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

NORM–3.2

Monitoring NORM — operational monitoring requirements

Government of **Western Australia**
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1 General information

1.1 Purpose

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

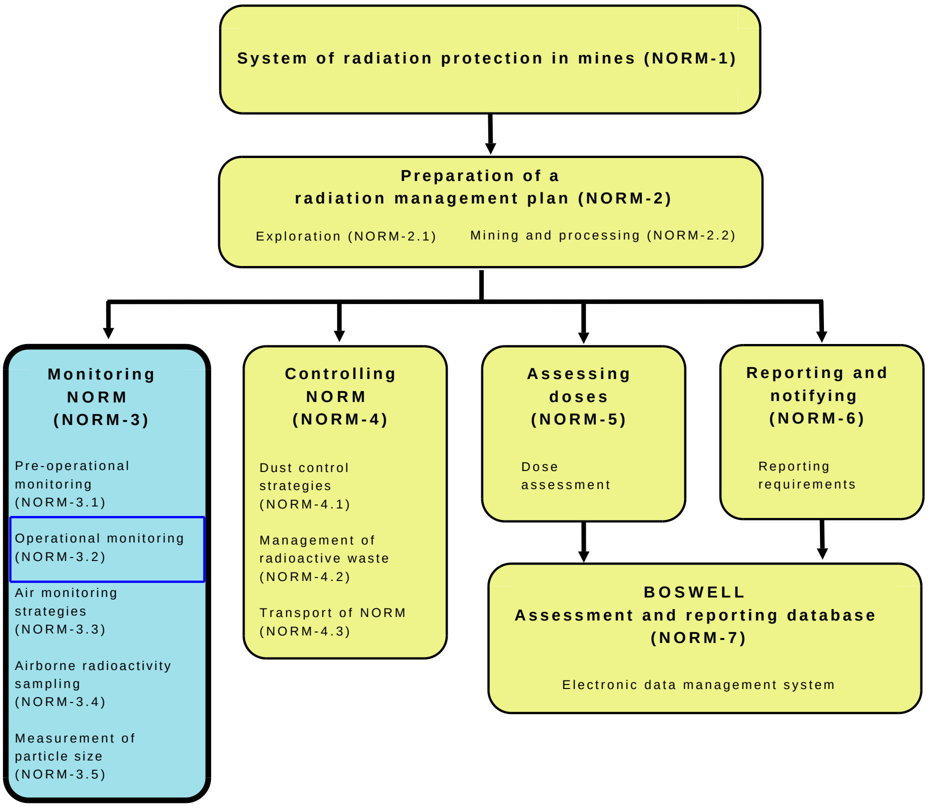
1.2 Scope

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 ([1]).

1.3 Relationship to other NORM guidelines

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

Figure 1.1: Relationship to other NORM guidelines



2 Guidance

2.1 Introduction

Operational radiation monitoring of an exploration, mining and/or mineral processing site aims to:

- demonstrate compliance with regulatory limits;
- determine radiation exposure of individuals, groups and members of the general public; and
- provide information on the effectiveness of engineering and administrative control measures.

Workplace conditions, individual exposures, and assessment of the potential impact an operation may have on the environment must be assessed. It is therefore necessary to clearly distinguish between monitoring carried out for the purpose of assessing occupational exposure of workers and monitoring conducted to quantify both the potential for environmental impact of the operation and the possible level of radiation exposure to members of the general public.

The main purpose of an occupational radiation monitoring program is to ensure workforce exposure to radiation remains below the regulatory annual limit and are As Low As Reasonably Achievable (ALARA). This is usually achieved by personal monitoring or by area surveys coupled with employee time and motion studies.

The purpose of the environmental radiation monitoring program is to ensure that radiological impact on the local environment and potential exposures of members of the general public are kept ALARA and, where applicable, below regulatory limits. This program is closely related to site specific pre-operational monitoring, and its overall aim is provide data for the restoration of the environment to the same conditions that existed prior to commencement of exploration, mining and mineral processing operations. This is usually achieved by area monitoring, water and air sampling, and biological monitoring, if necessary.

As with any monitoring program, the extent to which certain program elements are considered is dependent on site specific considerations such as mineral being mined/processed, radionuclides' concentrations in operational and other site areas, number of employees involved in different stages of the exploration/mining/processing operation, present and proposed future land use, potential exposure pathways both for employees and members of the public, variability of radiation parameters, etc.

2.2 Elements to be considered in the program design

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

- the potential for radionuclides in the material mined/processed to change their physical and chemical characteristics due to the treatment of the material at the operation and potential changes in their concentrations and distribution in the local environment;
- possible pathways of exposure of workers, and possible changes in the pathways' characteristics for members of the public and local environment; and

- all areas on site to be classified as a supervised or controlled area.

The purpose of the design phase is to establish which sites and what personnel need to be monitored, the frequency of measurement required, and the monitoring method to be used, including monitoring instrumentation and radiation parameters to be measured.

2.2.1 Radioactivity content and characteristics

A variety of different methods for the treatment of minerals are used. The detailed assessment of the behaviour of radionuclides is necessary to establish potential pathways of radiation exposure to workers and to the environment, and to evaluate any changes to these pathways.

In situations where only physical processing of ore takes place (e.g. gravimetric or electrostatic separation, crushing, etc,) a change in radionuclides' behaviour is unlikely. Therefore, the only issue to be considered would be a possible increase in radionuclides concentrations in processed material or in workplace dust. Where fine grinding of the mineral takes place, the possibility of dust inhalation increases significantly and radon/thoron levels in air may also be elevated.

In a situation where the processing of minerals is complex or mineral concentration is undertaken (involving either chemical or thermal processing or both), a detailed study is required to determine if changes in radionuclides' behaviour and changes in secular equilibrium of both uranium and thorium decay chains occur.

For example:

1. Polonium and lead from some minerals may be volatilised at comparatively low temperatures (above 250–300℃) and be attached to dust particles. These elements may collect on the filters in exhaust stacks.
2. During some stages of chemical processing, radium atoms may become mobile and then be carried by different process streams through the processing plant. Then at a later stage, for example after treatment with sulphuric acid, the radium may be deposited as scale inside pipes or as sediment inside processing vessels.

The radiation safety officer at a processing plant should have the training that will allow him/her to assess chemical, physical and thermodynamic factors that may influence the behaviour of all radionuclides in the mineral process. Alternatively, the involvement of a specialist team familiar with the plant chemistry/engineering or an external radiation protection expert would be required to ensure that the assessment of radiological situation in the processing environment is accurate.

It also is important to include into the monitoring program any artificial sources of radiation that are being used on site. This would include such devices as:

1. XRF (X-ray fluorescence) machines in the laboratory and portable X-ray instruments that may be used in mineral exploration.
2. Radiation gauges that are used for flow control and typically contain either ^{137}Cs or ^{60}Co, which emit gamma radiation.
3. Product quality devices such as 'in-stream analysers' that may contain ^{55}Fe, ^{238}Pu, ^{241}Am or ^{244}Cm, which emit alpha particles.
4. Portable gauges for the purpose of monitoring soil moisture content containing ^{241}Am/Beryllium–9), where beryllium is combined with ^{241}Am to produce neutrons from the alpha bombardment of the beryllium nucleus.

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

2.2.2 Pathway analysis

After determining which radionuclides need to be included in the monitoring program, an assessment of potential exposure pathways should be assessed.

If the list of identified radionuclides is the same for both the pre-operational monitoring stage and the operational monitoring stage, an assessment of potential radiation exposure to members of the general public and the local environment should be carried out in a similar method to the one undertaken prior to the commencement of operations. However, it may be necessary to carry out this assessment at a greater frequency.

If the list of 'radionuclides of interest' has changed significantly, the monitoring program must be modified to accommodate the change.

In occupational environments, the two main exposure pathways are internal exposure (inhalation and ingestion) and external exposure. External radiation exposure will need to be assessed in almost all cases. This includes exposure to radiation from surface contamination, in particular where it has been established that radionuclides emitting relative high energy beta particles are present in the working environment. These radionuclides may accumulate on plant surfaces and protective clothing worn by workers.

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; and
2. Radon (^{222}Rn), Thoron (^{220}Rn) and their progeny.

Ingestion:

1. Drinking water – should only be considered in cases where on-site drinking water is supplied from a local source (e.g. a bore).
2. Dust (incidental) – only when the potential exists due to employees not following the working rules for controlled areas.

At the end of this stage:

- the list of 'radionuclides of interest' is coupled with pathways of potential exposure;
- the monitoring required is known; and
- the media to be monitored is identified.

2.2.3 Identification of supervised/controlled areas and employees to be monitored

Guideline NORM–6 Reporting requirements provides information on threshold levels used in identifying supervised and controlled radiation areas. These are based on potential employee exposure of 1 mSv/year and 5 mSv/year, respectively.

The detailed assessment of radionuclides in the process and the potential radiation exposure pathways will allow for the accurate estimation of the site areas that will most likely be classified as supervised or controlled. After the predictions have been made, an assessment of the worker's involvement in the relevant processes should be carried out.

On exploration sites, the radionuclides' concentrations are typically not known, at least at the time of the commencement of exploration activities. It is, therefore, very important that the monitoring program is structured in a way that will allow the determination of supervised (and, where applicable, controlled) areas as soon as possible after the exploration commences.

On mine sites, an assessment of radionuclides' concentrations in the ore prior to mining together with the site's mine plan will allow for the timely prediction of pits or underground areas that may need radiological classification.

In processing environments where the process is fully automated the worker's involvement is expected to be minimal and only personal radiation exposure that may need to be assessed will be the one that may be received during routine or non-routine maintenance. In other cases, where plant equipment requires regular cleaning and maintenance, potential exposure of all employees involved in routine operation and maintenance of processing plants will need to be assessed.

Typically, employees in working groups expected to receive a radiation dose in order of 1 mSv/year will not be monitored on a personal basis. Rather, their doses will be estimated on a group basis. Employees that are expected to receive doses in excess of 4 mSv/year need to be monitored individually.

For employees who are expected to receive doses between 1 and 4 mSv per year, a combination of group and individual monitoring can be used. For example, five employees out of group of 15 can be issued with personal dosimeters — thus a 'cross-section' of employees is monitored to confirm the data of the group dose assessment carried out on the basis of area measurements.

At the end of the final stage of the operational radiation monitoring program design the following information should be available:

1. Radionuclides to be monitored.
2. Media to be monitored.
3. An updated environmental radiation monitoring program which is basically an amended version of the pre-operational program.
4. Working groups of employees for which area monitoring data will be used for the dose assessments.
5. Working groups of employees for which individual radiation monitoring will be necessary to ensure that the assessment of radiation exposure is as accurate as possible.

This information should be sufficient for the design of a comprehensive monitoring program. At this point a consultation with DMP (and, in some cases, with other government departments) will be necessary. This will ensure that:

1. An independent assessment of the proposed monitoring program is undertaken.
2. Any amendments can be made.
3. The program can receive statutory approval.

2.2.4 Other considerations

After the initial design of the operational monitoring program some elements may seem excessive. However, it is important to maintain the program as broad as practicable. Monitoring provides important supplementary benefits to industrial and public relations, reassurance and motivation to the workforce and the general public. It also provides information useful in the determination of liability in the event of the expression of adverse health effects in individual workers or claims of land contamination.

It is also important to keep in mind that radiation protection is only one (and, frequently, relatively minor) element in ensuring the overall occupational health and safety of workers in mining and minerals processing industry.

The radiation monitoring program should be established and managed in close cooperation with those responsible for other areas of occupational hygiene, health and safety — as radiation protection measures can sometimes significantly influence the exposure of workers to other agents. For example:

1. Dust control/extraction units may be required inside processing plants with expected high concentrations of airborne dust. It is, however, known that if these are installed without having due regard to other factors, they may become a serious source of the exposure of workers to the unacceptable noise levels.
2. Protective clothing provided to employees for the protection from surface contamination can cause heat stress, particularly in the summer months. The examples of such workplaces are remote exploration sites where temperatures in excess of 40°Care common and the vicinity of heat sources (kilns, driers, etc.) in relatively enclosed workplaces such as processing plants. Whilst being protected from surface contamination, workers will be only be able to perform duties in certain areas for very short periods due to the protective clothing interfering with body's capacity to lose heat.

2.3 Monitoring methods

Measurement of the identified radiation parameters at the particular exploration, mining or mineral processing operation provides a method for detecting anomalous operating conditions and for the indication that corrective action should be taken. Apart from the monitoring of radioactivity concentrations, the typical program should also contain monitoring of the performance of the control equipment such as dust control systems and measures for identifying deficiencies in the initial design of routine operations.

Typically, during first year of operation, comprehensive surveys of external gamma radiation, airborne radioactive dust, radon/thoron and their progeny, and surface contamination levels should be conducted.

The monitoring program may be adjusted after the first year of operations (after the consultation with DMP and other Government departments, if applicable) to ensure that only those radionuclides and exposure pathways that contribute a measurable radiation exposure of employees, members of the general public and the local environment are being monitored. The pathways that contribute only 5–10% to the overall exposure level may not need to be monitored frequently and the monitoring program can be adjusted accordingly.

2.3.1 External gamma radiation

2.3.1.1 Individual (personal) monitoring

In most circumstances, exposure to the external gamma radiation is assessed by the systematic monitoring of individual workers. In some cases it is suitable to estimate the exposure from the results of workplace monitoring. For example, when the:

- method based on workplace monitoring has been shown to be acceptable;
- exposure levels are relatively constant and can be reliably assessed by carrying out an area survey; or
- workers concerned are regularly employed in either unclassified or in a supervised area, and enter controlled areas only occasionally.

Individual monitoring is normally required for workers who routinely work in areas that are designated as 'controlled' because of the external radiation hazard. The individual monitoring program for external exposure to gamma radiation is intended to demonstrate that the worker's exposure has not exceeded a dose limit and to verify the adequacy of workplace monitoring.

For workers in 'supervised areas', it may be simpler to use a limited number of individual dosemeters rather than to adopt a comprehensive program of monitoring of the workplace. In many cases individual monitoring for the purposes of dose records and re-assurance of employee's is a good practice for all workers in a supervised area.

Individual monitoring is typically carried out using thermo-luminescent (TLD) badges. There are many providers of this service and it is important to ensure that:

1. TLD badges designed for exploration, mining and mineral processing environment are available (the badges should be suitable for the operational conditions — dust, heat, humidity).
2. A particular TLD service is approved for use in Western Australia.

There are two types of TLD badges — personal and 'control'. A 'control' badge is supplied with each TLD issue and it must be stored in an area where it is not exposed to sources of ionising radiation or excessive heat (inside the storage box for the duration of the monitoring period). If a new employee is requested to wear the TLD badge for the first time, it must be ensured that this person is notified of his/her responsibilities and rules for the wearing of the badge.

If a TLD badge is lost or damaged, the data obtained in other periods during the monitoring year must be averaged and used as a substitution for the period in which data could not be obtained through direct measurement (and a specific note inserted into the 'Boswell' database clarifying that the result is an estimate). Please refer to Norm–7 Boswell assessment and reporting database for more information.

Example: *Data:* The results reported by the monitoring services for 'J Smith' for the monitoring year are: 1st quarter: 250 μSv; 2nd quarter: 310 μSv; 3rd quarter: The badge is lost; 4th quarter: 430 μSv. Therefore, the annual exposure to the external radiation of 'J Smith' will be:

$$= 250 + 310 + \frac{250 + 310 + 430}{3} + 430 = 1320\,\mu Sv$$

Another useful instrument that can be used for individual monitoring is a personal integrating electronic dosimeter. These are very useful in surveys of particular work practices but not for the dose assessments, as typically their batteries must be regularly recharged or replaced and an appropriate background reading must be subtracted.

2.3.1.2 Area (positional) monitoring

Area monitoring is used extensively for surveying purposes when there is a need to monitor trends. It is also essential in environmental radiation monitoring. The advantage of a survey meter over a TLD badge is that an instantaneous dose rate is obtained, thereby permitting fast implementation of corrective action where required. Locations that are specifically used for trend analysis should be clearly marked, either in the environment or on a map/plan. Such surveys should form an integral part of the overall radiation protection program as the success, or otherwise, of control measures used to minimise employee radiation exposures can then be readily assessed.

The choice of an appropriate surveying instrument for a specific application depends on numerous factors, such as:

- portability;
- mechanical ruggedness;
- ease of use and reading;
- ease of servicing; and
- reliability.

In addition to these general requirements, survey instruments must be appropriately calibrated by the calibration service approved for use in Western Australia. The survey meters must be suitable for the radiation that needs to be measured at a particular exploration, mining and/or mineral processing site. A very clear interpretation of the registered results and their use in dose estimates must be available. An additional technical note on data interpretation and survey instruments in general is provided in Appendix B of the Guideline NORM–3.1 Pre-operational monitoring requirements.

Limits for gamma dose rates are described in Table 1 of the Guideline NORM–6 Reporting requirements.

2.3.2 Airborne radioactivity surveys

2.3.2.1 Atmospheric dusts

In many circumstances involving exposure due to airborne radionuclides from NORM, workplace dust monitoring is required. Monitoring procedures are introduced to demonstrate satisfactory working conditions, compliance with statutory limits, or in cases where individual monitoring is unable to provide sufficient data (e.g. when radioactivity content in the workplace air is expected to be relatively low, but an estimate of a potential exposure is required).

For new operations, individual monitoring is likely to be needed and should be considered. As data on individual radiation exposure at a particular exploration/mining/processing site accumulates, the need for routine individual monitoring should be reviewed.

In existing situations it may be difficult to determine whether individual monitoring of workers is necessary. Such monitoring should be used routinely only for workers who are employed in designated 'controlled areas', specifically in relation to the radioactivity in the air. If initial monitoring has shown that it is unlikely that annual radiation doses from dust inhalation will exceed 1 mSv (including both dust and radon/thoron and their progeny), then individual monitoring may be unnecessary, but workplace monitoring should be undertaken.

Workplace monitoring usually consists of sampling dust in selected locations and collecting airborne radioactivity on the filter. The filter can then be analysed for gross alpha activity for the determination of either radon/thoron and their progeny concentrations, and/or gross alpha activity concentrations.

The frequency of individual monitoring will be significantly dependent on the expected exposure levels. Typically, the following schedule can be used:

1. Expected annual dose $<$ 1 mSv – workplace monitoring, occasional confirmatory individual monitoring.
2. 1 mSv $<$ Expected annual dose $<$ 4 mSv – workplace monitoring complemented by individual monitoring of 25% of the work group every quarter – every employee wears an individual monitor (dust cassette, radon monitor) at least once a year (minimum of 12 personal samples for the work group).

3. 4 mSv < Expected annual dose < 10 mSv, regular individual monitoring program, either 6 samples from every employee every year or 24 samples per year from a work group (whichever the greatest); to ensure that sufficient data is available for personal dose assessments, complemented by workplace monitoring.
4. Expected annual dose > 10 mSv, a comprehensive individual monitoring program, 2 individual samples are required from every employee every month to ensure that sufficient data (at least 24 samples) is available for personal dose assessments, complemented by workplace monitoring. Additional investigations that will need to be undertaken may include determinations of dust Activity Median Aerodynamic Diameter (AMAD), dust solubility, uranium–thorium content ratio, secular equilibrium of both uranium and thorium decay chains, etc.

Please refer to NORM–3.3 Air monitoring strategies and to NORM–3.4 Airborne radioactivity sampling for more information on the program design and the analysis of samples; and to NORM–5 Dose assessment for airborne radioactivity levels derived for different concentrations of radionuclides.

From the environmental perspective it is important to continue high-volume dust sampling at all locations identified during the pre-operational stage. Several other locations should also be added to the monitoring program, depending on the character of operations, the radionuclides present in the mineral that is mined/processed, on concentrations of these radionuclides in the process, and the proximity of the critical group of members of the public. Initially, it is recommended to continue taking samples of environmental dust quarterly, with the subsequent assessment after first year of operation when the monitoring frequency should be reviewed. Typically, at an operational site the sampling is undertaken every six months.

It is also important to sample all stacks and exhaust vents to ensure that any radionuclides emitted from them are accounted for in the estimation of exposures for members of the critical group of members of the public. Typically, daily emissions of uranium and thorium are assessed. In many circumstances it is also appropriate to determine the levels of lead and polonium as well. For practical purposes an annual assessment of concentrations of ^{210}Po and ^{210}Pb (from the uranium decay chain) and ^{212}Pb (from the thorium decay chain) is recommended.

Individual and workplace samples should be taken in accordance with Australian Standard AS 3640–2004, environmental samples — in accordance with Australian Standards AS 3580.3–2003 and/or AS 3580.10.1–2003. Additional information is provided in the following Guidelines:

- NORM–3.1 Pre-operational monitoring requirements;
- NORM–3.3 Air monitoring strategies;
- NORM–3.4 Airborne radioactivity sampling; and
- NORM–3.5 Measurement of particle size.

2.3.2.2 Radon and thoron

Where the levels of radon (^{222}Rn) and thoron (^{220}Rn) in air have been identified during the pre-operational monitoring as requiring additional assessment, the monitoring should be undertaken. Typically, passive samplers for the monitoring of radon and thoron are used throughout the workplace as they integrate the data over a period of several months and provide average concentration in Bq/m^3.

The monitoring of radon and thoron concentration 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. Due to the variability of this equipment and to the fact that some of it is not suitable for the industrial/mining use an advice should be sought from an appropriate authority, prior to the use of a particular instrument on an exploration, mining and/or processing site.

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.

2.3.3 Water quality surveys

From an occupational exposure perspective, water monitoring should be undertaken for potable water supply, where this is drawn from nearby underground aquifers. Water samples are typically taken every six months to evaluate the ingestion of radionuclides by employees and to determine if contamination of potable ground water is occurring by seepage pathways.

From an environmental perspective, it is important to continue water monitoring at all bores, wells and surface water bodies identified during the pre-operational stage. Several other locations should also be added to the monitoring program depending on the character of operations, the radionuclides present in the mineral that is mined/processed, on concentrations of these radionuclides in the process and their solubility in water, and the proximity of the critical group of members of the public. Initially, it is recommended that samples of water continue to be taken every six months with subsequent assessment after the first two years of operation, when the monitoring frequency should be reviewed. Typically, sampling at an operational site is undertaken once a year.

As with all other radiation parameters, the sampling frequency is dependent on the magnitude of observed waterborne radionuclide concentrations.

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

Information and procedures can be found in the Australian Drinking Water Guidelines [8].

2.3.4 Other monitoring

2.3.4.1 Assessment of secular equilibrium

If material containing natural radionuclides is either treated with chemicals and/or heated to more than 250–300℃, it will be necessary to sample all generated waste to establish if both thorium and uranium decay chains are still in secular equilibrium. This will allow for the estimation of environmental mobility of different radionuclides in the long term and it is required to ensure that the waste is deposited in appropriately designed facilities, where necessary.

To evaluate the degree of equilibrium in the thorium decay chain it is necessary to measure the specific activities of ^{232}Th, ^{228}Ra, ^{228}Th and ^{212}Pb/^{212}Po. 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}Po/^{210}Pb.

Thorium and uranium decay series are described in Appendix B of the guideline NORM–2.1 Preparation of a radiation management plan – exploration. The amount of samples will vary significantly depending on the characteristics of the particular site, mineral processed and its treatment.

2.3.4.2 Surface contamination

Surface Contamination means the presence of a radioactive substance on a surface in quantities in excess of 0.4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 0.04 Bq/cm^2

for all other alpha emitters. Low toxicity alpha emitters are natural uranium, natural thorium, ^{235}U, ^{238}U, ^{232}Th, ^{228}Th and ^{230}Th when contained in ores, physical or chemical concentrates; or alpha emitters with a half-life of less than ten days.

Occupational monitoring is usually undertaken in crib and change rooms, control rooms and in all supervised and controlled areas. Auditing of personal hygiene practices of workers should also be undertaken.

The measurement of easily removable radionuclides on plant surfaces can be useful for assessing operating conditions, but it gives only a very indirect measure of potential exposure. Therefore, it is recommended that the monitoring emphasis in the occupational environment should be placed on inspection and housekeeping audits.

A program of surface contamination monitoring can be used to:

- assist in preventing possible spread of contamination;
- detect failures of containment or departures from good operating practices; and
- restrict surface contamination to levels at which the general standards of good housekeeping are adequate to maintain exposures as low as practicable.

It is also important to ensure that all items leaving a particular site classified as supervised or controlled area have surface contamination at very low levels. These items may include vehicles, parts of plant and different machinery that is sent from the site, either for repairs or for the disposal. Particular attention must be paid to situations when potentially contaminated equipment is planned to be re-used in another industry (e.g. the use of elevators from a mineral separation plant in a grain handling and/or storage facility). In some operational plants where dust on surfaces can be clearly seen, the radiation hazard is related to the amount of this dust that can be readily re-suspended. It is therefore important that regular cleanup programs are in place to ensure this hazard is minimised.

Surface contamination is usually monitored by direct measurement (e.g. alpha scintillation probe) or indirectly, by wiping a surface with a filter paper and subsequent alpha counting of this paper. The first technique yields total (fixed plus removable) contamination, while the second will indicate the percentage of removable contamination. A wipe test efficiency factor must be incorporated to relate the removable contamination to the total surface contamination. For example, in the case of treatment plant dusts and in the absence of relevant experimental data, a wipe test efficiency factor of 60% can be used. An appropriate survey monitor should be available and should be calibrated in a way that allows easy interpretation of results and their comparison with the levels given in NORM–6 Reporting requirements.

2.3.4.3 Biota samples

In cases where a reference plant or animal is selected for the study instead of the critical group of the members of the public, it is necessary to continue this monitoring on the annual basis to ensure than any changes can be identified as early as possible.

2.3.4.4 Task related monitoring

Task related monitoring is conducted to provide information about a particular operation and to give, where necessary, a basis for decisions on the conduct of the operation (e.g. if a particular work practice results in exposures that are significantly higher than other similar ones).

It is particularly useful when short-term work is carried out under conditions that will be unsatisfactory for permanent use. Task related monitoring is usually conducted in the same way as routine monitoring, unless the circumstances of the operation change significantly (e.g. if radionuclides involved may be different or the potential magnitude of internal exposure may be significantly greater).

2.3.4.5 Quality assurance

Quality assurance comprises planned and systematic actions that are necessary to provide adequate confidence in the results of a monitoring program. Quality assurance includes quality control, which involves all those actions by which the adequacy of equipment, instruments and procedures are assessed against established requirements.

It is important that any monitoring program should include, as an integral part, a quality assurance part, which will ensure that:

- equipment and instruments function correctly;
- procedures are correctly established and implemented;
- analyses are correctly performed with limited errors;
- records are correctly and promptly maintained;
- the required accuracy of measurements is maintained; and
- systematic errors are minimised to the extent possible.

In the design of a quality assurance program the following factors are usually taken into account:

1. Quality of equipment and instruments.
2. Training and experience of personnel.
3. Verification of procedures by the routine analysis of control samples and the use of standard methods for analysis.
4. Frequency of calibration and maintenance of equipment and instruments.
5. The need for traceability of the results of monitoring program to the National Standard.
6. The degree of documentation needed to demonstrate that the required quality has been achieved and is maintained.

The level of accuracy required for all types of undertaken measurements depends on the type of the measurement made and its importance from the point of view of the protection of the workers and the environment. Please note that even the best method currently available for making a measurement may be subject to large errors, which may simply have to be accepted (e.g. the variability of gamma measurements with a portable instrument, where the accuracy may be as low as $\pm 20\%$, in some circumstances).

The scope and extent of a quality assurance program will also depend on the importance of the measurements from the point of view of protection of the workers and the environment. On the other hand, quality control actions may vary from a simple functional test of an instrument by way of a built-in check source to the thorough and frequent calibration of an alpha-counting assembly to determine if the equipment complies with established requirements concerning low level of background counts, efficiency, accuracy (statistical analysis such as chi-square test is required).

In the Australian Mining and Mineral Processing Code, ARPANSA [3] requires that "the quality assurance program which is compliant with Australian Standards should be implemented, including traceability of all radiation measurements to Australian metrological standards where possible".

Metrology is defined by the International Bureau of Weights and Measures (BIPM) as 'the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology.'

The Australian Standards referred to above are:

- Environmental Management Systems [4];

- Quality Management Systems [5];
- Occupational Health and Safety Systems [6]; and
- Occupational Health and Safety Systems [7].

2.4 Data presentation

Data should be presented for assessment to the appropriate authority (and, if required to other Government Departments) in a form as described in Guideline NORM–6 Reporting requirements.

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