Radiological dose criteria for heavy mineral sands residues in Queensland[1]

This position paper explores the application of radiological criteria for dose rates related to gamma radiation at sites or decision areas impacted by heavy mineral sands residues (HMSRs)[2], which are being assessed under the Queensland contaminated land framework. These sites can include former heavy mineral sands processing plants and mining sites, or other land where HMSRs have been placed as stockpiles or fill, pumped as tailings slurries, or used for trenching backfill, sub-slab bedding sands, top-dressing, and the like.

The ASC NEPM (2013, B1) describes that specialised forms of assessment are required for sites affected by, amongst others, radioactive substances. In situations where these occur, the ASC NEPM recommends that guidance for assessment requirements is sought from the relevant jurisdictional environmental or health authority. And that while the general principles of site assessment are applicable, compliance with specialised safety protocols and assessment guidance is essential to ensure the protection of human health and the environment.

In Queensland, the primary guidance is from Queensland Health (2020), which while establishing a framework for dose criteria in the assessment and management of contaminated land, does not specifically establish dose criteria which are analogous to the health investigation levels (HILs) as established under the ASC NEPM guidance. As the assessment and management of contaminated land in Queensland is based on the ASC NEPM guidance, it is considered necessary to specify dose criteria as HILs, to allow integration of the assessment and management of land impacted by HMSRs into the broader contaminated land framework. This includes for the listing of sites on the land registers under the *Environmental Protection (EP) Act* 1994.

Accordingly, this position paper seeks to integrate the general approach for the use of HILs, along with the associated data assessment requirements from the ASC NEPM (2013, B1 and B2), with the specific requirements for radiological dose criteria in Queensland for HMSRs.

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[1] Salmon M.C. (June 2021) *Radiological dose criteria for heavy mineral sands residues in Queensland*, Version 3 (revised with updated guidance and dose criteria), Easterly Point Environmental, Byron Bay NSW.

[2] Heavy minerals with a specific gravity of greater than 2.85, e.g. rutile (4.21), zircon (4.68), ilmenite (4.72) and monazite (4.8 - 5.5).

1. Application of the "HIL" dose criteria

The suggested dose criteria relate only to existing exposure situations[3] which are being addressed under the Queensland contaminated land framework. Remediation or disposal activities, including the transport of radioactive materials, should be considered as planned exposure situations[4], and therefore subject to current environmental and radiation safety legislation (Queensland Health 2020).

The following are not addressed by this position paper, for which specific technical and regulatory advice should be sought:

- emergency exposure situations;
- other forms of radiological contamination, including alpha and beta radiation;
- other industries or processes with radioactive sources or other forms of naturally occurring radioactive materials (NORMs); and
- heavy mineral sands sites or facilities where planned exposure situations exist, such as where current regulated practices are occurring.

Application of this position paper is also based on the reasonable assumption that the sites or decision areas have been appropriately investigated by suitably qualified and experienced practitioners[5], including both at surface and depth. All radiological investigations should include the development of site-specific, robust conceptual site models (CSMs) in accordance with the ASC NEPM (2013, A and B1), and should be supported by sufficient evidence using a weight of evidence approach.

ANZG (2018) describes weight of evidence as:

> *the process to collect, analyse and evaluate a combination of different qualitative, semi-quantitative or quantitative lines of evidence to make an overall assessment of contamination. Applying a weight of evidence process incorporates judgements about the quality, quantity, relevance and congruence of the data contained in the different lines of evidence.*

2. Environmental media and exposure pathways

The nature of heavy mineral sand grains means they are not readily soluble, such that contamination of surface water and groundwater is not normally a major concern in the assessment of land contamination in relation to heavy mineral sands. Other potential pathways include ingestion of minerals and indirect pathways such as in food or water, although for mineral sands, because of their insoluble nature, these pathways are not generally considered to be realistic.

Whereas inhalation of dust containing long-lived alpha-emitting radionuclides is a potential exposure pathway, the heavy nature of the minerals, and the relevant concentrations, means that dust is not a realistic exposure pathway where the dry processing of heavy mineral sands does not occur. Another potential exposure pathway is inhalation of the short-lived decay products of radon gas. However, this requires poorly ventilated areas to allow build up, and is

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[3] Existing exposure situations – a situation of exposure that already exists when a decision on the need for control needs to be taken, e.g. due to residual radioactive material that derives from past practices that were not subject to regulatory control (ARPANSA 2017).

[4] Planned exposure situations – a situation of exposure that arises from a planned operation of a source or from a planned activity that results in an exposure due to a source. Since provision for protection and safety can be made before embarking on the activity concerned, associated exposures and their probabilities of occurrence can be restricted from the outset (ARPANSA 2017).

[5] Including membership of the Australasian Radiation Protection Society (ARPS), or similar, and certification as a practitioner in the contaminated land field, e.g. CEnvP or CPSS (see Page 10).

not generally a characteristic of these minerals as the radioactive gas radon is mostly retained within the mineral sand grains.

For HMSRs, it is exposure to external gamma radiation from the concentrates and the like that is generally targeted, with the media of concern being soils and fill materials. Nevertheless, this approach needs to be confirmed on a site-specific basis, to confirm that surface waters, groundwaters and air are not specific media of concern. This should include the development of a site-specific, robust CSM.

3. Dose quantities

Radiation exposure is measured as an absorbed dose, which is equivalent to the energy in joules (J) deposited in a kilogram (kg) of a substance by the radiation. The dose units are expressed as grays (Gy) for absorbed dose, but also as sieverts (Sv) for equivalent dose (H), which is absorbed dose multiplied by a radiation weighting factor (WR), or Sv for effective dose (E), which is the equivalent dose multiplied by a tissue weighting factor (WT).

As the WR for gamma radiation is 1, Sv are at times considered to be effectively interchangeable with Gy for HMSRs when considering H equivalent dose. Conversion from Gy to Sv is undertaken when E effective dose is being considered, noting that UNSCEAR (1982) describes that "The primary assessment of radiation exposure of individuals should be carried out in terms of absorbed dose".

Where the assessment of the distribution of absorbed dose in body tissue is considered as stochastic effects, that is the likelihood of radiation related cancers, E effective dose is considered. Any such assessment must consider the photon energy and angular distribution of the flux of all electromagnetic and particle radiation, as well as assumptions about depth of exposure, time of exposure, mass energy absorption, backscatter radiation, direction of radiation, movement of the irradiated person, organs exposed, and the like.

In these instances, UNSCEAR (1982) selected 0.7 for conversion of Sv to Gy, as the "most appropriate average value of the quotient of effective dose equivalent rate to absorbed dose rate in air for males and females". UNSCEAR (2000) revised this value based on age categories, and described that:

> *The Committee has used a coefficient of 0.7 Sv Gy^{-1} to convert absorbed dose in air to effective dose equivalent and effective dose. This result was based on an analysis in the UNSCEAR 1982 Report, and more recent calculations have confirmed the validity of this value for adults. However, newer calculations using Monte Carlo radiation-transport codes indicate that higher values should be used for infants and children. These values, for average energies of gamma rays, are 0.9 Sv Gy^{-1} for infants and 0.8 Sv Gy^{-1} for children.*

As dose criteria are established as E effective dose in Sv, it is necessary to convert between Sv and Gy where field measurements are recorded in Gy. Use of 0.8 Sv Gy^{-1} is suggested as the mid-point value, which is considered to be both conservative and yet realistic.

4. Background dose

Radiological assessments also need to consider naturally occurring terrestrial and cosmic radiation, with ARPANSA (2008) describing the average annual dose in Australia from terrestrial gamma radiation as approximately 0.3 mSv, and from cosmic radiation at sea level as approximately 0.3 mSv. The determination of background, that is ambient background concentrations (ABCs), should be by direct measurement at "a clean reference site with a comparable soil type to the site being examined" (NEPC 2013, B5b).

However, as some former heavy mineral sand sites can display large variations of naturally occurring exposed heavy minerals, a default value for coastal South East Queensland of 0.133

μGy/h is suggested. This consists of 0.095 μGy/h terrestrial air kerma[6] rate, considered the 95th percentile of Queensland air kerma rates (Kleinschmidt and Watson 2016), plus a cosmic contribution of 0.038 μGy/h for coastal South East Queensland.

Where considered appropriate, the method recommended within the ASC NEPM may be used for determining the background dose rate, rather than this default value; assuming sufficient sampling and technical rigour is used in determining the average background dose rate, including sufficiently representative and precise data (see for example, Salmon 2020).

5. Exposure duration

In determining potential exposures from measured or derived dose rates, it is necessary to include the likely, realistic exposure duration, with exposure duration being variable depending on the proposed land use and the relevant guidance.

In the assessment of site contamination, if land is to be certified as requiring no management, then full time occupancy should be assumed; as if hours are specified less than full time occupancy, what management techniques exist to ensure that the expected and the actual occupancies are essentially identical? However, where management is to be enacted, there is scope for the specification and documentation of more realistic exposure durations.

Table 1 shows potential exposure durations based on the ASC NEPM (2013, B7) and ARPANSA (2017).

Table 1: Possible exposure durations

	Days	Hours per day[1]	Total hours per year
Full time occupancy	365.24	24	8,766
ASC NEPM (2013, B7) *Guideline on Derivation of Health-Based Investigation Levels*			
Residential HIL-A, accessible soil	365	20 / 4	8,760
Residential HIL-B, non-accessible soil	365	20 / 1	7,665
Open space/recreational HIL-C	365	0 / 2	730
Commercial/industrial HIL-D	240	8 / 1	2,160
ARPANSA (2017) *Guide for Radiation Protection in Existing Situations*			
Residential	-	-	7,000
Occupational	-	-	2,000

Table notes:
1. Indoors / outdoors.

6. Dose criteria

ARPANSA (2017) describes that "Dose criteria serve as boundaries within which the optimisation process takes place and serve to reduce inequities of exposure". Three types of dose criteria are applied in radiation protection (ARPANSA 2017):

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6 Kerma (kinetic energy released per unit mass) is the term attributable to absorbed dose from uncharged ionising radiation. This is the parameter measured by field surface gamma radiation surveys; which can also be approximately derived from the activity concentrations of soil samples.

- *Dose constraints – a prospective and source-related restriction on the individual dose from a source, which provides a basic level of protection for the most highly exposed individuals from a source, and serves as an upper bound on the dose in optimisation of protection for that source.*

- *Dose limits – the value of the effective dose or the equivalent dose from planned exposure situations that shall not be exceeded.*

- *Reference levels – in emergency or existing controllable exposure situations, this represents the level of dose or risk, above which it is judged to be inappropriate to plan to allow exposures to occur, and below which optimisation of protection should be implemented; the chosen value for a reference level will depend upon the prevailing circumstances of the exposure under consideration for the public and non-human biota.*

These dose criteria are for the radioactive source, and exclude natural background levels.

Queensland Health (2020) describes that an annual dose of 0.3 mSv is a dose constraint for planned exposure situations, that is situations based on current regulated practices. This dose constraint is the dose that approved disposal of radionuclides to the environment should not exceed for these practices. This value is consistent with typical variations in natural background radiation levels in Australia, which ARPANSA (2008) describes as of the order of 0.1 – 0.3 mSv/y, with the variation due to differences in altitude, latitude and geology.

Section 54 of the *Radiation Safety (RS) Regulation* 2010 specifies a dose limit for public exposure of persons, as total effective dose, of no more than 1 mSv per year for licenced radiation practices with ionising radiation sources. This dose limit is consistent with that specified by ARPANSA (2020), which sets a dose limit of 1 mSv in a year as effective dose for members of the public.

It is generally appropriate to consider HMSRs as mineral substances that are radioactive materials that are not a radioactive substance. In which case, Section 58 of the RS Regulation specifies that a person in possession of such material must ensure that for public exposures, another person does not receive a total effective dose from ionising radiation emitted from the material of more than 1 mSv per year.

As the dose limits are for total effective dose, it is the stochastic effects which are being controlled, that is potential radiation induced cancers and genetic damage (hereditary effects), as these are considered to generally occur without a threshold level of dose. Tissue reactions, or deterministic effects, are relevant at much higher doses, such that controlling for stochastic effects is considered to be protective of these reactions.

ARPANSA (2017) describes that reference levels are used for optimisation of protection in existing exposure situations, and that an intermediate reference level of 10 mSv/y above natural background levels applies to legacy sites. And notes that "revision of the intermediate reference level to improve the situation progressively is required". For existing exposure situations, such as former unregulated HMSRs, Queensland Health (2020) describes that "Actual or potential annual doses to persons up to 5 mSv are within the tolerable range for existing exposure situations". Although it is also noted that:

> *Although annual doses to a person of up to 5 mSv are tolerable, it should be kept in mind that dose optimisation is a key principle. Remediation is more likely to be justifiable as the annual dose to a person approaches 5 mSv, whereas an annual dose to a person in the region of 1 mSv may only be justifiable if easy to achieve.*

Table 2 of Queensland Health (2020), *Action reference levels for radioactive contamination and guidance for action*, describes the actions that may be taken if the estimated actual or potential annual effective dose, arrived at after a health risk assessment considering the current or reasonably foreseeable land use, exceeds the stated reference level. For existing exposure situations, this describes that sites should be recorded on the environmental management register (EMR) where the estimated annual dose is above 5 mSv, and that below this annual dose, there is no requirement to record sites on the EMR; unless buried material is confirmed or suspected and its impact has not been assessed.

Guidance on recording land on the EMR (Queensland Health 2020) includes that:

> *If there is no possibility, under reasonably foreseeable situations, of surface or buried material being redistributed or concentrated on site or being removed off-site, resulting in an annual dose above 5 mSv (either on or off site), there is not sufficient concern to justify management, remediation or recording on the EMR.*
>
> *If the health risk assessment for a site did not consider likely future land use circumstances, particularly the disturbance of buried contaminants, the site should be recorded on the EMR even though the current estimated dose may be less than 5 mSv.*

In contrast, Queensland Health (2020) describes that:

> *For sites that have, or could foreseeably have, a sensitive use, the preferred endpoint for remediation is that sufficient radioactive contaminant is removed so that a person's annual exposure due to the contaminant is no more than about 0.3 mSv to 1 mSv. If that preferred endpoint cannot be reasonably achieved there should be sufficient explanation to demonstrate why that is the case.*

In reaching the remediation endpoint, Queensland Health (2020) notes that in some cases the "radiation exposure will remain elevated but low enough to be acceptable without having to place restrictions on the use of the site", whereas in other cases "the endpoint may be a tolerable level but one that requires the site to be on the EMR and subject to a site management plan".

In interpreting the various dose criteria, it is helpful to consider the magnitude of these values in the context of radiation protection overall. ARPANSA (2014), for example, describes that in regard to exposure of the whole body, below 10 mSv are considered to be "very low doses, which correspond to the range of exposure any member of the public may experience under normal circumstances on a yearly basis". In regard to cancer and heritable effects, ARPANSA (2014) describes that:

> *For radiation protection purposes, the estimates of stochastic risk use the detriment-adjusted nominal risk coefficient of dose. This includes the risk of all cancers and heredity effects, averaged over all variation caused by age, gender, race and other factors, and the severity of the disease ('detriment'); into one common number. This is estimated by the International Commission on Radiological Protection [ICRP 2007] to be approximately 5% per Sv.*

This notes that the risk coefficient may need to be adjusted as new scientific knowledge becomes available, and that irrespective of the form of the dose-responsive relationship, to manage the potential risks at such exposures, dose should in all cases be kept as low as reasonably achievable (ALARA)[7]. Although it is also highlighted that the risk coefficient is specified in Sv, while the reference levels discussed are in mSv, i.e. 0.005% per mSv.

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[7] That actual exposure, likelihood of exposures and number of exposed persons should be as low as reasonably achievable (ALARA), taking into account economic and societal factors (ARPANSA 2017).

7. Data assessment

The ASC NEPM (2013, B1) recommends the 95% upper confidence limit (UCL) of the arithmetic mean ($\bar{x}$) as the key statistical estimate of exposure, as well as that no value exceeds 250% of the relevant action level (*max test*), and that the standard deviation of the sample data is ≤ 50% of the relevant action level. The 95% UCL$\bar{x}$ provides a mechanism to account for uncertainty in whether the data set is large enough for the mean to provide a reliable measure of central tendency, noting that small data sets result in higher UCLs (NEPC 2013, B2).

The use of the 250%/50% rules serve to highlight potential hotspots and to avoid the diluting of higher dose rates by the averaging of these with lower dose rates. That is, measures of central tendency are suitable for estimating exposures only where it can be shown that they adequately represent the sources being considered.

For this reason, the data should be thoroughly examined and displayed, and no single metric should be used in isolation, but rather a weight of evidence/lines of evidence approach should be used. As noted in DoE (1998), sample locations and results should be plotted on site plans for the various depths, and in addition to estimates of population parameters, histograms or frequency distributions should be used to illustrate the distribution results.

8. Suggested "HIL" dose criteria

Based on the forgoing, and the regulatory dose limit of 1 mSv/y for members of the public, at the most conservative exposure duration of 8,766 hours per year, using the mid-point conversion coefficient of 0.8 Sv Gy^{-1} and including background radiation (terrestrial and cosmic), the residential land use criterion proposed is 0.3 µGy/h (1 mSv/y). This can be thought of as the HIL-A value in the context of the ASC NEPM (2013, B1).

This dose criterion should be compared to the 95% UCL$\bar{x}$ of the collected sample data for the site or decision area. Additionally, using the ASC NEPM data assessment framework of the maximum value not exceeding the action level by more than 250%, the maximum value for residential land use should not exceed 0.5 µGy/h (2.5 mSv/y), and the standard deviation of the data set should be ≤ 0.2 µGy/h (0.5 mSv/y).

The null hypothesis (H_O) for residential land use should therefore be of the form:

H_O: 95% UCL$\bar{x}$ > 0.3 µGy/h; max test > 0.5 µGy/h; and std dev. > 0.2 µGy/h

Dose criteria for other land uses are shown in Table 2, along with the dose constraint. The dose constraint, consistent with the ALARA principle, should be set as the remediation target level where remediation is required (Queensland Health 2020). Where the land use dose criteria are exceeded, ongoing site management is required to allow the proposed land uses.

Table 2: "HIL" dose criteria for heavy mineral sands residues by land use (µGy/h) [1, 2]

	95% UCL$\bar{x}$ [3]	Maximum	Standard deviation
Dose constraint [4] – 0.3 mSv/y	0.2	0.25	0.15
Residential (HIL-A and HIL-B) [4] – 1 mSv/y	0.3	0.5	0.2
Open space/recreational (HIL-C) [5] – 1 mSv/y	2.0	4.5	1.0
Commercial/industrial (HIL-D) [6] – 1 mSv/y	0.7	1.6	0.4

Table notes:
1. Coefficient of 0.8 Sv Gy^{-1} used to convert absorbed dose in air to effective dose.
2. Includes background of 0.095 µGy/h terrestrial and 0.038 µGy/h cosmic.

3. 95% upper confidence limit (UCL) of the arithmetic mean ($\bar{x}$).
4. Exposure duration of 8,766 hours per year.
5. Exposure duration of not more than 730 hours per year.
6. Exposure duration of not more than 2,160 hours per year.

9. Rationale for "HIL" dose criteria

Queensland Health (2020) is considered the primary guidance for the assessment requirements in regard to land contaminated by radioactive material in Queensland, and should be referred to for guidance on the assessment, management and remediation of HMSRs in Queensland. However, the variable dose levels specified in regard to listing of land on the land registers do not allow clear, unambiguous direction to regulators, land owners, consultants or contaminated land auditors in regard to notification of land, or, where appropriate, for the removal of land from the land registers.

DES (2015) describes that the need to list land on the EMR will be considered where "A notifiable activity is being carried out on the land, or a notifiable activity has previously been carried out on the land, except where it has been demonstrated that the land is not contaminated". Notifiable activities prescribed under Schedule 3 of the EP Act relevant to HMSRs include "Landfill – disposing of waste (excluding inert construction and demolition waste)"; noting that the types or quantities of waste are not specified. Additionally, in some circumstance, "Mine wastes" and/or "Mineral processing" may also apply. Therefore, where HMSRs have been placed on land, listing on the EMR may be required based on the occurrence of a notifiable activity.

Land may also be listed on the EMR when the land is considered to be contaminated land, with DES (2015) describing that:

> *Contaminated land is interpreted in accordance with the EP Act to be land, including associated water or airspace, that is … contaminated by a hazardous contaminant, which if improperly treated, stored, disposed of or otherwise managed, is likely to cause material or serious environmental harm by adversely affecting environmental values, including those related to ecological health or public amenity, safety or health or otherwise protected under an environmental protection policy or regulation, of the land or other land or another part of the environment.*

Queensland Health (2020) describes that land should be recorded on the EMR if the annual dose is above 5 mSv, or "the health risk assessment did not consider likely future land use circumstances, in particular a more sensitive land use" or "buried radioactive material is confirmed or suspected but its impact has not been assessed". It also describes that remediation may be justifiable in the region of 1 mSv only "if easy to achieve". While the intent of these statements is reasonable, the question of who should determine their validity on a case by case basis is not addressed in Queensland Health (2020). Where the person funding the assessment and management of HMSRs affected land is making the determination, financial considerations will generally take precedence; at times at the expense of health and environmental considerations.

Alternatively, where DES or contaminated land auditors approved by DES are making such determinations, a higher weighting will be assigned to health and the environment. Accordingly, it is considered necessary to set a dose criteria that ensures that land impacted by HMSRs is addressed consistently with other types of contamination, whilst also being consistent with the existing Queensland regulatory framework. Review of this existing regulatory framework, including from national and state guidance and state legislation is summarised in Table 3 in regard to acceptable dose limits.

Table 3: Dose limits from relevant regulatory guidance

Reference	Dose limit (mSv/y)	Application of dose limit
ARPANSA 2020	1	Dose limit for members of the public as effective dose.
NHMRC/NRMMC 2018	1	Radioactivity in drinking water, with the need for and the degree of remedial action determined based on advice from the relevant state health authorities, and should include a cost–benefit analysis.
Queensland Health 2020	0.3 - 1	Remediation target levels for sites that have, or foreseeably have, a sensitive use; the preferred end point for remediation.
Queensland Health 2020	1	If decontamination of a site is not possible, or not carried out within a reasonably short time following the contamination, the site may be recorded on the EMR.
S. 53 RS Regulation	1	The radiation dose limits applying to the occupational exposure of a person to ionising radiation emitted from the source, other than while involved in carrying out the practice.
S. 54 RS Regulation	1	A licence holder in possession of an ionising radiation source for a radiation practice while the practice is carried out, the radiation dose limits applying to the public exposure of a person to ionising radiation.
S. 57 RS Regulation	1	The radiation dose limit applying to the occupational exposure of a pregnant woman to ionising radiation while involved in carrying out the practice.
S. 58 RS Regulation	1	A person who possesses a mineral substance that is a radioactive material that is not a radioactive substance must ensure that for public exposures another person does not receive a total effective dose from ionising radiation emitted from the substance.

The setting of analogous ASC NEPM HILs as dose criteria, consistent with the existing legislative requirements, is considered to be a realistic and easy to achieve approach for ensuring that appropriate, objective and unambiguous decisions can be made regarding the assessment and management of land potentially impacted by HMSRs. Furthermore, this approach allows consistency in the assessment and management of radiological contamination along with other chemical and mineral forms of contamination, which often potentially occur in concert with radiological contamination.

By setting a clear dose criteria for defining contaminated land, sites which do not present a potential risk to health and the environment can be addressed outside of the contaminated land framework. Conversely, sites which may potentially pose a risk to health and the environment can be managed unambiguously within the existing framework, under the existing regulatory oversight using relevant policies and guidance, including use of Queensland Health (2020) and the ASC NEPM (2013) for their assessment, management and remediation,

10. References

Australian and New Zealand Governments (ANZG) (2018) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2008) *Management of Naturally Occurring Radioactive Material (NORM); Radiation Protection Series No. 15*.

ARPANSA (2014) *Protection Against Ionising Radiation; Radiation Protection Series F-1*.

ARPANSA (2017) *Guide for Radiation Protection in Existing Exposure Situations; Radiation Protection Series G-2*.

ARPANSA (2020) *Code for Radiation Protection in Planned Exposure Situations; Radiation Protection Series C-1 (Rev. 1)*.

Department of Environment (DoE) (May 1998) *Draft Guideline for the Assessment & Management of Contaminated Land in Queensland*.

Department of Environment and Science (DES) (2015) *Guideline Listing and removing land on the land registers*, (Ref. ESR/2016/2044, Version 1.02).

International Commission on Radiological Protection (ICRP) (2007) *The 2007 Recommendations of the International Commission on Radiological Protection*. ICRP 103. Ann. ICRP 37.

Kleinschmidt R. and Watson D. (2016) Terrestrial gamma radiation baseline mapping using ultra low density sampling methods, in *Journal of Environmental Radioactivity, 2016, 151(3): p. 609-622*.

National Environment Protection Council (NEPC) (2013) *National Environment Protection (Assessment of Site Contamination) Measure 1999,* including *Amendment Measure 2013* (No. 1) (ASC NEPM), including:
- *Schedule A: Recommended General Process for Assessment of Site Contamination*;
- *Schedule B1: Guideline on Investigation Levels for Soil and Groundwater*;
- *Schedule B2: Guideline on Site Characterisation*;
- *Schedule B5b: Guideline on Methodology to Derive Ecological Investigation Levels in Contaminated Soils*; and
- *Schedule B7: Guideline on Derivation of Health-Based Investigation Levels*.

National Health and Medical Research Council (NHMRC) and National Resource Management Ministerial Council (NRMMC) (2018) *Australian Drinking Water Guidelines*, Version 3.5, updated August 2018.

Queensland Health (2020) *Land contaminated by radioactive material – A guide to assessment, management and remediation*.

Salmon M.C. (2020) *Design of Assessment of Site Contamination Investigations*, ACLCA Queensland, Contaminated Land Technical Practice Guideline TPG 7.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (1982) *Ionizing Radiation: Sources and Biological Effects, 1982 Report to the General Assembly, Annex A, Dose assessment models*.

UNSCEAR (2000) *Sources and Effects of Ionizing Radiation: 2000 Report to the General Assembly, Annex A - Dose assessment methodologies*.

Current recognised certification schemes are:
- the Environment Institute of Australia and New Zealand's Certified Environmental Practitioner (CEnvP) scheme as a Site Contamination Specialist (SCS); and
- Soil Science Australia's Certified Professional Soil Scientist (CPSS) scheme for Contaminated Site Assessment and Management (CSAM).