Managing naturally occurring radioactive material (NORM) in mining and mineral processing — guideline

NORM–3.1

Monitoring NORM — pre-operational monitoring requirements

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

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MIAC

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1. General information

1.1. Purpose

To provide guidance on the practical ways of pre-operational monitoring in relevant exploration, mining and mineral processing operations and on the assessment of obtained data.

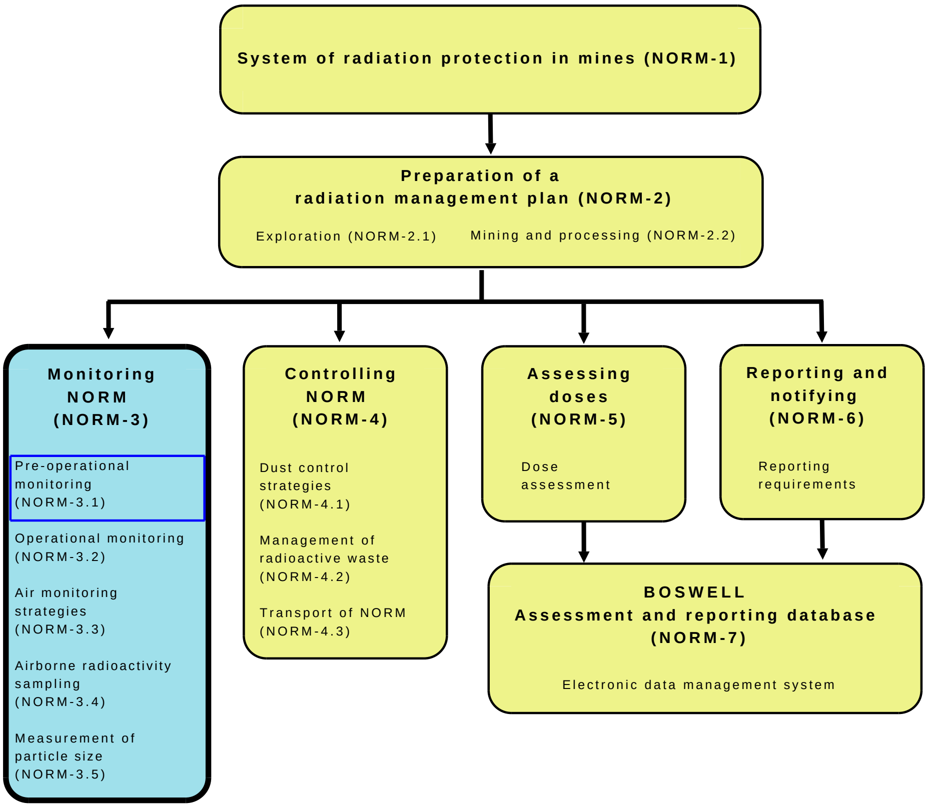
1.2. Scope

This guideline applies to all exploration, mining and mineral processing operations in Western Australia that use or handle naturally occurring radioactive material (NORM) and come within the scope of Part 16 of the Mines Safety and Inspection Regulations 1995 [3].

1.3. Relationship to other NORM guidelines

The flowchart in Figure 1.1 shows the shows the arrangement of the Radiation Safety Guidelines.

Figure 1.1.: Relationship to other NORM guidelines



2. Guidance

2.1. Introduction

Pre-operational monitoring is conducted to obtain (establish) baseline data on background radionuclide concentrations and dose rates in the environment, at locations where exploration, mining and mineral processing operations are proposed to take place. This data then allows for:

- an assessment of the impact of proposed operations to the local environment; and
- an appropriate baseline reference for the subsequent rehabilitation.

It is important to identify and characterise the parameters that the proposed operations are likely to affect. Any parts of the existing environment with higher than local average levels of radioactivity must be identified and described.

As with any monitoring program, the extent to which program elements are considered is dependent on site specific considerations such as the mineral mined/processed, present and proposed future land use, potential exposure pathways, variability of radiation parameters. The purpose of pre-operational monitoring is mainly to address baseline meaurements for a new mine or processing plant and not just for the exploration. Depending on the level of radiation hazard, some of the elements discussed below may not be required. A suggested pre-operational radiation monitoring program is outlined in Appendix A on page 13. For a relatively limited uranium exploration campaign, the appropriate authorities should be consulted on what pre-operational monitoring is required. The aim of recording this information in exploration is to be able to bring the environment (radiation levels included) back to the state that existed prior to exploration activities taking place.

2.2. Elements to be considered in the program design

There are three important stages in the design of a pre-operational radiation monitoring program, involving the identification of:

- radionuclides in the material to be mined/processed, their concentrations and distribution in the local environment;
- possible pathways of the exposure of members of the public and local environment; and
- critical group of members of the public and, where applicable, critical reference plant/animal.

2.2.1. Radioactivity content and characteristics

The generic data on radionuclides and their concentrations in the material to be mined and/or processed is typically available from geological or other data. The data on the contents of these radionuclides at the proposed exploration or mining/mineral processing site should be obtained for local soil, ground and surface water, and biota. Any potential effects that exploration, mining and/or processing operations may have on both the concentrations and physical/chemical states of these radionuclides must be considered.

All development proposals (exploration, mining, concentration/separation, chemical/thermal processing, waste disposal, etc.) must be evaluated and their potential effect assessed. One of the most important items to determine may be is to establish if naturally occurring uranium and thorium are in secular equilibrium with their decay products and if the proposed operation is likely to influence this secular equilibrium and the mobility of radionuclides in the environment. It should be noted that some minerals, despite being in their 'natural state', may already be depleted of certain radioisotopes from thorium and/or uranium decay chains prior to exploration/mining/processing, and it is very important to establish if this is the case prior to the commencement of operations.

At the end of this stage a list of 'radionuclides of interest' is compiled.

2.2.2. Pathway analysis

After it has been determined which radionuclides will need to be included into the monitoring program, the assessment of potential pathways of exposure should be undertaken. In general, radionuclides from an exploration or mining/processing site could reach humans and the surrounding environment via atmospheric release, aquatic release, or both.

Two main pathways of exposure for humans are internal exposure (inhalation and ingestion) and external exposure. External exposure to gamma-radiation will need to be assessed in almost all cases; the potential pathway of exposure via surface contamination may also be applicable.

A detailed assessment of potential internal exposure must be conducted on a case-by-case basis and the following pathways of exposure considered:

Inhalation:

1. Re-suspended dust.
2. Radon (^{222}Rn) and its progeny.
3. Thoron (^{220}Rn) and its progeny.

Ingestion:

1. Drinking water.
2. Incidental — dust and soil.
3. Home-grown produce, milk, meat, and locally caught aquatic organisms (e.g. fish, mussels, shellfish).

It is very important to remember that when exploration, mining and/or processing is proposed to be carried out in remote areas of Western Australia, a particular regard will need to be given to the lifestyle and practices of local population. Indigenous people may be at a higher risk of radiation exposure at and around exploration and mining sites due to, for example:

- travelling on dusty roads in open vehicles;
- sitting on the ground, living and sleeping in temporary structures with earth floors;
- absence of adequate washing facilities, consuming local biota and cooking in the ground; and
- recreational activities (particularly by children).

In these cases the exposure to radiation may be a result of not only *direct* pathways of radiation exposure such as external gamma-radiation, inhalation of dust/radon, and ingestion of drinking water, but also several *indirect* ones, which may also need to be assessed including:

- ingestion of contaminated flora (both surface and aquatic);
- ingestion of contaminated fauna (both surface, air and aquatic); and
- incidental ingestion of dust and soil (particularly for children).

At the end of this stage the list of 'radionuclides of interest' is coupled with the pathways of potential exposure and the identification of monitoring that will be required is carried out.

2.2.3. Identification of a critical group

The last stage in the design of pre-operational monitoring program is to identify the 'critical group'. According to the Australian Code of Practice for Mining and Mineral Processing [4], *the critical group is a group of members of the public comprising individuals who are relatively homogeneous with regard to age, diet and those behavioural characteristics that affect the doses received and who receive the highest radiation doses from a particular practice.*

In Western Australia, mining and mineral processing operations can be located relatively far from populated areas and serviced by fly-in fly-out personnel. After the completion of a particular project it is not uncommon that people may only stay in the area once every several years and then, only for very short periods of time. Therefore, their potential exposure to radiation cannot be adequately quantified..

In some other cases, identification of the critical group may not be possible due to the distance from the proposed site being too far for a group to receive any measurable radiation dose. However, even in such situations, there still exits a need for the operator to demonstrate that the impact of the operation on the local environment is minimal or negligible; and, in these cases a reference plant/animal may be selected for the study.

It may be difficult for a local community to grasp the difference between occupational and environmental impact — people are part of an ecosystem and this should be addressed; either by the study of a plant/animal or a critical group. While it may be very difficult to explain your baseline measurements in terms of milliSieverts and Becquerels to a community, being able to to say that a particular water hole, the animals and plants around it are no different from before will have a better reception. This is an example when some part of a radiation monitoring program may not be required from a purely technical point of view, but social considerations have been taken into account.

On conclusion of the pre-operational radiation monitoring program design, the following information should be available:

1. Radionuclides to be monitored.
2. Media to be monitored.
3. Critical group whose radiation exposure will be assessed.

This information is sufficient for the design of a comprehensive monitoring program. At this point a consultation with the DMP (and, in some cases, with other government departments) is highly advisable to ensure that an assessment of the proposed monitoring program can be carried out and any amendments required are made prior to the commencement of monitoring.

2.2.4. Other considerations

After the initial design of the pre-operational monitoring program some elements may seem unnecessary. It is important to maintain a program that is as broad as practicable. This is due to the fact that if an anomaly in radionuclides concentrations and/or distribution is not identified during the pre-operational stage, it may be attributed to the exploration, mining and/or processing operations and a costly remediation program may subsequently be required. Examples of such anomalies include:

- naturally elevated radon concentrations in homes of the members of the critical group of the members of the public;
- disequilibrium between radionuclides from uranium and thorium decay chains in local soil and in the minerals to be mined, and elevated concentrations of ^{226}Ra and/or ^{228}Ra in local ground water; and
- elevated radium, polonium or lead concentrations in native vegetation.

2.3. Monitoring methods

2.3.1. Gamma radiation surveys

A gamma radiation survey is required over all proposed mining/processing areas before mining commences and prior to the removal of topsoil. The purpose of this amount of monitoring is for comparison with post-mining levels to classify the site appropriately in accordance with the Contaminated Sites Act and Regulations [8, 9]. This data would also be incorporated into the Environmental Impact Statement (EIS).

Grid intervals required are dependent on the variability of radiation levels however, grid intervals of 100 metres×100 metres are generally acceptable. If gamma radiation levels are substantially above typical background levels in the area (i.e. above 0.3 μSv/h), increased grid resolution (to 50 metres×50 metres) may be warranted. Additionally, a survey should also be carried out in areas where processing plants that may be a source of emissions are proposed, and where the increase in concentration of radionuclides may take place. This survey should utilise a 50 metres×50 metres grid. In some cases a 25 metres×25 metres grid may also be useful. Figure 2.1 on the following page demonstrates the differences in grid sizes.

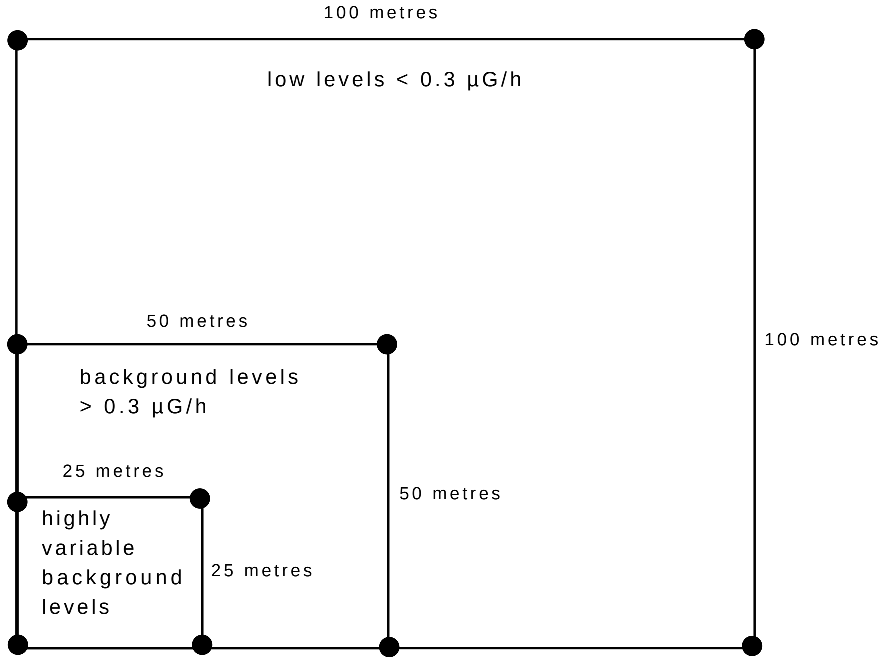
For exploration operations the gamma monitoring grid will be identical with the drill spacing grid.Readings will be taken at drill collar locations where there will be any contamination and hence the best place for checking effectiveness of cleanup. Other areas to consider for surveys include sample storage, access roads, vehicle cleaning, and even possibly the camp site.

When carrying out environmental gamma surveys it should be done at a height of one metre from the ground. Keeping the monitor and audio indicator in the 'on' position is also recommended as this will allow for the identification of smaller areas with elevated gamma radiation levels, which may be missed if the monitor is only switched on at selected locations. Figure 2.2 on page 7 shows an environmental meter setup for measurement.

All monitoring locations should be accurately recorded (i.e. using the Global Positioning System (GPS) receiver) so that, after rehabilitation, background radiation levels can be correctly compared with pre-exploration and/or pre-mining ones.

In some cases, when a gamma survey needs to be carried out for the area larger than 25–30 km^2 and the gamma radiation level is relatively constant, it may be acceptable to separate the area into several smaller blocks and carry out the delineation by recording the coordinates of

Figure 2.1.: Gamma survey – recommended grid sizes



these blocks with the GPS receiver, instead of coordinates of individual survey points. Additional consultation with DMP is required in regards to not only the requirements for the recording of survey coordinates for a particular project, but also about the grid size.

In cases where transportation of material containing elevated concentrations of natural radionuclides between sites on public roads may occur, a survey on the proposed transport route is also recommended. This is to ensure that all possible spillages arising after the completion of the project are identified and areas rehabilitated. Depending on the length of the route the readings may be taken at intervals of between 200–1000 metres.

Monitors specifically designed for the monitoring of environmental radiation levels produce the most accurate gamma radiation measurements. The most appropriate monitor is one that allows aggregating of the environmental data for a period of time (typically 30, 60 or 120 seconds). The use of older style monitors (those with analog 'arrow' display and scaled in non-S.I. units — milliRöentgen per hour (mR/h), etc.) is not recommended in environmental monitoring as some of them have a tendency to over-read in low ranges.

Additionally, survey instruments must be appropriately calibrated by a calibration service approved for use in Western Australia. The survey meters must be suitable for radiation requiring measurement at a particular exploration, mining and/or mineral processing site. A very clear interpretation of the registered results must be available. An additional technical note on data interpretation and survey instruments in Appendix B on page 14.

Ideally, the instrument used for gamma survey should also used for any monitoring carried out in the same area after exploration/mining and rehabilitation.

Figure 2.2.: Mini-Instruments 6–80 environmental radiation survey meter

An important point to note when using the Mini–Instruments 6–80 :
'The G–M tube in this instrument is energy compensated for radiation entering radially. While the response is not ideal, it is acceptable for most measurements. With the tube held vertically the contribution from ground contamination is treated symmetrically and direct radiation from a distant source would arrive nearly normal to the axis of the tube. For determination of ground contamination immediately below the tube, it is sensible to hold the tube horizontal but the cosmic contribution may be higher. Most surveys have been done with the tube vertical so for inter comparison of results this is the preferred method.' [7]

2.3.2. Airborne radioactivity surveys

2.3.2.1. Atmospheric dusts

Samples of atmospheric dust should be taken in accordance with Australian Standard AS 3580.3–2003. High-volume samplers are used to collect the samples for a minimum of 24 hours at selected locations. (This has been the standard in the WA mining and mineral processing for about 15 yearsSamples are later analysed for gross alpha activity and, depending on the identification of radionuclides carried out during the program design stage, an additional analysis of filters may be carried out (for example, for ^{226}Ra or ^{228}Ra). Typically, it is not necessary to measure the size of dust particles (Guideline NORM–3.5 Measurement of particle size) in the pre-operational monitoring program.

The suggested locations for monitoring are:

1. At or near the site boundaries.
2. In the sector predicted to have the highest dust concentration during operations.
3. At location remote (or ‘upwind’) from the site to obtain a background concentrations.
4. Depending on the proximity of residential areas, sampling may also need to be conducted in these locations. Samples should be collected to take account of seasonal variations (e.g. quarterly).

In certain circumstances, two background positions can be selected upwind — one at a distance of about 2–3 kilometres from the proposed exploration/mining/mineral processing site and another — approximately 100–200 metres from the site boundary. This is particularly useful in situations where soil in the area is known to contain elevated concentrations of identified radionuclides and a block of land with little vegetation or a block of arable land is located in the immediate vicinity of the proposed site. The dust carried onto the site by wind from the adjacent agricultural property will, therefore, not be mistakenly attributed to the exploration, mining and/or processing operation.

Another method for monitoring of atmospheric dust is the use of dust deposition gauges, particularly in locations where the use of high-volume monitor may be impractical. This should be done in accordance with Australian Standard AS3580.10.1–2003.

2.3.2.2. Radon and thoron

It may be important to quantify the levels of radon (^{222}Rn) and thoron (^{220}Rn–220) in air prior to commencement of operations. Typically, soil radon flux (in Bq/m^2/sec) is measured using the charcoal cup method. This method involves using the inverted sealed container (typically for 24 hours) to collect radon from the soil surface, where radon is absorbed onto an activated charcoal trap and the subsequent analysis is undertaken in a laboratory.

Other passive samplers for the monitoring of radon and thoron are available and are very useful in area measurements as they integrate the data over a period of several months and provide average concentration in Bq/m^3.

The monitoring of radon/thoron concentrations can also be carried out by taking grab samples of air onto a standard 25 mm filter and later analysing this filter for gross alpha activity.

There are also several types of electronic equipment that may be used to determine radon and thoron concentrations such as the shown in figure on the next page. Due to the variability of this equipment and to the fact that some of it is not suitable for the industrial/mining use, advice should be sought from an appropriate authority prior to the use of a particular instrument on an exploration, mining and/or processing site.

Figure 2.3.: Electronic sampling of radon

Solar/battery powered radon sampler

Sampling should be carried out at the same locations where the monitoring of atmospheric dust is conducted. Additional information can be found in the Guidelines NORM–3.3 Air monitoring strategies and NORM–3.4 Airborne radioactivity sampling.

The concentrations of radon and thoron and their daughters in the atmosphere vary by more than an order of magnitude over the diurnal cycle, and driven also by the weather pattern and pumped by rainfall events. It may be necessary to install a weather station at an advanced exploration site, such as the one shown in Figure on the following page to gain a better understanding of the characteristics of the site.

2.3.3. Water quality surveys

In order to determine the correct locations for water monitoring the groundwater flow direction and penetration rate in soil (gradient) need to be established. The groundwater flow direction will allow for the correct location of monitoring bores, the rate of water penetration in soil (in meters per year) is needed to estimate a potential effect of any aqueous release of radioactivity on the critical group of members of the public and on local aquifers (including biota).

Typically, the following samples are required to characterise water quality:

1. Several groundwater samples from bores hydrologically down-gradient from a point of a possible aqueous release of radionuclides (tailings disposal areas, processing plant site).

Figure 2.4.: Weather station

Solar/battery powered weather station collecting site meteorological data

2. One groundwater sample from each well within 1 or 2 km of a possible aqueous release of radionuclides which are or could be used for potable water supplies, watering of livestock, or crop irrigation (the distance will significantly depend on the rate of water penetration in soil).
3. One or two samples from each surface water body (dams or wetlands) within the vicinity of the proposed operations.
4. Several groundwater samples from bores hydrologically up-gradient from a point of a possible aqueous release of radionuclides (tailings disposal areas, processing plant site) — for the establishment of the local background values.

The amount of bores to be monitored down-gradient and up-gradient should be determined based on the size of the proposed site, the gradient of groundwater flow, proximity to the critical groups of the members of the public, and on the solubility and mobility of identified radionuclides in the ground water.

The amount of samples to be taken from each surface water body depends on the size of this body. For example, one sample from a running creek will be sufficient, but two samples will need to be taken from a relatively large (more than 0.5 hectares in size) stagnant wetland or pond.

While analysis of samples for gross alpha and gross beta activities can be useful, analysis of all samples for all radioisotopes identified earlier is also recommended (in case of most NORM, an analysis for ^{226}Ra and ^{228}Ra concentrations is required).

2.3.4. Other monitoring

2.3.4.1. Soil sampling and assessment of secular equilibrium

In many cases, analysis of soil and collected dust samples in order to establish if both uranium and thorium decay chains are in the equilibrium in the local environment will be required.

To evaluate the degree of secular equilibrium in the uranium decay chain it would be necessary to measure the relative activities of ^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb. To evaluate the degree of equilibrium in the thorium decay chain it would be necessary to measure the specific activities of ^{232}Th, ^{228}Ra, ^{228}Th and ^{212}Pb.

Thorium and uranium decay series are described in Appendix A of the guideline NORM–1 Applying the system of radiation protection to mining operations. The amount of samples will vary significantly depending on the characteristics of the particular site, mineral to be mined/processed and its intended treatment.

2.3.4.2. Surface contamination

In the cases where measurable amounts of radionuclides are detected in the airborne dust prior to the commencement of exploration, mining and/or processing operations surface contamination levels in the local environment may need to be assessed. For critical group members of the public this can be done by taking wipe samples from the surfaces around and inside premises used for human habitation. Alternatively, a monitor calibrated for the measurement of surface contamination can be used in this assessment.

In situations where a critical group cannot be adequately established, swipe samples can be taken in the areas where dust has been accumulating for some period of time. A monitor such as alpha probe is likely to be inadequate in these situations.

The amount of measurements will vary significantly depending on the characteristics of the particular site, mineral to be mined/processed and its intended treatment.

2.3.4.3. Biota samples

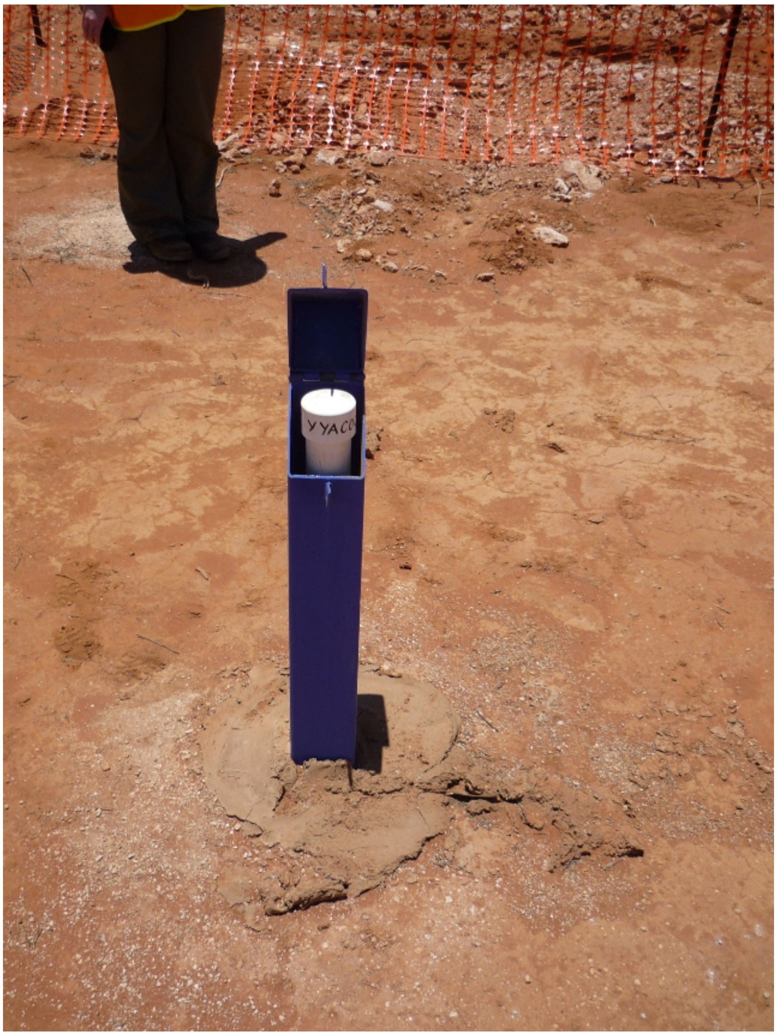
In situations such as those described in Section 2.2.3 on page 4 (where a reference plant/animal is selected for the study), additional consultation with the appropriate authority will be necessary to ensure that appropriate species are selected for this assessment.

Local biota can be separated into flora and fauna. Typically, entry by radionuclides into flora is through uptake of radionuclides (from water, soil and dust deposition). Typical pathways of radiation exposure of fauna are ingestion (water, soil, flora containing elevated concentrations of radionuclides) and inhalation (dust, radon, thoron).

Pre-operational samples of native vegetation (and crops, where applicable) and local fauna may need to be collected and analysed for content of radionuclides of interest as identified earlier. The amount of samples/measurements will vary significantly depending on the characteristics of the particular site, mineral to be mined/processed and its intended treatment.

Biological surveys are essential for sustainable resource management, especially in areas with poorly known biological communities or for ecological communities that have, until recently, escaped the attention of researchers. For example, stygofauna are a group of mostly crustacean invertebrates that live in the groundwater of many calcrete uranium deposits. Their distribution, biological diversity, and ecology is poorly known outside of Western Australia [10]. Stygofauna have been used as environmental bargaining chips, as reasons to delay or prevent mining operations by various environmental groups and proponents of stygofauna research and taxonomy, arguing that stygofauna are, by dint of their habitat in restricted aquifers, extremely biologically important [11]. Figure 2.5 shows a Stygofauna trap.

Figure 2.5.: Stygofauna trap



2.4. Data presentation

Data should be presented for the assessment to the appropriate authority in a form described in NORM–6 Reporting requirements.

A. Appendix with a suggested pre-operational radiation monitoring program

Measured parameter	Site/item monitored	Frequency/amount of measurements	Measurement technique
1. Gamma radiation	Proposed mine site	Once-off survey: →100 m ×100 m grid — all site →50 m x 50 m grid — areas with elevated levels and proposed plant site	Properly calibrated gamma radiation monitor
	Proposed route for the transport of material	Once-off survey, readings every 200 – 1000 meters	
2. Atmospheric dust	→ At or near site boundaries →Where the highest dust concentrations are predicted during operations →One or two remote (upwind) locations →Residential areas (where applicable)	Four samples per year, taking seasonal variations into account	High-volume sampler [5] Dust deposition gauge [6] with subsequent analysis of samples for gross alpha activity concentrations and, if needed, for specific radionuclides
3. Radon flux	At all locations specified in (2) above.	Once-off for 24 hours	Charcoal cup method
4. Radon and thoron in air	At all locations specified in (2) above.	→Radon — four quarterly samples (three months each)	Track etch detectors
		→Thoron — grab samples	Rock method (NORM–3.4, Appendix A3) Approved electronic instruments
5. Water quality	→Down gradient from potential release point →Up-gradient from potential release point	One sample from each identified bore every six months	Grab sampling, laboratory analysis for identified radionuclides and, where warranted, for gross alpha and gross beta activity
	→Wells within 1–2 km from potential release point	One sample from each well every six months	
	→Surface waters in the vicinity of operations	One–two samples from each water body every six months	
6. Soil sampling	Determined after consultation with DMP		
7. Surface contamination	Determined after consultation with DMP		Swipe samples, properly calibrated alpha/beta probe
8. Biota samples	Determined after consultation with DMP		Laboratory analysis for identified radionuclides

B. Appendix about survey instruments and their data interpretation

B.1. General considerations

The survey instruments designed to measure gamma radiation in the environment at a particular exploration, mining and/or minerals processing site must have certain characteristics such as:

- ability to respond to the radiation being measured;
- sufficient sensitivity to measure radiation at the desired level;
- suitable response time;
- appropriate energy dependence; and
- be calibrated for the gamma ray energies of interest.

These characteristics should be confirmed with the calibration service.

The most accurate gamma radiation measurements can be obtained with a monitor that is specifically designed for the monitoring of environmental radiation levels.

So-called 'scintillometers' that are typically used by geologists at exploration sites for the determination of the uranium ore grade and for core logging are, as a rule, unacceptable for use in measurements of gamma-radiation in the workplace and in the environment.

B.2. Data interpretation

A very important consideration is to ensure that data obtained can actually be accurately interpreted.

A typical survey monitor may have different scales such as:

- microRöentgen per hour (μR/hr);
- microgray per hour (μGy/h); and
- microSievert per hour (μSv/hr).

→ Röentgen — related to the degree of ionization in air

→ gray/Rad — absorbed dose in air

→ rem/Sv — dose equivalent

It is very important to ensure that the data are not misinterpreted, as on many occasions the following approximate interpretation is used:

$$100\,Roentgen = 100\,rem = 1\,gray = 1\,Sievert$$

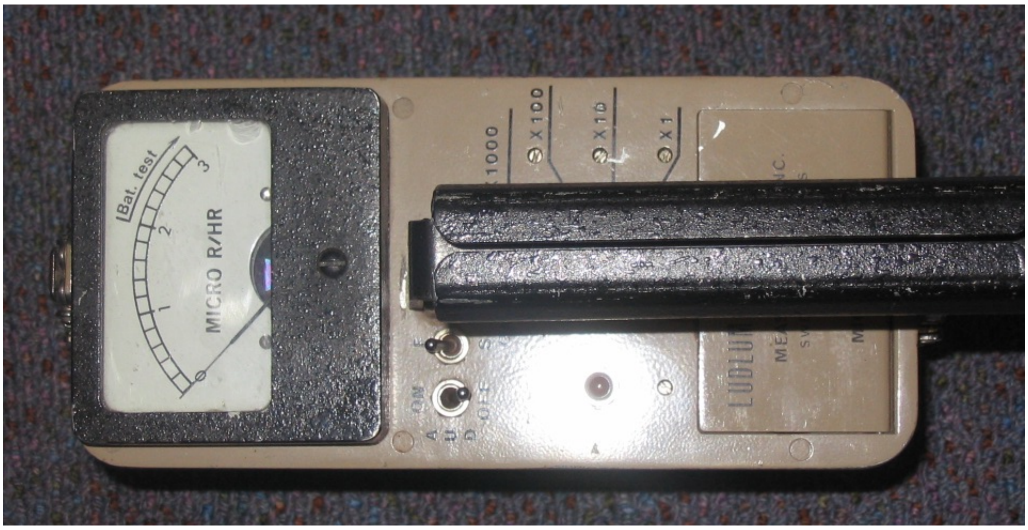
This is generally NOT correct and the following interpretations of data may be used, but only *after* the consultation with an appropriate authority:

The correction factors described below can be used only with an approval from an appropriate authority, due to the variety of the instruments used in surveys and the fact that these instruments are calibrated by different laboratories.

Instrument measuring in Röentgen

1. A certificate of calibration from an authorised laboratory should clearly state that the monitor is, indeed, calibrated to read values in mR/hour (or in μR/hour).
2. The actual relationship between Röentgen and rem is that one Röentgen produces 0.96 rem in tissue (however, this may typically be ignored as an insignificant difference).
3. One Röentgen produces 0.87 Rad in air [1].
4. The coefficient of 0.7 Sv/Gy is "the most appropriate average value of the quotient of effective dose rate to absorbed dose rate in air for males and females for environmental exposures to gamma rays" [2].

Figure B.1.: The Ludlum 12S meter reads in μR/h



Therefore, a potential error of interpretation could be quite significant, as described in the calculation example below:

Results of a post-mining survey The results indicate that the level of gamma radiation on a site is 27 μR/h in comparison with 15 μR/hour registered during the pre-mining survey.

If the 'direct' relationship is used, the calculation of a dose to a member of the general public that would be living in the area will be as follows:

- the 'excess' dose rate is 27 – 15 = 12 μR/h;
- the result will be:

$$\frac{(12\,\mu R/h \times 8760\,hours)}{1000} = 105.1\,mRem = 1.05\,mSv$$

that is above the limit of exposure for the members of the general public (1 mSv/year).

If, however, the use of appropriate coefficients is made, the situation is completely different and the calculation of a dose to a member of the general public that would be residing or working in the area will be as follows:

- the 'excess' dose rate is 27 – 15 = 12 μR/h;
- assuming that one Röentgen produces 0.87 Rad in air:

$$\frac{(12\,\mu R/h \times 8760\,hours)}{1000} \times 0.87 = 91.5\,mRad = 0.92\,mGy$$

(absorbed dose in air);

- If the factor of 0.7 Sv/Gy [2] is also applied, the annual dose for the member of the public will be 0.92 × 0.7 = *0.64 mSv*, that may be acceptable in some situations.

It is, therefore, clear that the overestimation of radiation dose from external gamma radiation can be as high as 40–45%.

Instruments measuring in gray

A certificate of calibration from an authorised laboratory should clearly state that the monitor is, indeed, calibrated to read values in μGy/h

Then the dose could be estimated as follows: If an 'excess' dose rate for a member of the general public is measured at 0.06 μGy/h, an annual dose estimation would be:

$$\frac{(0.06\,\mu Gy/h \times 8760\,hours)}{1000} \times 0.7\,Sv/Gy = 0.37\,mSv$$

Figure B.2.: The Mini-Instruments environmental radiation survey meter reads in μGy/h

Instruments measuring in Sievert

A certificate of calibration from an authorised laboratory should clearly state that the monitor is, indeed, calibrated to read values in μSv/h.

Then the dose could be estimated as follows: If an 'excess' dose rate for a member of the general public is measured at 0.05 μSv/h, an annual dose estimation would be:

$$\frac{(0.05\,\mu Sv/h \times 8760\,hours)}{1000} = 0.44\,mSv$$

Figure B.3.: The Bicron 'micro rem' meter reads in μSv/h

Instruments measuring in multiple units

Several types of monitors (particularly newer, electronic models) have scales in both mR/h and μGy/h (or, sometimes, in μSv/h); and a change between different units is achieved by simply moving one of the instrument's controls into the appropriate position. A certificate of calibration from an authorised laboratory should clearly state that the monitor is, indeed, calibrated to read values in the specified units. Alternatively, the calibration may be provided only for one parameter (for example, for μGy/h) and both calibration certificate and a calibration sticker on the instrument should clearly state which scale should be used during monitoring, and which should not.

Another important consideration

An additional complication arises when a specific correction factor that should be applied to the obtained readings is also provided during the calibration of the instrument (like, for example, for the mineral sands industry — when a correction factor for monazite was sometimes provided during the calibration of monitors by the Radiation Health Section of the Health Department of WA may be between 0.7 and 1.3 for different scales of different instruments).

If any supplementary, material-specific factors are introduced during calibration — additional information from the laboratory carrying out this service will be required to ensure that the data can be adequately interpreted.

It is also essential that the 'raw data' obtained during gamma radiation surveys is kept to ensure that any possible mistakes in data interpretation may be corrected at a later stage, if required.

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