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

NORM–3.3

Monitoring NORM — air monitoring strategies

Government of **Western Australia**
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1. General information

1.1. Purpose

To provide guidance on the measurement of the airborne radioactivity that may be encountered in exploration, mining and mineral processing operations.

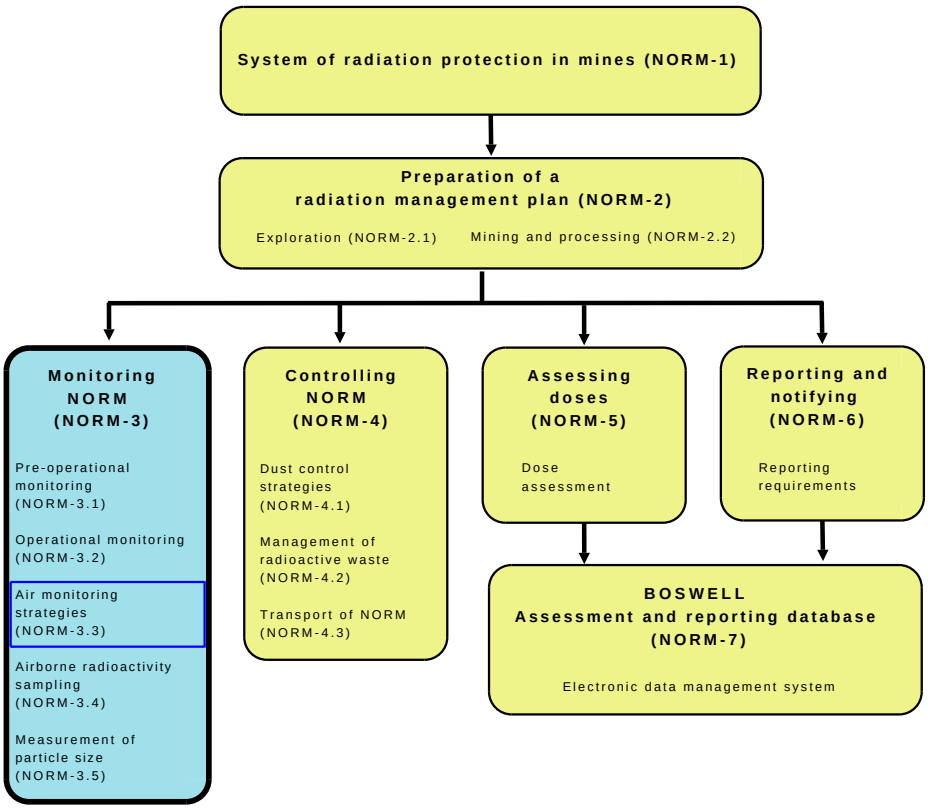
1.2. Scope

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 how the Radiation Safety Guidelines are arranged.

Figure 1.1.: Relationship to other NORM guidelines



2. Guidance

2.1. Introduction

NORM-3.3 deals primarily with the monitoring of radioactivity in air and assumes that readers are familiar with the practice of dust monitoring. One pre-requisite for appointment as RSO is successfully completing the Certificate III in Surface Ventilation Technician (Mining Industry) and/or Certificate IV in Surface Ventilation Officer (Mining Industry) courses (Current course provider: Industrial Foundation for Accident Prevention (IFAP) — www.ifap.asn.au). For further guidance on dust sampling strategies, frequency of sampling, repeat sampling and the statistics of occupational hygiene distributions, publications such as "Simplified Monitoring Strategies" [4] and "A Strategy for Assessing and Managing Occupational Exposures" [5] are recommended.

Regular monitoring for airborne radioactivity (dust, radon/thoron and their progeny) should be performed in exploration, mining and mineral processing operations where there is a possibility of radiation exposure via the inhalation pathway.

A personal air sampler placed in the worker's breathing zone can collect a sample that is representative of the activity concentration in air, which the worker has inhaled. Air concentration measurements, combined with assumptions of breathing rates and measured exposure times, can be used to estimate the intake of radioactivity.

When establishing the frequency of measurements for radon/thoron and their progeny, historical results, expected variations in measurements and the degree of hazard should be taken into account. The frequency should be increased if:

- measured concentrations exceed the usual range in the individual workplace or specified reference levels are exceeded; and
- major changes are made to the ventilation system, the layout of the exploration site or mine/plant or the method of exploration, mining and/or processing.

In setting up the frequency of dust monitoring, the concentrations of radioactive dust, its size distribution and the potential for its inhalation or ingestion should be taken into account. The levels of exposures that are predicted due to the concentrations of radioactive dust are a key factor in deciding the nature and extent of any individual monitoring program that may be necessary.

The main purposes of an airborne radioactivity monitoring program are to:

1. Assess committed effective dose equivalent and committed dose to individual organs, due to internal exposure.
2. Enable informed decisions to be made regarding protection of the workers from internal radiation exposures.
3. Facilitate the achievement of air contamination concentrations that are As Low As Reasonably Achievable (ALARA).
4. Identify long term trends and to detect short term excessive levels.
5. Test procedures and plant including the effectiveness of engineering and institutional controls.

2.2. A suggested flow chart for airborne radioactivity sampling

It is important not to embark on a full-scale personal monitoring program without detailed knowledge of the seriousness of radiation issues at a particular operation. This may include consideration of the range of actual exposures of employees performing different tasks at different locations under the normal variation of working conditions.

In the first instance, workplace (positional) monitoring should be undertaken. Monitoring frequency of personal sampling (and more refined dose assessments) that will be required in accordance with the level of potential personal radiation exposure is suggested in Figure 2.1 on the next page.

Methods different from the one above may also be acceptable to the appropriate authority. For example, it may be useful to modify the flow chart to suit a specific exploration/mining/processing operation by re-defining the limits given from effective dose (in mSv) to Annual Limits on Intake (ALI, in Bq) or Derived Air Concentrations (DAC, in Bq/m^3). When making such conversions, please refer to Guideline NORM–5 Dose assessment. Other parameters, such as dust particle size and its solubility may need to be considered in this modification and suitable conservative values should be chosen.

Details of the monitoring requirements each level of airborne activity can be found by referring to sections of this Guideline, as indicated by Figure 2.1 on the next page.

2.3. Positional airborne radioactivity sampling

2.3.1. Sampling

Established fixed positions that will provide samples representative of conditions in each area of the workplace should be used. Samples should always be collected in the same position. A simple qualitative visual survey (e.g. using a beam of light) can be invaluable in identifying dust sources, patterns and movement within the workplace—thus helping direct the subsequent monitoring efforts. Alternatively, if greater accuracy is required, personal sampling may be substituted for positional sampling.

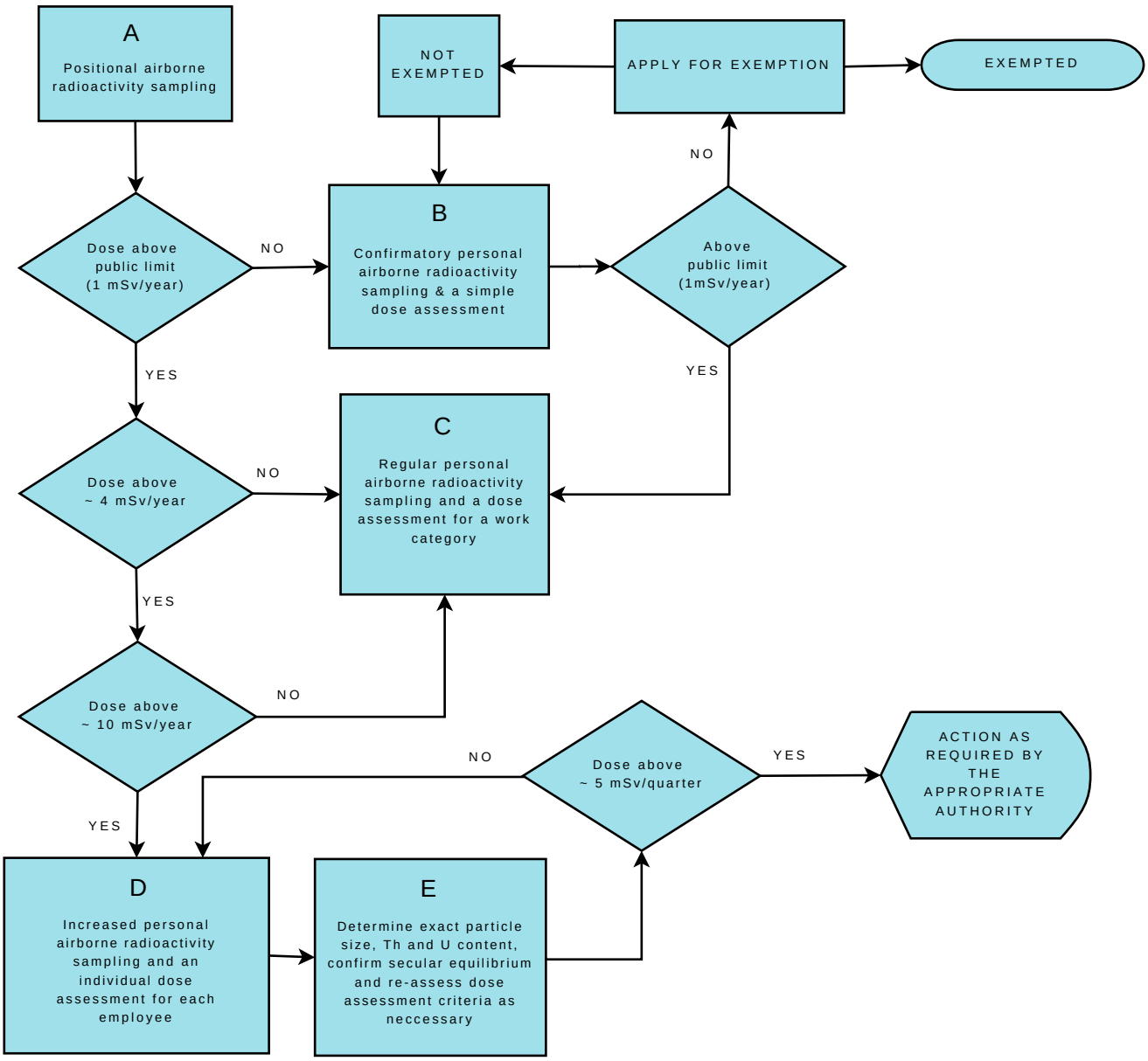
Samples should be collected in accordance with the Australian Standard [3]. An alternate sampling technique may be by using grab sampling. A high volume sampler can be used to collect dust from at least 500 litres of air. The sampling should be designed to give representative samples over a working shift and some variation analysis may be required.

The frequency of sampling will depend on the level of dust concentration and its variability. In order to confirm that annual doses are below the 1 mSv limit, samples should be collected at a minimum of three monthly intervals. Values consistently exceeding the 1 mSv limit should be investigated, and this may require further sampling.

In the case of radon/thoron and their progeny, a certain number of samples will need to be taken either by time integrated measurements or grab samples, as described in Guideline NORM–3.4 Airborne radioactivity sampling. Appropriate electronic instruments may also be used. Consultation with DMP is required to determine the frequency and method of this monitoring, and the resultant value should be accounted for in the assessment of the internal dose.

The location of fixed position samplers to provide representative samples needs to be done with care and with reference to the actual working conditions of employees in the areas. Improperly located positional samplers may under or over estimate personal dust exposure by a large factor and invalidate subsequent dose assessment. The sampling strategy employed will need to be site and area specific.

Figure 2.1.: Airborne radioactivity sampling



Key:
A – Section 2.3 on the preceding page
B – Section 2.4 on the next page
C – Section 2.5 on page 6
D – Section 2.6 on page 7
E – Section 2.7 on page 7

2.3.2. Gross alpha determination and dose assessments and exemptions

Gross alpha determination — refer to the Guideline NORM–3.4 Airborne radioactivity sampling.

Effective dose equivalent assessments — refer to the Guideline NORM–5 Dose assessment.

The result should be compared with the annual public exposure limit of 1 mSv/year. If the result is below this value, confirmatory personal monitoring is recommended. If, however, the result is above 1 mSv/year a regular personal airborne radioactivity sampling program should be established.

2.4. Confirmatory personal airborne radioactivity sampling

2.4.1. Sampling

Personal total dust sampling should consist of regular sampling of selected members of the workforce for a set period (typically six months). Monitoring of these representatives should be conducted monthly with different members selected for each monitoring period. Monitoring should be conducted for greater than 4 hours and preferably for a full shift and care should be taken that the work of the monitored employee is representative of the work normally conducted by the work group members.

Samples should be collected in accordance with the Australian Standard [3]. Additional grab samples may be taken to assess variability of dust levels. These samples should be of at least 100 litres in volume and sampling should be designed to give a variety of working conditions; some variation analyses would be required.

Sampling frequency will depend on the level of dust concentration and its variability. It will also depend on the size of the work group and the variability of their activities. Sampling should be conducted so as to ensure that there are at least 12 representative samples taken per set period on members of the work group.

In the case of radon/thoron and their progeny, a certain number of samples will need to be taken either by time integrated measurements or grab samples, as described in Guideline NORM–3.4 Airborne radioactivity sampling. Appropriate electronic equipment may also be used. Consultation with DMP is required to determine the need and, if necessary, frequency and methods, for personal monitoring for radon/thoron and their progeny.

2.4.2. Gross alpha determination and dose assessments and exemptions

Gross alpha determination — refer to the Guideline NORM–3.4 Airborne radioactivity sampling.

Effective dose equivalent assessments — refer to the Guideline NORM–5 Dose assessment.

If personal sampling confirms that the internal exposure of employees is less than the 1 mSv limit, an estimate of the total dose should be carried out.

The result should include all possible pathways of radiation exposure (ingestion and exposure to external sources of radiation — refer to the Guideline NORM–5 Dose assessment) and must again be compared with the annual public exposure limit of 1 mSv/year. If the result is below this value, an application for an exemption [1] can be lodged with DMP.

1. The applications for exemption should be made on the basis of at least one year's sampling results. Results should be presented separately for each specific area for which exemption is sought.

2. The data supplied to support an application for exemption should be of high quality i.e. full account must be taken of counting statistics and the number of samples should be sufficient to support the claim that levels are below the 1 mSv limit. A minimum of ten sample results would be required for each area.
3. It is expected that some confirmatory monitoring may be required to provide assurance that exemption from regular monitoring is appropriate. DMP will recommend the frequency and nature of confirmatory monitoring on a case-by-case basis.

If the result of dose assessment is between 1 and 4 mSv/year, regular personal monitoring is recommended.

2.5. Regular personal airborne radioactivity sampling

2.5.1. Sampling

Regular personal dust sampling can be carried out for work group representatives or for individual workers, as appropriate.

In case of sampling of work group representatives, monitoring should be conducted monthly with different members selected for each monitoring period. Sampling should be done in accordance with the sampling regime as described in Appendix A on page 9.

In case of sampling of individual workers, the sampling should consist of regular sampling of all members of the work group. Sampling should be conducted so as to ensure that each employee in the work group is sampled at least six times per year.

In both cases, monitoring should be carried out for greater than four hours and preferably for a full shift and care should be taken that the work of the monitored employee is representative of the work normally conducted by the work group members.

Samples should be collected in accordance with Australian Standard [3]. Additional grab samples may be taken to assess variability of dust levels. These samples should be of at least 100 litres in volume and sampling should be designed to give a variety of working conditions; some variation analyses would be required.

Sampling frequency will depend on the level of dust concentration and its variability. It will also depend on the size of the work group and the variability of their activities.

In case of radon/thoron and their progeny a certain number of samples will need to be taken either by time integrated measurements or grab samples, as described in Guideline NORM–3.4 Airborne radioactivity sampling. Appropriate electronic equipment may also be used. A consultation with DMP is required to determine the need (and, if necessary, frequency and methods) for personal monitoring for radon/thoron and their progeny.

2.5.2. Gross alpha determination and dose assessments and exemptions

Gross alpha determination — refer to the Guideline NORM–3.4 Airborne radioactivity sampling.

Effective dose equivalent assessments — refer to the Guideline NORM–5 Dose assessment.

The result should be compared with the value of 4 mSv/year (20% of the annual exposure limit of 20 mSv/year for designated employees). If the result of dose assessment is between 4 and 10 mSv/year, continuation of a regular personal monitoring as described in Section 2.5.1, is recommended. If the result is above 10 mSv/year, the establishment of a more comprehensive personal monitoring program is recommended.

2.6. Increased regular personal airborne radioactivity sampling

2.6.1. Sampling

The increase in personal monitoring may result in a comprehensive individual sampling of all members of the relevant work groups. Monitoring should be conducted for greater than four hours and preferably for a full shift and care should be taken that the work of the monitored employee is representative of the work normally conducted. Any non-routine occurrences should be noted.

Samples should be collected in accordance with Australian Standard [3]. Additional grab samples may be taken to assess variability of dust levels. These samples should be of at least 100 litres in volume and sampling should be designed to give a variety of working conditions; some variation analyses would be required.

Sampling frequency will depend on the level of dust concentration and its variability. It will also depend on the level of radioactivity concentration to which the individual is exposed and to variability in that exposure.

Sampling should be conducted so as to ensure that each employee is sampled at least 12 times per year.

In the case of radon/thoron and their progeny a certain number of samples will need to be taken either by time integrated measurements or grab samples, as described in Guideline NORM–3.4 Airborne radioactivity sampling. Appropriate electronic equipment may also be used. Consultation with DMP is required to determine the need (and, if necessary, frequency and methods) for personal monitoring for radon/thoron and their progeny.

2.6.2. Gross alpha determination and dose assessments and exemptions

Gross alpha determination — refer to the Guideline NORM–3.4 Airborne radioactivity sampling. Some analysis of the variability of alpha concentration in air will be required to determine the appropriate mean air concentration for the employee.

Effective dose equivalent assessments — refer to the Guideline NORM–5 Dose assessment. The annual intake of radionuclides is determined on an individual group basis and estimate the effective dose equivalent is based on known or approved values of Activity Median Aerodynamic Diameter (AMAD — Guideline NORM–3.5 Measurement of particle size) and using individual occupancy factors.

The results should be compared with the value of 10 mSv/year (50% of the annual exposure limit of 20 mSv/year for designated employees). If the result of dose assessment is between 4 and 10 mSv/year, continuation of a regular personal monitoring as described in Section 2.5 on the facing page, is recommended. If the result is above 10 mSv/year (and approaching 5 mSv/year in a 3-month period), additional investigations should be carried out.

2.7. Additional investigations

In consultation with DMP, the following should be carried out:

1. The AMAD of the dust (Guideline NORM–3.5 Measurement of particle size) should be determined by an approved method. This AMAD will be used in dose calculations in areas where that AMAD is applicable and for specific work groups.

2. The solubility of the dust should be determined so as to indicate the ratio between soluble and insoluble parts. For this determination a high volume sample will be needed and a laboratory analysis performed.
3. The ratio between thorium content and uranium content should be determined. Again a large volume sample will be required for laboratory analysis.
4. Secular equilibrium should be evaluated by measurement on a large volume air sample. The thorium and uranium decay series are described in Appendix B of the guideline NORM–2.1 Preparation of a radiation management plan – exploration.
5. 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. If not accessed previously, a determination of the loss of thoron (^{220}Rn) through emanation from the dust should be made.
6. 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. If not assessed previously, a measurement of radon (^{222}Rn) emanation from the dust should also be performed.

If investigations reveal the levels of radioactivity collected on personal samples to be measurably higher than that detected by positional monitoring in the same operational area, a special task monitoring program can be initiated. The program involves taking short-term (20–30 minutes in length) samples from individual employees performing the task that is known (or suspected) to cause elevated exposure. The values obtained from individual employees are assessed and a particular standard job procedure may be modified to ensure that radiation exposure is kept as low as practicable.

A. Appendix showing the estimation of the optimum sample size

A.1. Work category sampling

If a maximum risk worker cannot be selected for a particular work category with reasonable certainty, then it is necessary to resort to random sampling of the group of workers.

The procedure is to randomly sample the group whose members have a similar expected exposure risk. The objective is to select a sub-group of adequate size to ensure that there is a high probability that the random sample will contain at least one worker with high exposure (if one exists).

According to "Simplified Monitoring Strategies" [4], *the number of samples to take remains the most difficult issue in any monitoring strategy.* The number of samples will influence the precision of the exposure estimate and the attached confidence levels.

Table A.1 details the sample size required for various work group sizes:

Table A.1.: Sample size for work groups

Group Size	Employees to be sampled
< 8	All
8	7
9	8
10	9
11 – 12	10
13 – 14	11
15 – 17	12
18 – 20	13
21 – 24	14
24 – 29	15
30 – 37	16
38 – 49	17
50	18
∞	22

The key aspect of this strategy is the selection of a 'maximum risk worker' from a group of workers of similar exposure risk. If the group is not homogeneous, in terms of exposure risk, then workers should be reclassified into additional groups to ensure homogeneity.

Additional guidance for the sampling of work categories has been developed in order to align airborne radioactivity monitoring programs carried out at different mining and processing sites in Western Australia. It is suggested that the frequency of monitoring is dependent on:

- the potential annual radiation exposure of an employee in a particular work category (based on the measured level of airborne radioactivity); and

- the number of employees in a particular work category.

Firstly, the reasonable levels of airborne radioactivity concentrations in the dust are used to estimate potential annual internal radiation exposure levels, using the default particle size value (AMAD) of 5 μm and 2000 working hours per year:

Table A.2.: Dependency between the exposure and airborne radioactivity concentrations

Internal dose (mSv/y)	Activity (Bq/m^3) — uranium dust	Activity (Bq/m^3) — thorium dust
0.5	0.059	0.026
1.0	0.119	0.052
2.0	0.238	0.104
3.0	0.357	0.156
4.0	0.476	0.208
5.0	0.595	0.260
6.0	0.714	0.312
7.0	0.833	0.364
8.0	0.952	0.417
9.0	1.071	0.469
10.0	1.190	0.521
12.0	1.429	0.625
15.0	1.786	0.781

The values in Table A.2 can be modified to reflect the circumstances of a particular site, for example where both thorium and uranium is expected to be present in the airborne dust and/or radon and thoron exposure may need to be taken into account.

The following steps are taken in the development of the monitoring program where:

- an average airborne radioactivity concentrations would result in internal radiation exposure of less than 1 mSv/year ($\leq$ 0.119 Bq/m^3 for uranium dust and $\leq$0.052 Bq/m^3 for thorium dust) it is suggested that personal monitoring of employees in this work category is not required;
- an average airborne radioactivity concentrations indicate that internal radiation exposures in excess of 1 mSv/year are possible, the measured values are averaged to the closest value in Table A.2; and
- the number of employees in a particular work category is multiplied by the expected annual internal dose value and the result is the number of samples required from the employees in this work category per year.

Please note that due to the fact that monitoring levels for each work category will need to be carried out annually and that statistical analysis of monitoring data needs to be performed – the number of samples cannot be less than 12 per year (one sample per month).

An example: There are five work categories at a site processing mineral containing thorium.

The levels of airborne dust radioactivity for these categories have been measured and are as follows:

1. 'Laboratory' – 0.031 Bq/m^3;
2. 'Metallurgist' – 0.069 Bq/m^3;
3. 'Supervisor' – 0.147 Bq/m^3;
4. 'Maintenance' – 0.189 Bq/m^3; and
5. 'Operator' – 0.297 Bq/m^3.

There are 8 employees in the laboratory:

- 2 metallurgists;
- 3 supervisors;
- 9 maintenance personnel; and
- 15 operators.

The design of the monitoring program is carried out as follows in each work category:

1. 'Laboratory': the level is sufficiently low to carry out positional monitoring only. The location of the monitoring positions and the frequency of monitoring should be determined in consultation with laboratory personnel.
2. 'Metallurgist': the measured airborne radioactivity level corresponds to the value of 0.052 Bq/m^3 (potential exposure of 1 mSv/year, Table A.2). The value of 1 is multiplied by the number of employees in the work category (2). The result is that only two samples per year need to be taken, which will not be sufficient for the statistical analysis and the assessment of the requirement for the monitoring of this category in a subsequent year. Therefore, there will be a need to take 12 samples for employees in this work category.
3. 'Supervisor': the measured airborne radioactivity level corresponds to the value of 0.156 Bq/m^3 (potential exposure of 3 mSv/year, Table A.2). The value of 3 is multiplied by the number of employees in the work category (3). The result is that only six samples per year need to be taken, which (as for the work category 'metallurgist') will not be sufficient for the statistical analysis and the assessment of the requirement for the monitoring of this category in a subsequent year. Therefore, there will be a need to take 12 samples for employees in this work category. Due to the relatively low airborne radioactivity levels for both 'metallurgist' and 'supervisor' work categories the merger of these categories into one may be considered.
4. 'Maintenance': the measured airborne radioactivity level corresponds to the value of 0.208 Bq/m^3 (potential exposure of 4 mSv/year, Table A.2). The value of 4 is multiplied by the number of employees in the work category (9). The result is that 36 samples per year need to be taken for employees in this work category.
5. 'Operator': the measured airborne radioactivity level corresponds to the value of 0.312 Bq/m^3 (potential exposure of 6 mSv/year, Table A.2). The value of 6 is multiplied by the number of employees in the work category (15). The result is that 90 samples per year need to be taken for employees in this work category.

Bibliography

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[2] *Mines Safety & Inspection Act, 1994.*

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