used in coal seam gas hydraulic fracturing activities.

4. Environmental risk assessment and management framework

Operators should apply the principles, framework and process for risk management outlined in the Joint Australian/New Zealand Standard AS/NZS ISO 31000:2009: “Risk management – Principles and guidelines” (Standards Australia Limited and Standards New Zealand, 2009).

Detailed information about the environmental risk management process is outlined in the AS/NZS Handbook HB 203:2012 “Managing environment-related risk” (Standards Australia Limited and Standards New Zealand, 2012).

The process for assessing and managing environmental risks arising from chemicals associated with onshore petroleum activities should follow the framework defined in the AS/NZS ISO 31000 (Standards Australia Limited and Standards New Zealand, 2009). Consistent with this framework (Figure 1), the following sections will be addressed in this Guidance:

1. communication and consultation;
2. establishing the context;
3. risk assessment (identification, analysis and evaluation);
4. risk treatment; and
5. monitoring and reviewing risk assessment.

This Guidance will provide particular emphasis on the risk assessment process, which is relevant to DMP's assessment of chemical disclosure within an EP.

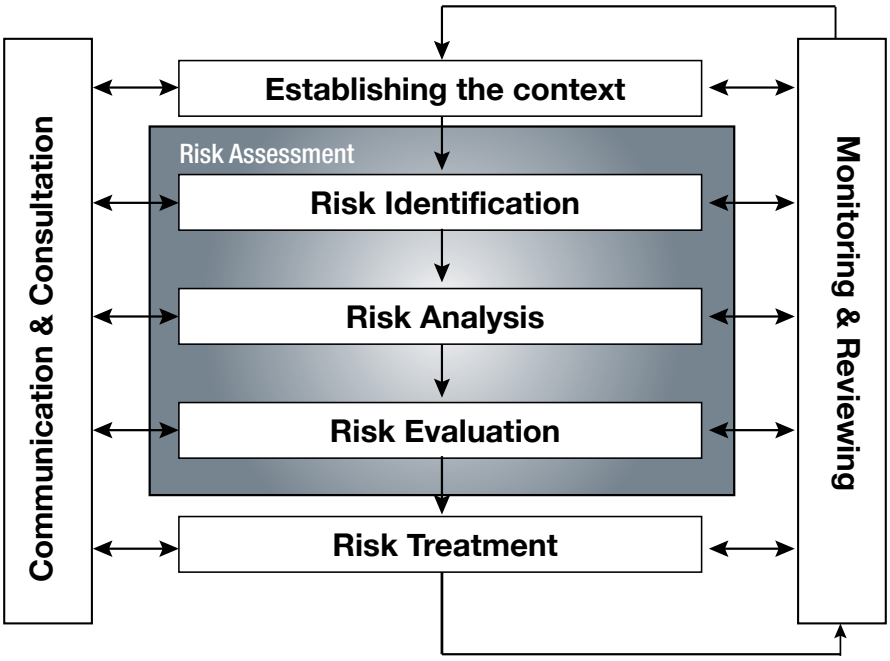

Figure 1: Risk management process (AS/NZS ISO 31000: 2009)

4.1 Communication and consultation

Communication and consultation on environmental risk management in relation to chemicals should be conducted by Operators as an integral part of the consultation process, as required in regulation 15(11). Additional guidelines on the process of risk communication and consultation can be found in HB 327:2010.

As a first step, internal and external stakeholders should be determined. A communication plan and strategy should be developed to ensure upfront and on-going communication and consultation with the relevant stakeholders in the risk management process. To maximise the benefits and ensure the effectiveness of the communication and consultation process, it is important to identify which stakeholders should be involved or consulted at each stage of the risk assessment process.

As part of DMP's regulatory role in assessing potential environmental risks and impacts for products and chemicals being used in petroleum activities, it will seek advice from other government agencies (where appropriate) including:

- Department of Environment Regulation (DER);
- Department of Water (DoW);
- Department of Health (DoH);
- Department of Agriculture and Food WA (DAFWA)
- Office of the Environmental Protection Authority (OEPA);
- Department of Health and Ageing – National Industrial Chemicals Notification and Assessment Scheme (NICNAS) [Aust. Govt.]; and the
- Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) [Aust. Govt.].

Operators are encouraged to engage consultants familiar with relevant regulations, agency expectations, codes or practice, guidelines and standards to undertake the necessary research, stakeholder engagement and/or preparation of appropriate risk documentation.

All issues of concern to stakeholders should be acknowledged, recorded and addressed in the risk assessment process. Local residents should be duly informed about the proposed petroleum activities and the associated risks where appropriate.

4.2 Establishing the context

Prior to assessing the environmental risks associated with chemicals, it is essential to define the approach and objectives for risk management; and the scope and criteria for the risk assessment process.

The risk management approach and objectives should be consistent with corporate environmental policy (required in regulation 17(1)(a)); and take into account the legal obligations relating to environmental protection; organisational commitments and values; and views of stakeholders.

The scope and criteria for the risk assessment process should include the risk assessment methodologies, risk criteria and performance evaluation, as an integral part of the requirements in regulation 14(3).

The following considerations should also be included in relation to environmental risk assessment of products and chemicals used in petroleum activities:

- **Legislation, policies and guidelines:** Identification of any statutory, regulatory, policy, codes of practice and guidelines in relation to chemical use, storage, transport and disposal. This will be important in determining the approach and objectives for risk management, performance standards and risk criteria.
- **Environmental values:** Identification of environmental values (ecological and beneficial uses) in the project area and the surrounding environment to be protected. Research, surveys and/or monitoring programs should be conducted to identify environmental sensitive areas (including terrestrial, aquatic, and/or subterranean flora and fauna). Environmental values also include beneficial uses (e.g. local drinking water sources, livestock water sources, crop irrigation). Some environmental values may be more sensitive to certain chemical hazards, thereby requiring the use of more stringent objectives, standards and criteria.
- **Risk assessment methodologies:** Identification of risk assessment methodology to define and measure consequences and likelihoods in relation to chemical use. Generic information about risk assessment techniques is provided in the International Standard IEC/ISO 31010: 2009 “Risk management – Risk assessment techniques” (IEC, 2009); and the environmental risk management process outlined in the AS/NZS Handbook HB 203:2012 “Managing environment-related risk” (Standards Australia / Standards New Zealand, 2012).
- **Risk criteria**: Risk criteria for chemicals should be defined before the risk assessment process commences and may be reviewed, refined or modified as required during the process. Criteria may be imposed by legal and regulatory requirements, organisational objectives and policy, or derived from acceptable standards, guidelines, codes of practice, baseline data, and/or professional experience and judgement. In relation to environmental risks associated with chemical use in petroleum activities, this may include reference to (where appropriate):
  - ANZECC Water Quality Guidelines (ANZECC and ARMCANZ, 2000) in relation to water quality guidelines for various chemical pollutants in both freshwater and marine waters. The DoW and DEC may provide further advice in relation to risks to water quality from discharges to groundwater and surface water. The DEC may provide further advice where environmentally sensitive wetlands are involved in the risk assessment.
  - Assessment of Site Contamination National Environment Protection Measure (1999) in relation to investigation levels for soil and groundwater contamination. The DEC may provide further advice in relation to triggers for investigation of soil, sediments or water contamination in the risk assessment.
  - Australian Drinking Water Guidelines (2011) in relation to chemicals being used in, and for the protection of, public drinking water source areas. The DoW and DoH may provide further advice where drinking water quality is involved in the risk assessment.
  - National Environment Protection (Air Toxics) Measure (2004) in relation to standards for hazardous air pollutants, namely benzene, toluene, xylene, formaldehyde, benzo(a)pyrene (as a marker for polycyclic aromatic hydrocarbons). The DEC and DoH may provide further advice where air pollutants and risks to sensitive receptors are identified in the risk assessment.
  - If no established environmental concentration standard / guideline / limit is available, risk criteria can be derived from toxicity thresholds, such as hazard quotients (HQs) and risk quotients (RQs), calculated as the ratio of predicted exposure concentration to the predicted ”No Effect” concentration. It is recommended that a professional toxicologist is used to assist with this process.

- **Baseline environmental data:** This is important for determining which chemicals are present in the immediate environment (i.e. soil, sediments, groundwater, wetlands, waterways, public drinking water source areas and catchments, and air) prior to site construction and any chemical use occurs. Baseline chemistry can help to verify whether harmful chemicals (e.g. salts, acid, heavy metals, radioactive elements and persistent organic chemicals) are already present in the environment from historical land uses or if there are natural sources. The collection of baseline data may include sampling of soils, wetlands, watercourses, groundwater, groundwater dependent ecosystems and water wells in proximity to the petroleum site.

4.3 Risk assessment

Risk assessment in relation to products and chemicals used in the petroleum industry is the focus of this Guidance and will be addressed in Chapter 5.

4.4 Risk treatment

Risk treatment or mitigation involves selecting options and implementing measures to reduce the risk levels that were identified as priority risk ratings in the risk evaluation process.

DMP recommends that the following hierarchy be used for mitigating risks associated with product or chemicals:

- Avoid or remove the product or chemical if deemed an unacceptable level of risk;
- Substitute the product or chemical if deemed an unacceptable level of risk;
- Minimise the use of the product or chemical;
- Reduce any residual risk of the product or chemical to "As Low As Reasonably Practicable" (ALARP), by finding solutions to limit the hazard and exposure pathways.

Advice may be sought on proposed risk treatment measures from DMP and other government agencies and consultants as appropriate. Examples of chemical related risk treatment/mitigation measures to avoid or reduce environmental risks associated with petroleum activities may include:

- Alternative location of wells, storage facilities and retention ponds at an adequate distance from a protected source or sensitive area (such as a private water well, drinking water supply, wetland or a creek);
- Using drilling and fracturing fluids with no or reduced toxicity and eco-toxicity;
- Minimising on-site storage of concentrated fracturing chemicals and/or storing these chemicals in double skinned tanks on-site;
- Ensuring proper well construction and well integrity (such as using approved methods and materials for casing and cementing of wells, adequate depth of surface casing below the lowest groundwater and proper cementing of the casing);
- Provision of blowout prevention control equipment and measures;
- Mapping of existing geological fractures through seismic mapping;
- Selection of technology and control systems to prevent any fracture propagation beyond the target zone or intersection with natural fractures that could provide a path for fracturing fluids to contaminate water resources;
- Incorporation of spill prevention and control mechanisms as part of engineering design, construction and operational procedures (such as process controls and warning systems, spill/leak containment structures, shut-down systems;
- Provision of contingency planning and measures for responding to spills and releases of hazardous chemicals;
- Construction of stormwater drains to control runoff during construction and operation of the wells and after their abandonment;
- Provision of appropriate liners and sufficient freeboard for on-site retention ponds;
- Storage of drilling and fracturing wastewater in purposely built tanks, instead of retention ponds;
- Reusing and recycling of wastewater;
- Use of effective air emission control equipment and measures (such as vapour capture and recovery systems; and venting and flaring of gases at sufficient stack heights).

4.5 Monitoring and reviewing risk assessment

Regular or periodic monitoring and reviewing the risk assessment are an important aspect of the risk management framework to:

- Ensure that risk treatment and control measures are effective and efficient;
- Detect and incorporate changes to the operational and risk management processes including changes to risk criteria;
- Identify emerging issues affecting the levels of risk;
- Improve the certainty and accuracy of risk assessment; and
- Minimising the levels of risk through continuous learning and improvement.

Monitoring and reviewing risk assessment should be incorporated as part of the implementation strategy of an EP (required in section 3.8 of the EP Guidelines):

- Methods for environmental monitoring should include appropriate indicators and quality controls; and use of internal and/or external audits to verify the attainment of objectives and accuracy of reporting.
- Responsibilities for monitoring and reviewing risk assessment and the resources required should be clearly defined and adequately provided.
- The results of monitoring and reviewing should be recorded, documented and reported to DMP and where appropriate, other stakeholders.
- Collection of environmental data should continue throughout the project life to include data from research, field observations and investigations; and to identify the spatial and temporal variations in the surrounding environments. The data will improve the accuracy of the risk assessment and the certainty of the environmental performance.

Regulation 20 of the petroleum environment regulations also requires Operators to revise and resubmit their EP for approval every 5 years. This includes a review of environmental risks, mitigation and treatment options to ensure their currency and relevance.

5. Environmental risk assessment of chemicals

Environmental risk assessment of chemicals should form a specific component of the risk assessment required in regulation 14(3) of the petroleum environment regulations. The need to undertake an environmental risk assessment of chemicals will be determined by the operator and / or by DMP on a case-by-case basis, but is likely to be required for petroleum or geothermal activities where:

- Risk, complexity or uncertainty exists regarding the use of products or chemicals;
- Activities involve a high level of public interest or concern about human health and environment issues;
- Sensitive receptors or important environmental values are in proximity to, or may be impacted by, the petroleum activity.

Where this is likely to include significant risks and/or impacts to environmental values (including those associated with chemicals), DMP may seek advice from other agencies and / or refer a proposed petroleum activity to the Environmental Protection Authority (EPA) for environmental impact assessment.

Under the terms of a DMP-EPA memorandum of understanding, DMP will also refer a petroleum activity (either onshore or offshore) if it is proposed in or within 500 metres of an environmentally sensitive area. DMP will also liaise with the EPA if a proposed activity is within two kilometres of a town site, coastline or likely to impact a water reserve area (including a water reserve, water catchment, and groundwater protection areas and declared or proposed water supply catchment area) (DMP and EPA, 2009).

This Guidance provides further information on the key stages of the environmental risk assessment process, having regard to both products and chemicals, including:

- **Risk identification** – including identifying products and chemicals being used, a hazard assessment and an exposure assessment (Chapter 5.1).
- **Risk analysis** – including developing an understanding about the level of risk for the product or chemical, identifying the consequence and the likelihood of the environmental risk eventuating (Chapter 5.2).
- **Risk evaluation** – including evaluating the outcomes of the risk analysis against risk criteria, including which product or chemical risks require mitigation or treatment and their relative priority (Chapter 5.3).

5.1 Risk identification for products and chemicals

Hazard identification of products and chemicals is the first step in the risk identification process. In the context of products and chemicals being used in a petroleum activity, operators must understand how the product will be used and whether they have potential to cause unplanned, unwanted impacts to the receiving environment (e.g. groundwater contamination, air pollution, impacts to flora and fauna) or to human health. Understanding the hazardous properties of products and the chemicals contained therein is important in this regard.

DMP considers a product, chemical or substance to be a hazard if:

- it meets health hazard criteria (Section 5.1.1);
- it meets environment health hazard criteria (Section 5.1.2);
- it has specifically been identified as a pollutant, contaminant or a hazardous good under Western Australian or Australian legislation or regulations.

Wherever environmental risk assessment of products or chemicals is undertaken, DMP requires the entire product to be risk assessed or tested against hazard criteria. Where this is not possible, DMP will accept risk assessment or testing of its separate chemical ingredients (within the product) against hazard criteria. Where the product contains only one chemical, then it will be assessed or tested against the hazard criteria. This process of determining whether a product or chemical is hazardous is consistent with the "Approved Criteria for Classifying Hazardous Substances" (Commonwealth of Australia, 2004) and the "Globally Harmonised System of Classification and Labelling of Chemicals" (United Nations, 2011).

5.1.1 Health hazards

Health hazards in the context of this Guidance refer to adverse effects caused by products, chemicals and substances to people and communities (and the places they reside in) – otherwise referred to as 'sensitive receptors'. It does not refer to workers health or safety on site which is covered by other legislation. Collectively, the health hazards related to chemicals include:

- acute toxicity: adverse health effects to humans following short term exposure to a chemical or substance; and
- chronic toxicity: adverse health effects to humans following long term exposure to a chemical or substance.

5.1.1.1 Acute toxicity (human health)

Acute toxicity refers to the adverse effects of exposure to a product or chemical over a short period of time (usually less than 24 hours). Acute toxicity effects can result in lethal or sub-lethal effects (e.g. irritation) to humans.

While DMP advocates the use of low hazard chemicals in accordance with the ALARP principle, this is not always possible or practicable. Some products and chemicals are used in the petroleum industry specifically for their toxic properties. For example, biocides are used down-hole to prevent bacterial degradation of the well casing and to prevent well integrity failure.

Acute toxicity methods are based on guidelines from the Organisation for Economic Cooperation and Development (OECD) which mostly use toxicological testing on proxy species, such as rats, to give an indication of relative toxicity to humans.

As a minimum requirement in chemical disclosure, DMP requires human health acute toxicity data for all products using LC_{50} or LD_{50} data (as appropriate). The use of oral measures of LD_{50} is most appropriate where likely exposure routes are accidental ingestion of chemicals via drinking water or tainted food. Inhalation measures of LC_{50} are most relevant to substances that are likely to volatilise in air and mobilised to areas where sensitive receptors are located. Dermal measures are more relevant to worker safety from the risk of direct exposure to the chemicals (rather than indirect environmental exposure).

LD_{50} or LC_{50} data for each product or chemical should be compared to the criteria for determining whether it is 'harmful', 'toxic' or 'very toxic' (Table 1).

> LETHAL DOSE / LETHAL CONCENTRATION LD_{50}/LC_{50}

Acute chemical toxicity is determined by comparing the magnitude of the effect (the response) to the amount of hazard to which the target is exposed (the dose). LD_{50} is a measure for liquids and solids and lethal concentrations LC_{50} for vapour chemicals. These measure the lethal chemical concentration necessary to kill 50% of a population. Lethal dose and lethal concentration (LD_{50} and LC_{50}) are usually measured for non-human species, such as rats – these measures are often used as a proxy for human toxicity. However, it should be noted that extrapolation of toxicity from one species to another is problematic, as some species are more sensitive to certain chemicals compared to others.

There are separate LD_{50} /LC_{50} standards for inhalation, ingestion or skin contact depending on likely chemical exposure routes.

- *inhalation standards are more appropriate if the chemical is volatile (such as emissions from open air retention / evaporation ponds) and nearby sensitive receptors are at risk of exposure to volatile chemical fumes or odours;*
- *dermal (skin) contact standards are more appropriate where there is a direct risk of physical contact with the chemical;*
- *ingestion standards are appropriate where there is a risk of consumption either directly (e.g. chemicals within water supplies) or indirect consumption (e.g. chemicals in wastewater being used as irrigation water applied to crops or pastures).*

If a product has no specific human health toxicity data available, then the following sequence of options should be considered:

i. toxicity data for analogous products can be referred to where the chemical ingredients and composition are largely identical, i.e. no less than 95% similar (e.g. Portland Cement is produced by different manufacturers with very minor variations to content). A note must be made of which analogous product is being referred to as a comparison; or

ii. toxicity data may alternatively be referenced for each separate chemical ingredient within the product; or

iii. independent toxicity testing should be undertaken for the product.

Table 1: Acute chemical toxicity categories and criteria based on LD_{50} and LC_{50} values (Commonwealth of Australia, 2004)

Toxicity level	LD_{50} and LC_{50} criteria	Examples (all based on rat species)

Very toxic	LD_{50} < 25 mg/kg body weight (oral);
	LD_{50} < 50 mg/kg (dermal);
	LC_{50} < 0.5 mg/L/4hr (inhalation).
		mercuric chloride LD_{50} oral = 1 mg/kg;
		sodium cyanide LD_{50} oral = 6.4 mg/kg;
		sulfomethylated tannin LD_{50} oral = 3.5 mg/kg

Toxic	LD_{50} of 25 - 200 mg/kg body weight (oral);
	LD_{50} of 50 - 400 mg/kg (dermal); and
	LC_{50} of 0.5 - 2 mg/L/4hr (inhalation).
		pentachlorophenol LD_{50} oral = 27 mg/kg;
		tetramethylammoniumchloride LD_{50} oral = 50 mg/kg;
		chromium trioxide LD_{50} oral = 80 mg/kg;
		formaldehyde LD_{50} oral = 100 mg/kg;
		caustic soda LD_{50} oral = 100 mg/kg;
		thioglycolic acid LD_{50} oral = 114 mg/kg;
		glutaraldehyde LD_{50} oral = 134 mg/kg;
		acetylsalicyclic acid (aspirin) LD_{50} oral = 200 mg/kg.

Harmful	LD_{50} of 200 - 2,000 mg/kg body weight (oral);
	LD_{50} of 400 - 2,000 mg/kg (dermal);
	LC_{50} of 2 – 20 mg/L/4hr (inhalation).
		tetrakis(hydroxymethyl) phosphonium sulphate LD_{50} oral = 248 mg/kg;
		nickel sulphate hexahydrate LD_{50} oral = 264 mg/kg;
		4-chlorophenol LD_{50} oral = 367 mg/kg;
		naphthalene LD_{50} oral = 450 mg/kg;
		dichlorobenzene LD_{50}oral = 500 mg/kg;
		antimony trichloride LD_{50} oral = 595 mg/kg;
		toluene LD_{50} oral = 636 mg/kg;
		acetaldehyde LD_{50} oral = 661 mg/kg;
		chloroform LD_{50} oral = 695mg/kg;
		calcium hypochlorite LD_{50} oral = 850 mg/kg;
		sodium persulfate LD_{50} oral = 895 mg/kg;
		hydrochloric acid LD_{50} oral = 900 mg/kg;
		benzene LD_{50} oral = 930 mg/kg.

5.1.1.2 Chronic toxicity (human health)

Chronic toxicity refers to the adverse health effects caused by repeated exposures to chemicals, often at low doses, over prolonged periods (i.e. months to years). The chemical does not necessarily have to exhibit acute toxicity to cause chronic toxic effects to human health or the environment.

Chronic toxicity may also refer to a product or chemical being a known carcinogen, mutagen, or toxic to reproduction, fertility and development. Subsequently, use of these chemicals in the environment should be avoided where possible – especially where the chemical is persistent or bioaccumulative with active exposure pathways to sensitive environments, populated areas, water supplies or food chains.

Chronic toxicity methods are based on guidelines from the Organisation for Economic Cooperation and Development (OECD) which mostly use toxicological studies on proxy species, such as rats and mice over their lifespan, to give an indication of potential carcinogenic, mutagenic, reproductive or developmental effects.

Reference to a product's MSDS information may provide an indication whether a product or chemical ingredient is a known or suspected carcinogen, mutagen, teratogen, etc. The most widely used classification system for carcinogens and examples are provided in Table 2. Other carcinogen classification systems also exist including the International Agency for Research on Cancer; US National Library of Medicine Developmental and Reproductive Toxicology Database; European Union; and Safe Work Australia.

Table 2: Classification system for carcinogens and examples (Commonwealth of Australia, 2004; United Nations, 2011)

Carcinogen Classification	Examples
Group 1: Known carcinogen to humans	benzene; ethylene oxide; some polycyclic aromatic hydrocarbons, including benzo[a]-pyrene; formaldehyde; 2-naphthylamine; polychlorinated biphenyls; vinyl chloride
Group 2A: Probably carcinogenic to humans	acrylamide; some chlorinated toluenes; some polycyclic aromatic hydrocarbons; lead (and related compounds); some chloroethylenes; diethyl sulphate; 2-nitrotoluene; polychlorinated biphenyls; trichloropropane; vinyl bromide and vinyl fluoride.
Group 2B: Possibly carcinogenic to humans (suggestive evidence)	acetaldehyde; acetamide; some halogenated aliphatics; carbon tetrachloride; chloroform; dibenzopyrene; dichlorobenzene; naphthalene; vinylacetate
Group 3: Unclassifiable as to carcinogenicity in humans (inadequate information)	benzoy1 peroxide; bromoethane; chlorethane; ethylene; hydrochloric acid; paracetamol; poly vinyl chloride

5.1.2 Environmental hazards

Health hazards in the context of this Guidance refer to adverse effects caused by products, chemicals or substances to the environment (as defined in the petroleum environment regulations). Collectively, environmental hazards in relation to chemical use include:

- acute aquatic toxicity: adverse effects to marine or freshwater flora or fauna health following exposure to a chemical or substance;
- chronic aquatic toxicity: adverse effects to marine or freshwater flora or fauna health following exposure to a chemical or substance;
- bioaccumulation;
- persistence.

5.1.2.1 Acute aquatic toxicity (environment)

Ecotoxicity refers to a suite of toxicity tests on fish, crustacea and algae (or plant material) where the chemical is exposed to aquatic ecosystems. Ecotoxicity may be assessed with regard to short term or long term acute toxicity.

While DMP advocates the use of low hazard chemicals in accordance with the ALARP principle, this is not always possible or practicable. Some products and chemicals are used in the petroleum industry specifically for their toxic properties. For example, biocides are used down-hole to prevent bacterial degradation of the well casing and to prevent well integrity failure). Many of these chemicals could be toxic to fish, crustacea and aquatic plants and therefore the risks must be assessed and managed appropriately.

Acute ecotoxicity methods are based on guidelines from the Organisation for Economic Cooperation and Development (OECD) which mostly use toxicological testing on indicator aquatic species, such as fish, crustacea and macroalgae, to give an indication of relative toxicity to the aquatic environment. LC_{50} or EC_{50} data for each product or chemical should be compared to the criteria for determining whether it is 'harmful', 'toxic' or 'very toxic' (Table 3).

> EFFECTIVE CONCENTRATION (EC_{50})

EC_{50} is the concentration of a chemical that causes 50% of the maximum response for a given species after a specified exposure time. ErC_{50} is a specific measure for plants that reflects reduced growth rates

Table 3: Acute toxicity categories and criteria for aquatic organisms (United Nations, 2011)

Category	Species	LC_{50} and EC_{50} criteria	Method
Very toxic	Fish	LC_{50} (96hr) of ≤ 1 mg/L	OECD Test Guideline 203
	Crustacea	EC_{50} (48hr) of ≤ 1 mg/L	OECD Test Guideline 202
	Algae or other aquatic plants	ErC_{50} (72 or 96hr) of ≤ 1 mg/L	OECD Test Guideline 201
Toxic	Fish	LC_{50} (96hr) of > 1 to ≤ 10 mg/L	OECD Test Guideline 203
	Crustacea	EC_{50} (48hr) of > 1 to ≤ 10 mg/L	OECD Test Guideline 202
	Algae or other aquatic plants	ErC_{50} (72 or 96hr) of > 1 to ≤ 10 mg/L	OECD Test Guideline 201
Harmful	Fish	LC_{50} (96hr) of >10 to ≤ 100 mg/L	OECD Test Guideline 203
	Crustacea	EC_{50} (48hr) of >10 to ≤ 100 mg/L	OECD Test Guideline 202
	Algae or other aquatic plants	ErC_{50} (72 or 96hr) of >10 to ≤ 100 mg/L	OECD Test Guideline 201

If a product has no specific ecotoxicity data available, then the following sequence of options should be considered:

i. ecotoxicity data for analogous products can be referred to where the chemical ingredients and composition are largely identical, i.e. no less than 95% similar (e.g. Portland Cement is produced by different manufacturers with some having minor variations in content). A note must be made of which analogous product is being referred to as a comparison; or

ii. ecotoxicity data may alternatively be referenced for each separate chemical ingredient within the product; or

iii. independent ecotoxicity testing should be undertaken for the product. If independent ecotoxicity testing is deemed necessary, it is DMP's preference that testing be undertaken using local marine or freshwater endemic species. Further information about using endemic marine species in ecotoxicity testing is provided in DMP Petroleum Guidelines: "Drilling Fluid Management", although this guidance relates specifically to drilling fluids used in marine environments. DMP cannot provide further guidance (at this stage) about preferred endemic species for ecotoxicity tests relating to freshwater environments.

5.1.2.2 Chronic aquatic toxicity (environment)

Chronic toxicity data for aquatic organisms are generally less available than acute toxicity data and the range of testing procedures are less standardised (United Nations, 2011). Common measures of chronic toxicity to aquatic organisms include the NOEL and EC_{50} measures in accordance with OECD guidelines. NOEL or ECx data for each product or chemical should be compared to the criteria for determining whether it is 'harmful', 'toxic' or 'very toxic' (Table 4). Further environmental risk analysis may be required in these instances.

> NO OBSERVABLE EFFECTS LEVEL (NOEL/NOAEL)

(NOEL) and No Observable Adverse Effect Levels (NOAEL) which represent the highest exposure to a chemical without adverse effects to a particular species. The US EPA defines NOAEL as an "exposure level at which there is no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered as adverse, or as precursors to adverse effects". The NOEL and NOAEL are commonly used for setting regulatory limits for human exposure, and can be used as proxys measure for toxicity.

Table 4: Chronic toxicity categories and criteria for aquatic organisms (United Nations, 2011)

Category	Species	LC_{50} / EC_{50} criteria (persistent chemicals)	LC_{50} / EC_{50} criteria (biodegradable chemicals)	Method
Very toxic	Fish	NOEL or ECx ≤ 0.1 mg/L	NOEL or ECx ≤ 0.01 mg/L	OECD Test Guidelines 210
	Crustacea	NOEL or ECx ≤ 0.1 mg/L	NOEL or ECx ≤ 0.01 mg/L	OECD Test Guidelines 211
	Algae or other aquatic plants	NOEL or ECx ≤ 0.1 mg/L	NOEL or ECx ≤ 0.01 mg/L	OECD Test Guidelines 201
Toxic	Fish	0.1 < NOEL or ECx ≤ 1 mg/L	0.01 < NOEL or ECx ≤ 0.1 mg/L	OECD Test Guidelines 210
	Crustacea	0.1 < NOEL or ECx ≤ 1 mg/L	0.01 < NOEL or ECx ≤ 0.1 mg/L	OECD Test Guidelines 211
	Algae or other aquatic plants	0.1 < NOEL or ECx ≤ 1 mg/L	0.01 < NOEL or ECx ≤ 0.1 mg/L	OECD Test Guidelines 201
Harmful	Fish	-	0.1 < NOEL or ECx ≤ 1 mg/L	OECD Test Guidelines 210
	Crustacea	-	0.1 < NOEL or ECx ≤ 1 mg/L	OECD Test Guidelines 211
	Algae or other aquatic plants	-	0.1 < NOEL or ECx ≤ 1 mg/L	OECD Test Guidelines 201

5.1.2.3 Bioaccumulation

Bioaccumulation refers to chemicals that remain in the environment for long periods of time and are capable of long range movement through the landscape (e.g. groundwater plumes, atmospheric dispersion, organisms), building up in food chains and causing toxic effects. These chemicals typically resist degradation, in varying degrees, by biological, chemical and photolytic means and may have long lasting toxic environmental effects – even when concentrations are low.

Examples of bioaccumulative chemicals include:

- dioxin and dioxin like compounds;
- polycyclic aromatic hydrocarbons;
- most organochlorine pesticides (aldrin, chlordane, dieldrin, toxaphene, DDT)
- polychlorinated biphenyls (PCBs);
- dibenzo-p-furans;
- tetrabromobisphenol A (TBBPA).

> BIOACCUMULATION / BIOCONCENTRATION FACTOR (BAF / BCF)

Bioaccumulation is best measured using intact organisms in the laboratory or in the field. It is usually expressed as the Bioconcentration Factor (BCF) or Bioaccumulation Factor (BAF), which represents the ratio of a chemical in an organism (e.g. tissue sample) to the concentration in the organism's environment (e.g. water sample). Bioaccumulation measured in this way confirms that uptake takes place and integrates accumulation with biodegradation by the organism. It is worth noting that any single threshold value to define bioaccumulative chemicals may be misleading, as the specific species and predicted / measured values are important to the relevance of BAF/BCF.

Reference to a product's MSDS information is important for determining whether a chemical is likely to be persistent and/or bioaccumulative in the environment. However, this information is not always common in MSDS and further research and / or laboratory testing may be required; for example, the World Health Organisation's Environmental Health Criteria provides further information about research on properties of hazardous chemicals. Persistence, biodegradation and bioaccumulation measures are based on guidelines from the Organisation for Economic Cooperation and Development (OECD).

While BAF/BCF measures are preferred (Table 5), the log octanol-water partition coefficient can also be used to indicate bioaccumulation (Table 6). BAF, BCF and / or Log Pow data for each product or chemical should be compared to the criteria for determining whether it exceeds criteria for confirmed bioaccumulation (Tables 5 and 6). Further environmental risk analysis may be required in these instances.

Table 5: Criteria for confirmed chemical bioaccumulation in the aquatic environment (UN, 2011; US EPA, 2004; Government of Canada, 2000).

Measure	Criteria	Category	Method
Bioaccumulation Factor (BAF) or Bioconcentration Factor (BCF)	≥ 1000	Bioaccumulative	OECD Test Guideline 305 (fish)
Bioaccumulation Factor (BAF) or Bioconcentration Factor (BCF)	≥ 5000	Highly bioaccumulative	OECD Test Guideline 305 (fish)

Examples of chemical's BCFs for fish (Government of Canada, 2000a):

- Polychlorinated biphenyls, BCF = 99,667
- Dioxins and Furans, BCF = 19,000
- Hexachlorobenzene, BCF = 13,130
- Benzo[a]pyrene, BCF = 583

> LOG OCTANOL-WATER PARTITION COEFFICIENT

Bioconcentration factors show a correlation to the log of the octanol-water partition coefficient. The partition coefficient measures how hydrophilic or hydrophobic a chemical is and may be used to indicate those substances having significant potential to bioaccumulate. Hydrophobic chemicals with high octanol-water partition coefficients are preferentially distributed to lipids (fat cells) in animals, which tends to then bioaccumulate over time.

Table 6: Criteria for confirmed chemical bioaccumulation in aquatic environments (UN, 2011).

Measure	Criteria	Method
Logarithm of its octanol-water partition coefficient, Log Pow	≥ 4	OECD Test Guidelines 107 or 117

Examples of chemical's log Pow :

- DDT, log Pow = 6.2
- 1,2,4-trichlorobenzene, log Pow = 4.2
- Naphthalene, log Pow = 3.6
- Toluene, log Pow = 2.7
- Benzene, log Pow = 2.1

5.1.2.4 Persistence

Persistence refers to a substances inability to degrade in the environment over time. Degradation often infers that the hazardous nature of chemicals will become less toxic over time compared to the parent chemical; but this is not always the case (e.g. polycyclic aromatic hydrocarbons). The absence of degradation processes results in chemical sinks in the environment and / or bioaccumulation (the gradual build-up of chemicals in plants and animals over time). Persistent chemicals in the environment may cause chronic health problems, particularly in higher order food chain animals and humans.

Degradation threshold (half-life) data for each product or chemical should be compared to the criteria for determining whether it exceeds criteria for confirmed chemical persistence (Table 7). Further environmental risk analysis may be required in these instances.

> DEGRADATION HALF-LIFE

Persistence for organic chemicals is measured by degradation half-life (the period for a chemical concentration to be reduced by half) exceeds given thresholds (Table 7). Degradation of chemicals, whether it occurs by physical, biological or photolytic means, is important to ensure that their environmental impact is diminished over time. Degradation rates depend on factors like environmental temperature and pressure, chemical concentrations and volumes, the presence of oxygen, and geological and hydrological conditions. The concept of degradation for inorganic chemicals and metals has limited meaning, as the chemical may be transformed in the environment to either increase or decrease its toxicity.

Substances that rapidly degrade are quickly removed from the environment, posing little or no ongoing impacts to the environment. Chemicals are considered rapidly degradable in the environment if the following criteria are met (UN, 2011):

a) If in 28 day ready biodegradation studies, the following levels are achieved:
   i. Tests based on dissolved organic carbon: 70%;
   ii. Tests based on oxygen depletion or carbon dioxide generation: 60% of theoretical maxima;

b) If the preferred degradation data is not available, then the ratio of Biological Oxygen Demand (BOD-5 days) to Chemical Oxygen Demand (COD) being greater than (or equal to) 0.5; or

c) If other scientific evidence is available to demonstrate that >70% degradation can be achieved in the aquatic environment with 28 days.

Table 7: Criteria for degradation threshold (half-life) for confirming chemical persistence (Government of Canada, 2000).

Medium	Degradation threshold (half-life) criteria	Method
Air	≥ 2 days; or Can be atmospherically transported to a remote location.	
Water	≥ 182 days	OECD Test Guideline 301 (freshwater) OECD Test Guideline 306 (marine)
Sediment	≥ 365 days	
Soil	≥ 182 days	

5.1.3 Rapid hazard screening of products and chemicals

A rapid screening process is useful for operators to determine which products, and chemicals therein, are more likely to be hazardous and may present potential risks to the environment and human health. This allows products with low hazard risk to be readily excluded from further detailed environmental risk assessment.

5.1.3.1 Products and chemicals not generally requiring detailed risk assessment

While it should be noted that all chemicals can be hazardous under certain situations (even table salt and water); some products and chemicals are generally less hazardous than others and will not generally require detailed risk assessment. Products derived from natural substances such as water, guar gum, cellulose, plant material, sand, clays, will not require detailed risk assessment. Likewise, inert man-made substances, such as ceramics and glass, would not generally require a risk assessment.

Some products note in their MSDS that a product is 'not believed/understood' to be hazardous to the environment or human health. These statements contribute towards uncertainty and increases the level of risk associated with its use. Scientific data must be provided by the supplier or manufacturer to feasibly demonstrate that a product or chemical is not hazardous.

DMP recognises the use of PLONOR products when used in the marine environment. PLONOR – 'Poses Little or No Risk' refers to products used in the offshore petroleum industry that are perceived to be a low hazard to the marine environment. PLONOR is a specific list of products generated by the OSPAR Commission and established by the Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR Commission, 2012). The PLONOR list is only applicable to marine environments – it is not appropriate, nor designed for, application to onshore environments (where chemical properties, dilution factors, exposure pathways, species and environment risks are considerably different). A comparable list for onshore products is not currently available.

It should be noted that products and chemicals not requiring detailed risk assessment does not remove the need for the product or chemical to be disclosed in the DMP Chemical Disclosure Reporting Template.

> NO ENVIRONMENTAL RISK ASSESSMENT FOR CHEMICALS WILL BE REQUIRED IF:

- *Product is on the OSPAR PLONOR list (for marine environments only);*
- *Product is comprised of natural ingredients (e.g. water, plant material, cellulose, sand, natural clays, etc.);*
- *Product is an inert, man-made substance (e.g. ceramics, glass, mix / blends of natural products);*
- *Products or chemicals therein:*
  - *a) do not meet criteria for being 'harmful', 'toxic' or 'very toxic' to human health and / or the environment; and*
  - *b) are not classed as a known carcinogen, mutagen or toxicant to reproduction, fertility or development; and*
  - *c) do not meet criteria for being persistent or bioaccumulative.*

5.1.3.2 Products and chemicals generally requiring detailed risk assessment

A simple risk assessment process of general products and chemicals may be appropriate in some instances; for example, to inform the selection of the safest option when making decisions about which products or chemicals to use.

In comparison, some hazardous products and chemicals may potentially be more risky to use in certain environments, have higher consequences should contamination occur, and treatment options may be more intensive and costly. These products and chemicals are more likely to warrant detailed risk assessment, especially where:

- complex chemical issues are involved; or
- there is a plausible risk of significant health or environment consequences; or
- there is uncertainty regarding the level of risk involved.

Environmental risk assessment of chemicals also depends on many complex variables both intrinsic and extrinsic to the petroleum activity. This necessitates DMP to assess environment risks from products and chemicals on a case-by-case basis. Some of these variables may include:

- presence of plausible exposure pathways;
- the extent of risk mitigation in place;
- the amount of product being used or stored on site;
- the concentration of the product and chemicals being used down-hole;
- the extent of product and chemical dilution when used in the environment;
- whether the product and chemicals therein are being used in a sensitive environment;
- whether the product and chemicals therein are at risk of entering water supplies or the food chain;
- whether the chemical is volatile and may affect air quality for sensitive receptors;
- situations where there is a high level of public interest or concern about chemical use;
- whether the chemical is likely to exceed relevant environmental standards or other relevant guidelines;
- where there is considerable uncertainty regarding a products, or chemicals, hazardous properties.

In view of the above, DMP considers it inappropriate to present a generic list of products and chemicals that would generally require environmental risk assessment.

> ENVIRONMENTAL RISK ASSESSMENT FOR CHEMICALS WILL GENERALLY BE REQUIRED IF:

- *Products or chemicals therein;*
  - *a) meet criteria for being 'harmful', 'toxic' or 'very toxic' to either human health or the environment; or*
  - *b) are a known carcinogen, mutagen or toxic to reproduction, fertility or development; or*
  - *c) meet criteria for being persistent or bioaccumulative;*

    and;
- *Risk, uncertainty or complexity is associated with its use.*

5.1.4 Exposure assessment

Exposure assessment follows chemical hazard identification and assessment. It requires identification of potential chemical sources, consideration of the likely fate and transport of the chemical, identifying potential sensitive receptors that could be exposed to the chemical, and the likely exposure pathways. Exposure assessment is one of the more complex areas of risk assessment, requiring consideration of site-specific details on a case-by-case basis. While this Guidance provides an outline of exposure assessment, further detail about relevant methods is available at in the "Environmental Health Risk Assessment" guidelines (Department of Health and Ageing, 2012).

5.1.4.1 Sources of chemicals

Potential sources and risk events of chemical releases or emissions should be identified irrespective of whether or not the source is under the control of the operator. In these instances, chemicals may be released directly or indirectly into air, water, soil, waste or food. Consideration should be given as to how the product, and chemicals therein, will be used and how they could potentially be released to the environment.

Potential chemical sources and risk events in the petroleum industry may include:

- Above-ground chemical spills and leaks from:
  - Chemical onsite storage in containers or tanks;
  - Transfer of chemicals during use or mixing;
  - Transportation of chemicals (e.g. trucks, pipelines);
  - Wastewater or flowback retention ponds;
  - Well blowout (surface);
- Below-ground chemical spills and leaks from:
  - Inadequate well closure and plugging;
  - Uncontrolled fracture propagation;
  - Loss of well integrity;
  - Well blow out (sub-surface);
- Air emissions of chemicals caused by:
  - Flaring and burning of hydrocarbons;
  - Evaporation of volatile chemicals from evaporation / retention ponds;
  - Well blowout (surface)
  - Dust emissions from cementing products or other substances containing fine particles.
- Other:
  - Unrestrained access of fauna (e.g. birds, livestock) to evaporation / retention ponds;
  - Inappropriate reuse / disposal of flow-back water.

5.1.4.2 Chemical fate and transport

For each chemical source and risk event, the likely fate and transport of the chemical should be considered. Fate of a chemical depends on its chemical and physical properties including its persistence, solubility, binding ability, volatility and how it interacts with the environment media in which it is released.

Chemicals in air emissions will be mobilised from their source and dispersed at a rate depending on its ability to disperse and weather conditions. Chemicals released to surface water flows may be mobilised away from the source at a rate depending on solubility and water flows. Similarly, release to groundwater aquifers may result in movement away from the source over an extended period, depending on hydrogeological conditions. Depending on persistence, solubility and soil binding properties, chemicals released to soil have potential to remain at a site for many years or percolate into groundwater. The fate and transport pathways for a chemical will affect potential exposure routes for sensitive receptors (i.e. humans, fauna and sensitive environments).

5.1.4.3 Exposure pathways

A fundamental concept of risk assessment is that there must be plausible evidence of an exposure pathway linking the chemical source and the sensitive receptor (Department of Ageing and Health, 2012). Chemicals may exert an environmental effect, but may become an exposure problem when the chemical comes into contact with a sensitive receptor or sensitive environment. In this regard, people and communities in the immediate vicinity of the petroleum activity should always be identified as relevant stakeholders as they are most likely to be exposed in the event of a potential chemical release or discharge. The effect of chemicals on those receptors will be determined by the hazard, does and the exposure pathway, namely through inhalation, ingestion (oral) and/or skin contact (dermal).

Inhalation of chemicals is more likely in relation to:

- Air emissions of chemicals, particularly volatile chemicals;
- Dust and particulates;

Ingestion of chemicals is more likely in relation to:

- Contaminated drinking water;
- Contaminated food sources (such as livestock and crops tainted by chemicals);

Skin contact with chemicals is more likely in relation to:

- Contaminated soil and water sources;
- Direct exposure to chemicals on-site.

Exposure of sensitive receptors to chemicals may occur over:

- Short periods – usually following exposure to an temporary source or acute event (e.g. volatile organic chemicals being emitted in flaring as aerosol or gas; or a chemical spill to soil or water); or
- Long periods – typically where contamination occurs (e.g. persistent chemicals moving through a groundwater plume over several decades).

Availability of relevant and contemporary information about chemical hazards and properties, well integrity, equipment operation and process design is necessary to identify potential exposure pathways. Likewise, involvement of stakeholders and people with appropriate knowledge and expertise are important in the identification of plausible environmental issues and impacts.

A comprehensive list should be generated by the operator to identify potential chemical sources and risk events, and to identify all potential environmental risks and impacts associated with chemicals. The list should cover all potential exposure pathways. This process should help to identify environmental risks and impacts associated with chemical sources and risk events, relevant to the petroleum activity (Table 8).

Table 8: Example of environmental impact and sources for chemical sources and risk events

Risk Type	Source / risk event	Environmental risks and impacts
Surface chemical spills and leaks	Chemical onsite storage leaks/ spills	- Air emissions, i.e. volatile chemicals. - Groundwater contamination. - Surface water contamination. - Soil contamination. - Potential health impacts on local residents. - Potential impacts on vegetation, crops and pastures. - Potential impacts on local fauna and livestock.
	Spills during transfer of chemicals	
	Transport related spills	
	Retention pond leaks / overflows	
	Surface well blowout	
Subsurface chemical leaks	Inadequate well closure and plugging	- Groundwater contamination. - Potential impacts to surface water resources and ecosystems. - Potential impacts to local water supplies.
	Uncontrolled fracture propagation	
	Loss of well integrity	
	Subsurface well blowout	
Air emission	Flaring	- Air emissions, i.e. volatile chemicals. - Potential health impacts to local residents.
	Spills during transfer of chemicals	
	Transport related spills	
	Surface well blowout	
	Retention pond air emissions	
Other	Unconstrained fauna access to evaporation / retention ponds	- Loss of local fauna, livestock through direct chemical exposure. - Potential chemical tainting of crops, pasture, livestock drinking water, etc.
	Inappropriate reuse / disposal of flow back water	- Potential soil, water contamination. - Potential health impacts on local residents. - Loss of local fauna, livestock through direct chemical exposure. - Potential impacts to vegetation. - Potential chemical tainting of crops, pasture, livestock drinking water, etc.

5.2 Risk analysis for products and chemicals

Risk analysis involves developing an understanding of the potential environment risks and impacts identified from the risk identification process. Results of the risk analysis provide input to risk evaluation and will inform decisions on whether risks need to be treated or mitigated.

Risk analysis involves consideration of the risk sources or events, their positive and negative consequences, and the likelihood that those consequences will occur. The outcome of risk analysis is to determine a risk level which represents the relative magnitude of a risk eventuating (or combination of risks).

Methods and techniques used to determine the chemical risk consequence and likelihood levels are described in detail in the International Standard IEC/ISO 31010: 2009; and may include:

- Preliminary hazard analysis (PHA);
- Hazard and Operability study (HAZOP);
- Toxicity assessment;
- Root cause analysis;
- Fault tree analysis (FTA);
- Event tree analysis (ETA); and
- Bow tie analysis.

Risk analysis can be undertaken in varying degrees of detail, depending on the risk, the purpose of analysis, and the information and data available. The units used to express the level of risk can be qualitative (expressed by significance tests), semi-quantitative (expressed by numerical rating scales), or quantitative (estimated as probabilities of specified consequences in specific units), or a combination of these, depending on the methods for risk analysis.

5.2.1 Consequence analysis

In the context of this Guidance, consequence refers to an environmental outcome or impact arising from a chemical related discharge, emission or risk event occurring. Consequences may be certain or uncertain and may have positive or negative impacts. An assessment of consequence will indicate the seriousness of a chemical related risk event, which may be expressed in terms of corporate, environment, social and economic implications. It can also provide an indication of whether environmental objectives and risk criteria in the EP are likely to be met.

A key purpose of consequence analysis is to determine potential environmental impacts, so that the seriousness and magnitude of chemical risks (i.e. the level of consequence) can be rated and risk mitigation and treatment activities prioritised. The types of consequences included in the risk analysis and the way they are measured are defined when the context was established.

Consequences may be expressed in qualitative or quantitative terms. Where the severity of potential consequences is 'high' or 'very high', consequences should be analysed in further detail. For example, modelling the consequences of the potential discharge of a hazardous chemical from a petroleum activity into a marine park may help determine the best method to mitigate risks and to optimise risk treatment methods.

Some challenges associated with determining consequence ratings for chemical risks include situations where:

- transport and exposure pathways for a chemical are not well understood;complex or synergistic chemical reactions are not well understood;
- limited information exists for a product or its chemical ingredient's hazardous properties; or
- long timeframes are required for detecting human health and ecological impacts.

Where a detailed environmental risk assessment is undertaken for chemical risks, DMP recommends presenting chemical risks and consequence levels in a table, consistent with DMP's Guidelines for the Preparation and Submission of an Environment Plan (DMP, 2012a; Table 9).

Table 9: Example of consequence levels

Consequence levels	Types of risk events	Potential consequences/impacts	Response (if risk eventuates)
Very low (A)	Includes references to events that cause insignificant, slight, negligible and very low impacts.	- Objectives are met with certainty. - Risk criteria are being met with certainty. - Minor chemical incident. - Minimal environmental impacts.	- Not reportable to DMP - Monitor risk
Low (B)	Includes references to events that cause temporary, limited or minor impacts.	- Objectives are likely to be met. - Risk criteria are likely to be met. - Chemical incident. - Confined / localized environmental impacts.	- Not reportable to DMP - Monitor risk
Moderate (C)	Includes references to events that cause moderate or localized impacts.	- Objectives are at risk of not being met. - Risk criteria is at risk of not being met. - Significant chemical event. - Minor, but manageable, environmental impacts. - Potential health impacts. - Disruption to business activity.	- Reportable to DMP - Risk mitigation and treatment if appropriate
High (D)	Includes references to events that cause major, significant, or serious impacts	- An environmental objective is not met. - Risk criteria is exceeded. - Chemical pollution or contamination is likely. - Significant environmental impacts. - Significant health impacts. - Negatively impacts company.	- Reportable to DMP - Risk mitigation and treatment
Very high (E)	Includes references to events that cause catastrophic, very significant, critical, or extensive impacts.	- An environmental objective is not met. - Risk criteria is exceeded. - Chemical pollution or contamination occurs. - Irreversible significant impacts to environment. - Fatalities or serious health impacts. - Significant negative impacts for company.	- Reportable to DMP - Risk mitigation and treatment - Emergency response

It is also important to note that any chemical risk event identified through the environmental risk assessment process having a consequence level of 'moderate', or more serious than moderate, is deemed to be a "reportable incident" to DMP should the risk actually eventuate (i.e. an accident / incident occurs). This is a regulatory requirement as defined in the petroleum environment regulations (regulations 4 and 17(2)) and required in the EP.

5.2.2 Likelihood analysis

In the context of this Guidance, likelihood refers to the probability of an environmental risk event occurring. Risks that have a high likelihood (i.e. frequent occurrences) have a greater chance of a risk event or environmental impact actually occurring.

The purpose of likelihood analysis is to estimate the likelihood that a risk event will occur. This process can be used to make decisions about whether the chance or frequency is acceptable, and to reduce the chance of a risk event from actually occurring.

Methods for determining likelihood include using records of historical events, monitoring data, research, expert opinions, previous experiences and/or predictive modelling. Predictive modelling involves detailed mathematical models (including ground water models, surface water models and air dispersion models).

Likelihood analysis for chemical risks involves estimating the frequency or probability of an individual incident or risk event, a chain of events or several chains of events leading to an impact. This includes considering the probability of the chemical hazard reaching a sensitive receptor by different routes and pathways and the probability of causing an environmental and/or health impact. The probability of an environmental or health impact occurring is calculated by multiplying the individual risk event probabilities together over a specific timeframe.

For example, the determination of a likelihood level for a hazardous chemical spill from an on-site storage tank causing an environmental impact will need to consider the following:

- annual probability of a hazardous chemical spill of a given volume occurring from an on-site storage tank;
- safety procedures in place and risk mitigation measures (e.g. containment);
- length of timeframe that the hazardous chemical will be used or is stored on-site;
- frequency of use, transport and handling of the hazardous chemical;
- local environmental conditions and natural risk events that may cause storage failures (e.g. floods, fires, cyclones, etc.);
- likelihood of equipment, infrastructure or process failure;
- likelihood of human error.

Where a detailed environmental risk assessment is undertaken for chemical risks, DMP recommends presenting chemical risks and likelihood levels in a table, consistent with DMP's Guidelines for the Preparation and Submission of an Environment Plan (DMP, 2012a; Table 10).

Table 10: Examples of likelihood levels

Likelihood levels	Frequency of risk events	Examples of estimated probability of occurrence
Highly Unlikely (1)	Includes references to rare, remote, unheard of, exceptional.	< 0.1% chance of occurring. 1 year in 1000 years
Unlikely (2)	Includes references to infrequent, uncommon.	~ 1% chance of occurring. 1 year in 100 years
Possible (3)	Includes references to occasionally, periodically.	~ 10% chance of occurring. 1 year in 10 years
Likely (4)	Includes references to frequent, regular, common.	~ 50% chance of occurring. 1 in every 2 years
Highly likely (5)	Includes references to almost certain, expected, repeating.	>90% chance of occurring. Almost annually

5.3 Risk evaluation for products and chemicals

Risk evaluation involves comparing the level of risk determined in the risk analysis process (section 5.2) against the acceptable risk criteria defined when the context was established (section 4.2). Following risk analysis, the risk criteria may need to be reviewed to ensure their relevance and to determine the need for additional risk criteria.

The purpose of the evaluation process is to determine which risks are considered acceptable (against the established chemical risk criteria), and the priorities for risk mitigation and treatment. Decisions should be made at this stage whether to proceed or continue with the proposed products and chemicals, based on the level of risk and other considerations (such as public perceptions, social benefits and financial costs).

5.3.1 Risk rating

The risk rating is determined for a particular risk by combining the consequence level (section 5.2.1) with the likelihood level (section 5.2.2). The results of the risk evaluation process should be summarised in a risk matrix table (example at Table 11), noting that the main feature is to divide the table into thirds for relative priorities in risk treatment.

The three risk rating classifications are:

- Major risks: Levels of chemical risks are regarded as unacceptable or intolerable and risk mitigation and treatment measures are essential irrespective of the costs;
- Medium risks: Levels of chemical risks are regarded as unacceptable, but may be tolerable, and risk treatment and mitigation should apply where possible; and
- Minor risks: Levels of chemical risks are regarded as acceptable and no risk treatment is necessary.

Table 11: Example of a risk matrix

		Likelihood level				
		Highly unlikely (1)	Unlikely (2)	Possible (3)	Likely (4)	Highly Likely (5)
Consequence level	Very high (E)	Medium	Major	Major	Major	Major
	High (D)	Medium	Medium	Major	Major	Major
	Moderate (C)	Minor	Medium	Medium	Medium	Major
	Low (B)	Minor	Minor	Medium	Medium	Medium
	Very Low (A)	Minor	Minor	Minor	Minor	Medium

5.3.2 Uncertainty

When evaluating environmental risks, it is important to identify the uncertainties associated with the risk assessment process, and to communicate how each uncertainty has been or will be addressed and how this has or will influence decisions.

The uncertainties to be accounted for may include those associated with impact prediction models, lack of available information in the early stages of the project development, incomplete knowledge of the possible environmental impacts, the complexity and scale of the ecosystems and their interactions, and the long timeframes before any ecological change or toxicological impact may be detected.

Uncertainty in environmental risk assessment may be addressed by obtaining more data and information through environmental investigations and studies, researching comparable situations elsewhere, long term environmental impact monitoring; and / or using a conservative approach to provide a sufficient margin of safety.

Clear documentation of uncertainties provides an understanding of the reliability and confidence in the risk levels determined in the risk assessment process. An indication on the level of confidence in the risk levels is provided in Table 12.

Table 12: Indication of confidence in the risk levels determined

High confidence	Several expert investigations/studies Excellent survey data Long term monitoring results available Modeling conducted and calibration shows good adherence to real occurrences. Comparable events / situations available
Moderate confidence	Some survey data available Short term monitoring results available Modeling conducted but calibration shows occasional aberration from occurrences. Available information is adequate
Low confidence	No survey data No model verification possible No modeling conducted Available information is inadequate

6. Definitions

Acute toxicity refers to the adverse effects of exposure to a product or chemical over a short period of time (usually less than 24 hours).

ALARP As Low As Reasonably Practicable

AS/NZS Australian Standards / New Zealand Standards

BAF / BCF Bioaccumulation Factor, Bioconcentration Factor

Bioaccumulation refers to the build-up and movement of chemicals in the environment over long periods of time, typically causing toxic effects.

Bridging EP refers to a document that links specific activities or additional proposed activities to those already in an approved Environment Plan. The bridging EP is only appropriate for minor to moderate risks associated with additional or modified activities.

Chemical refers to any material that has a constant composition and distinct properties.

Chemical disclosure is the provision of information about chemicals to be used and their relevant properties.

Chronic toxicity refers to the adverse health effects caused by repeat exposures to chemicals, often at low doses, over prolonged periods (i.e. months to years).

Consequence is the outcome of a risk event affecting objectives.

DER Department of Environment Regulation (formerly Department of Environment and Conservation

DMP Department of Mines and Petroleum

DoH Department of Health

DoW Department of Water

DSEWPaC Department of Sustainability, Environment, Water, Population and Communities

EC_{50} refers to the concentration of a chemical that causes 50% of the maximum response for a given species after a specified exposure time.

Ecotoxicity refers to a suite of toxicity tests on fish, crustacean and algae (or plant material) where the chemical is exposed to aquatic ecosystems.

Environment is defined in regulation 4 of the petroleum environment regulations as:

- "ecosystems and their constituent parts, including people and communities; and
- natural and physical resources; and
- the qualities and characteristics of locations, places and areas; and
- the heritage value of places; and
- includes the social, economic and cultural features of the [above-mentioned]".

Environment Plan is a document prepared for a proposed petroleum activity, using an environmental management systems approach, in relation to requirements under the WA petroleum environment regulations.

Environmental health includes those aspects of human health determined by physical, chemical, biological and social factors in the environment.

Environmental value is a beneficial use or an ecosystem health condition.

EP Environment Plan

EPA Environmental Protection Authority

ErC$_{50}$ means EC$_{50}$ in terms of reduced growth rate.

Exposure is the amount of a particular chemical or substance that reaches a target organism or population in a specific frequency for a defined duration.

Exposure pathway is the way a chemical or substance moves through the environment to reach an exposed organism or population.

Hazard refers to the inherent properties of a chemical or situation having the potential to cause adverse effects.

ISO International Organisation for Standardisation

LD$_{50}$ / LC$_{50}$ Lethal Dose / Lethal Concentration of a particular chemical that when applied to organisms, is estimated to be fatal to 50% of those organisms under the stated test conditions.

Likelihood the chance or probability of something happening.

MSDS Material Safety Data Sheets

NICNAS National Industrial Chemical Notification and Assessment Scheme

NOEL / NOAEL No Observable Effect Levels and No Observable Adverse Effect Levels represent the highest exposure to a chemical without adverse effects to a particular species.

OECD Organisation for Economic Cooperation and Development

OEPA Office of the Environmental Protection Authority

Petroleum activity is defined under regulation 4 of the petroleum environment regulations, as a petroleum operation or works relating to exploration or development which may have an environmental impact, and may include:

- seismic or other surveys;
- drilling;
- hydraulic fracturing;

- construction and installation of a facility;
- operation of a facility;
- modification of a facility;
- decommissioning, dismantling or removing a facility; and
- storage of petroleum.

Risk refers to the effect of uncertainty on objectives.

Risk assessment is part of the risk management process of estimating the potential impact of a hazard to people, communities or an ecological system under a specific set of conditions and over a given time frame.

Risk criteria is the criteria or standards against which the significance of a particular risk is assessed.

Risk event is the occurrence or a change of particular circumstances related to a risk.

Risk identification is the process of finding, recognising and describing risks.

Risk management are coordinated activities to direct and control an organisation with regard to risk.

Risk treatment involves selecting options and implementing measures to reduce the risk levels that were identified as priority risk ratings in the risk evaluation process.

Substances refer to solids and solid mixtures that have consistent properties, including sands, muds, cements, proppants, ceramics and plant material.

Toxicity is the inherent property of a chemical to cause an adverse biological effect.

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