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

NORM–3.5

Monitoring NORM — measurement of particle size

Government of Western Australia
Department of Mines and Petroleum
Resources Safety

The Chamber of Minerals & Energy
Western Australia

MIAC

Reference

The recommended reference for this publication is:

Department of Mines and Petroleum, 2010. Managing naturally occurring radioactive material (NORM) in mining and mineral processing — guideline. NORM–3.5. Monitoring NORM — measurement of particle size: Resources Safety, Department of Mines and Petroleum, Western Australia, 32pp. <http://www.dmp.wa.gov.au/>

Published February 2010

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1. General information

1.1. Purpose

To provide guidance on the measurement of the particle size of radioactive dust 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. Definitions

Aerodynamic Diameter The Aerodynamic Diameter of a particle is defined as the diameter of a sphere of unit density (1 g/cm^3) that has the same aerodynamic behaviour (e.g. settling velocity) as the particle itself. Particles of the same physical diameter but different densities will have different terminal velocities and, therefore, different aerodynamic diameters.

Equivalent Aerodynamic Diameter (EAD) Two particles of different densities are said to have Equivalent Aerodynamic Diameter (EAD) if their densities and diameters are such that their terminal settling velocities are equal.

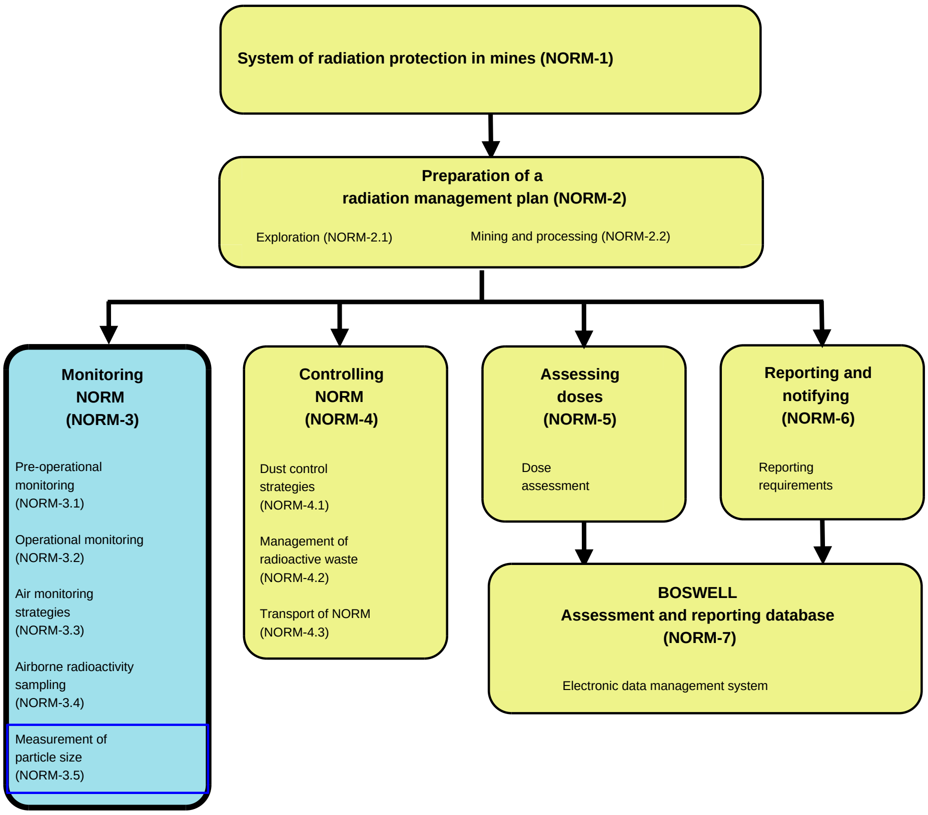
Activity Median Aerodynamic Diameter (AMAD) Activity Median Aerodynamic Diameter (AMAD) is the EAD value of radioactive dust such that 50% of the activity in the dust is associated with smaller particles. The accurate determination of this value is critical in the process of the assessment of internal exposure of employees (NORM–5 Dose assessment).

Mass Median Aerodynamic Diameter (MMAD) Similarly, the Mass Median Aerodynamic Diameter (MMAD) of airborne dust is the EAD value such that 50% of the mass of the dust is associated with smaller particles.

1.4. 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. Summary

The biological effects of inhaled dust depend on the size of dust particles and it is, therefore, necessary to determine this value and the associated radioactivity in the workplace atmosphere. Basically, the smaller particles of radioactive dust are easier inhaled and their depth of penetration in lungs is higher than for the larger particles. Figure 2.1 on the next page demonstrates how the size of dust particles affects their deposition in the human respiratory system.

Particles encountered in practice are rarely regular in shape, and size parameters can be assigned to them in different ways. There is a wide variety of instruments for the determination of the particle size, based on different physical principles. For example, a cascade impactor is based on particle inertia, a laser aerosol spectrometer is based on light scattering, and an electron microscope uses a projected area image. It is, therefore, important to specify the method of measurement whenever particle size data is discussed.

Appendix A in NORM – 5 describes the ICRP 66 [5] lung model for the respiratory tract regions. Deposition of dust particles is governed by either the activity median aerodynamic diameter (AMAD) or the mass median aerodynamic diameter (MMAD) of the inhaled aerosol. The percentage of activity or mass of an aerosol which is deposited in the different regions is given as a function of the AMAD of the aerosol distribution.

2.2. The monitoring method

AMAD is commonly determined using an inertial separation technique, which provides a direct determination of aerodynamic diameter. The inertial separation device separates the aerosol into particle size groups with a known range of aerodynamic diameter. The activity associated with each of the particle groups is easily determined by either radiological or chemical analysis, and statistical handling of data yields the activity median aerodynamic diameter (AMAD).

A personal lightweight cascade impactor is the preferred instrument for determining AMAD. The Marple cascade impactor shown in Figure 2.2 on the following page is an example of this type of equipment. Cascade impactor collection is based on the relative inertial properties of particles in an air stream changing its flow direction from perpendicular to parallel on the impaction surface. Particles with sufficient inertia due to their size and density will not follow the direction of airflow, but will impact upon and be retained by the collector surface. This principle is illustrated in a drawing in Figure 2.3 on page 5.

Figure 2.1.: Dust removal by the human respiratory system [3]

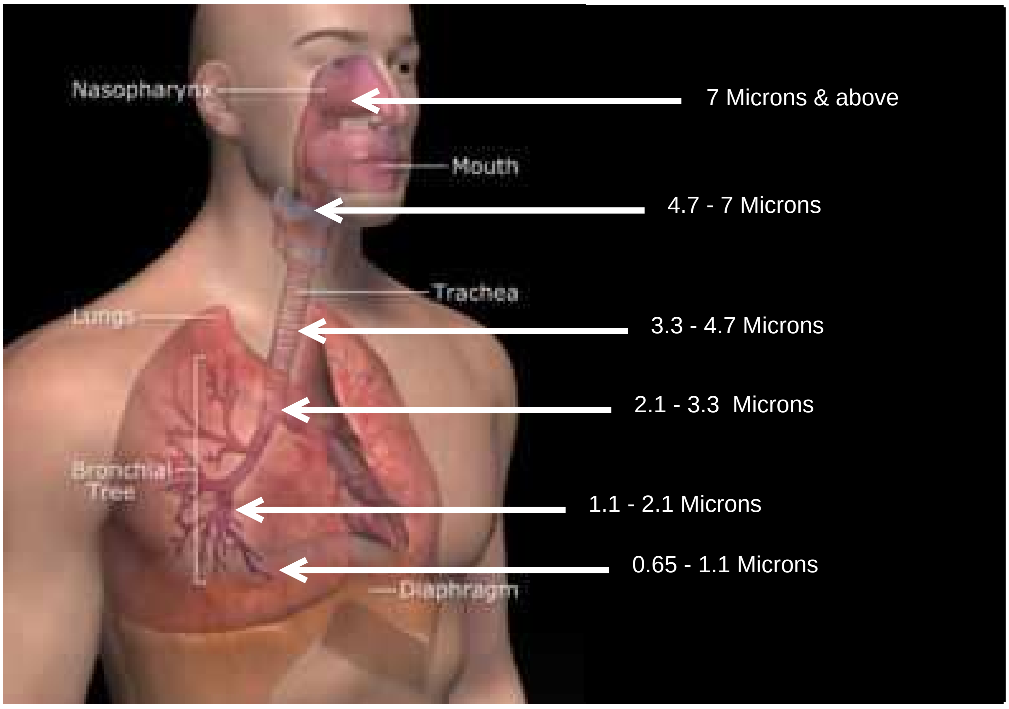


Figure 2.2.: The assembled Marple cascade impactor

Figure 2.3.: An illustration of the Marple cascade impactor operating principle [3].

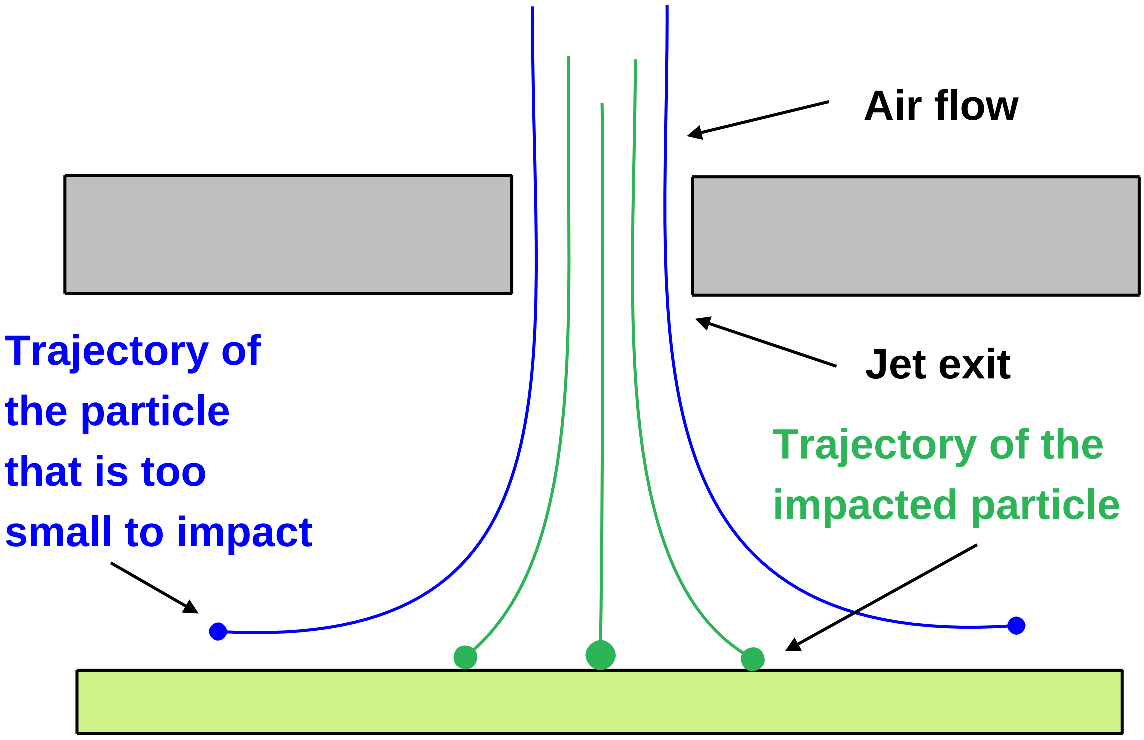
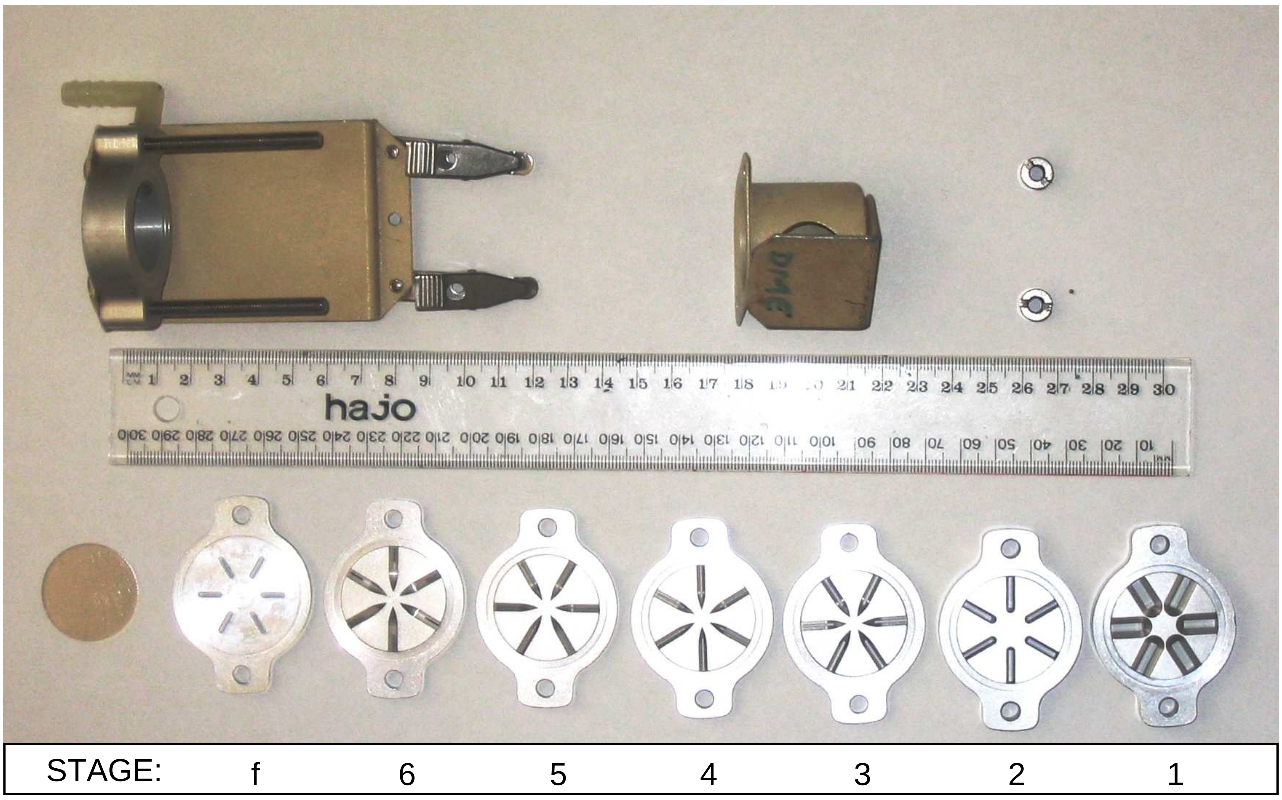


Figure 2.4.: The several stages that make up the Marple cascade impactor



As several impaction stages of decreasing jet widths (therefore ⇒ higher flow rates) are arranged in series, successive stages collect progressively smaller particles. A disassembled Marple cascade impactor showing the several impaction stages is shown in Figure 2.4 on the preceding page.

A mesh to hold the fine filter to collect all the particles passing the impaction stages usually follows the last stage which can also be seen in Figure 2.4. Many different models of personal impactor are currently available and a consultation with DMP is necessary prior to acquiring the equipment to ensure that it will be suitable for the industry sector in which it will be used. For example, several models were designed exclusively for the measurement of wood dust and, whilst marginally acceptable for phosphate and bauxite industry, may not be suitable in other industry sectors.

The main sources of error in the use of a personal impactor are wall loss, particle bounce and the incorrect choice of a collection surface. The errors due to the wall loss can be minimised by choosing an appropriate impactor model. To ensure that the possibility of other errors is also minimised the following precautions should be taken:

1. The use of bare metal, glass or other hard surface as an impaction surface should be avoided when sampling solid aerosols.
2. The use of glass fibre substrates may introduce significant errors, but for an 'approximate' measure of the size distribution AMAD they may be useful.
3. Oils and solvent/grease coatings used on collection substrates should be of suitable stability to prevent the coating 'flowing' under the jet, especially for the lower stages. If the coating flows under the jet, the exposed substrate surface will accommodate bounce and blow-off and consequently give incorrect results. Silicone grease or Vaseline in a suitable solvent are typically used.
4. Care should be exercised so that the loading capacity of the impactor is not exceeded. This can be accomplished by limiting the sampling time based on the expected dust concentration. Over-sampling manifests itself as trails of particles leading from the sample deposits towards the edge of the plate, rather than as well defined, discrete piles of particulates.
5. The incorporation of a deflector plate (inlet cowl) above the impactor inlet to prevent direct fall of large particles into the impactor (refer to Figures 2.2 on page 4 and 2.3 on the preceding page.

The *default* size of AMAD is 5 microns (μm) and in the absence of sufficient data the dose conversion factor associated with this particle value is used in dose assessments (Guideline NORM–5 Dose assessment). If, however, the AMAD of dust particles in a particular operation is significantly different from this value, a special particle size characterisation program can be used to obtain data for the quantification of AMAD. The typical requirements of the annual program:

1. At least two valid personal impactor samples are required for each month (several confirmatory positional samples are also recommended).
2. At least five personal impactor samples per year are required for each of the 'major' work categories.
3. A final report on the AMAD monitoring program should be presented to DMP as soon as possible after the first of April each year and before the Annual Occupational Radiation Monitoring Report. The data is assessed and, if warranted, an alternative dose conversion factor is provided to the company (please refer to guideline NORM–6 Reporting requirements for additional information).

2.3. Determining the AMAD

Once the dust particles have been sized by the impactor, an analysis of the activity associated with each particle size (aerodynamic diameter) fraction is required to determine the AMAD. Recommended analysis techniques include gross alpha counting and, in rare cases, x-ray fluorescence (XRF) spectrometry.

For glass fibre filter papers and oil-coated substrates of diameters less than 47 mm, the substrates can be analysed directly for alpha activity, similarly to the standard dust samples. However, practical limitations of this method include the possibility of alpha self-absorption due to large particles on top stage and, also, deposit build-up effects. Some impactors deposit the aerosol onto very small areas (usually rectangular or circular) and, given the small range of alpha particles, significant build-up can influence the registered activity.

Where the collection substrates are too large for the direct assay, or when too little sample is collected, other analysis techniques are required. With samples collected with high volume samplers and on large filter papers XRF method can be used. This involves grinding the filters with boric acid, pressing the mixture into a briquette and analysing by XRF for the element sought (thorium and/or uranium). For filters with a smaller dust loading, XRF of a fusion disc sample will increase the sensitivity.

Large samples can be removed from oil or solvent/grease coated substrates by appropriate chemical treatment (e.g. solvent washing). The collected material may then be re-deposited onto small filter papers for alpha counting or assayed using XRF, gamma spectroscopy, liquid scintillation counting or another appropriate technique. Such sample preparation will, however, increase the determination time and complicate the activity measurement.

Practical considerations, involving the choice of equipment include:

1. The collection media should preferably be in such a form that it can be placed directly into an alpha counter or be amenable to simple sample preparation.
2. The deposition pattern on collection substrates should be such that significant deposit build-ups do not occur to minimise alpha self-absorption effects.
3. The flow-rate through the impactor should be adjusted so that a range of particle size cut-offs can be collected to suit the dust distributions encountered in a particular operation. In general, flow rates between 2 and 5 litres per minute may be utilised in sampling.
4. The device must have a dust loading capability of greater than 0.5 mg per stage so that the substrates can be analysed directly by gross alpha counting.
5. The impactor should have the optimum number of collection stages (typically between 5 and 7 stages), which would allow size separation to be made with adequate resolution.

An example of the procedure for setting up of a seven-stage personal impactor and associated issues is presented in Appendix A on page 25.

3. Data processing

3.1. Manual data processing

3.1.1. MMAD and associated calculations

For the calculation of the total dust concentration three parameters are required:

1. 'pre-weight' of the each impactor stage i;
2. 'post-weight' of the each impactor stage i; and
3. sampling time.

Since the flow rate of the constant flow sampler is known (usually 2 litres per minute), the *volume* (V) of the sample is calculated as follows:

$$V(m^3) = \frac{T_{SAMP} \times FR}{1000}$$

where:

T_{SAMP} = sampling time in minutes; and
FR = sampler flow rate in litres per minute.

The *total weight of each stage* (TWi) is calculated as follows:

$$TWi(mg) = WTi_{POST} - WTi_{PRE}$$

where:

WTi_{POST} = weight of the stage i after sampling; and
WTi_{PRE} = weight of the stage i before sampling.

a) The *total weight of the sample* (TWS) is calculated as follows:

$$TWS = \sum_{i=1}^{7} (WTi_{POST} - WTi_{PRE})$$

$$= \sum_{i=1}^{7} TWi, i = 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}(f - final)stages$$

b) The *total dust concentration* (Dc) of the sample is calculated as follows:

$$Dc\,(mg/m^3) = \frac{TWS(mg)}{V(m^3)}$$

Table 3.1 on the facing page shows the dust size range for each impactor stage.

Table 3.1.: Marple Impactor Dust Size Range

Stage No	Size range (μm)	Median (mm)
1	50 – 21.3	32.6
2	21.3 – 14.8	17.75
3	14.8 – 9.8	12.04
4	9.8 – 6.0	7.67
5	6.0 – 3.5	4.58
6	3.5 – 1.55	2.33
F	1.55 – 0.1	0.39

In order to determine $MMAD$ the following calculations should be carried out:

1. Determine a cumulative % 'less than' for each stage:

   Stage 1:

$$Cum.\% < size = \left(\frac{\sum_{i=2}^{7} (WTi_{POST} - WTi_{PRE})}{TWS} \right) \times 100$$

   Stage 2:

$$Cum.\% < size = \left(\frac{\sum_{i=3}^{7} (WTi_{POST} - WTi_{PRE})}{TWS} \right) \times 100$$

   Stage 3:

$$Cum.\% < size = \left(\frac{\sum_{i=4}^{7} (WTi_{POST} - WTi_{PRE})}{TWS} \right) \times 100$$

   Stage 4:

$$Cum.\% < size = \left(\frac{\sum_{i=5}^{7} (WTi_{POST} - WTi_{PRE})}{TWS} \right) \times 100$$

   Stage 5:

$$Cum.\% < size = \left(\frac{\sum_{i=6}^{7} (WTi_{POST} - WTi_{PRE})}{TWS} \right) \times 100$$

Stage 6:

$$Cum.\% < size = \left(\frac{(WTf_{POST} - WTf_{PRE})}{TWS}\right) \times 100$$

Stage F:

$$Cum.\% < size = 0$$

2. Since all median values are known, calculate the natural logarithm of M for each stage:

   Stage 1: $\ln(M1) = \ln 32.6 = 3.484$

   Stage 2: $\ln(M2) = \ln 17.75 = 2.876$

   Stage 3: $\ln(M3) = \ln 12.04 = 2.488$

   Stage 4: $\ln(M4) = \ln 7.67 = 2.037$

   Stage 5: $\ln(M5) = \ln 4.58 = 1.522$

   Stage 6: $\ln(M6) = \ln 2.33 = 0.846$

   Stage F: $\ln(Mf) = \ln 0.39 = -0.942$

3. Calculate values $TWi \times \ln(Mi)$ for each stage and summarise them:

$$\sum_{i=1}^{7} TWi \times \ln(Mi)$$

4. Then the $MMAD$ value could be calculated as follows:

$$MMAD = exp\left(\frac{\left(\sum_{i=1}^{7}(TWi \times \ln(Mi))\right)}{TWS}\right)$$

5. Geometric standard deviation (GSD) for the $MMAD$ value should also be calculated:

$$GSD = exp\left(\sqrt{\frac{\left\{\sum_{i=1}^{7}\left(TWi \times \left(\ln\left(\frac{Mi}{MMAD}\right)\right)^2\right)\right\}}{TWS}}\right)$$

3.1.1.1. Calculation example – MMAD

Data The sample was worn for 8 hours (480 minutes) and the 'pre-weights' and 'post-weights' are:

Stage 1: $WT1_{PRE} = 28.58$ mg, $WT1_{POST} = 44.05$ mg

Stage 2: $WT2_{PRE} = 27.27$ mg, $WT2_{POST} = 43.94$ mg

Stage 3: $WT3_{PRE} = 27.25$ mg, $WT3_{POST} = 32.12$ mg

Stage 4: $WT4_{PRE} = 27.33$ mg, $WT4_{POST} = 27.77$ mg

Stage 5: $WT5_{PRE} = 26.75$ mg, $WT5_{POST} = 27.01$ mg

Stage 6: $WT6_{PRE} = 26.53$ mg, $WT6_{POST} = 26.67$ mg

Stage F: $WTf_{PRE} = 10.31$ mg, $WTf_{POST} = 10.47$ mg

Solution

1. The volume of the sample is

$$\frac{480\,minutes \times 2\,litres\,per\,minute}{1000} = 0.96\,m^3$$

2. The total weight of each stage is:

   Stage 1: $TW1 = WT1_{POST} - WT1_{PRE} = 44.05 - 28.58 = 15.47$ mg

   Stage 2: $TW2 = WT2_{POST} - WT2_{PRE} = 43.94 - 27.27 = 16.67$ mg

   Stage 3: $TW3 = WT3_{POST} - WT3_{PRE} = 32.12 - 27.25 = 4.87$ mg

   Stage 4: $TW4 = WT4_{POST} - WT4_{PRE} = 27.77 - 27.33 = 0.44$ mg

   Stage 5: $TW5 = WT5_{POST} - WT5_{PRE} = 27.01 - 26.75 = 0.26$ mg

   Stage 6: $TW6 = WT6_{POST} - WT6_{PRE} = 26.67 - 26.53 = 0.14$ mg

   Stage F: $TWf = WTf_{POST} - WTf_{PRE} = 10.47 - 10.31 = 0.16$ mg

   Total weight of the sample (TWS) is:

$$TWS = \sum_{i=1}^{7}(WTi_{POST} - WTi_{PRE})$$

$$= \sum_{i=1}^{7} TWi, i = 15.47\ +\ 16.67\ +\ 4.87\ +\ 0.44\ +\ 0.26\ +\ 0.14\ +\ 0.16 = 38.01\,mg$$

3. The total dust concentration is

$$\frac{38.01mg}{0.96m^3} = 39.59mg/m^3$$

4. Determine a cumulative % less than for each stage:

   Stage 1:

$$Cum.\% < size = \left[\frac{(TW2 + TW3 + TW4 + TW5 + TW6 + TWf)}{TWS}\right] \times 100$$

$$= \left[\frac{22.54}{38.01}\right] \times 100 = 59.30\%$$

   Stage 2:

$$Cum.\% < size = \left[\frac{(TW3 + TW4 + TW5 + TW6 + TWf)}{TWS}\right] \times 100 = \left[\frac{5.87}{38.01}\right] \times 100$$

$$= 15.44\%$$

   Stage 3:

$$Cum.\% < size = \left[\frac{(TW4 + TW5 + TW6 + TWf)}{TWS}\right] \times 100 = \left[\frac{1.00}{38.01}\right] \times 100 = 2.63\%$$

Stage 4:

$$Cum.\% < size = \left[\frac{(TW5 + TW6 + TWf)}{TWS}\right] \times 100 = \left[\frac{0.56}{38.01}\right] \times 100 = 2.63\%$$

Stage 5:

$$Cum.\% < size = \left[\frac{(TW6 + TWf)}{TWS}\right] \times 100 = \left[\frac{0.30}{38.01}\right] \times 100 = 0.79\%$$

Stage 6:

$$Cum.\% < size = \left[\frac{(TWf)}{TWS}\right] \times 100 = \left[\frac{0.16}{38.01}\right] \times 100 = 0.42\%$$

Stage F:

$$Cum.\% < size = 0.00\%$$

5. Natural logarithms for median values were calculated previously:

   Stage 1: $\ln(M1) = \ln 32.6 = 3.484$

   Stage 2: $\ln(M2) = \ln 17.75 = 2.876$

   Stage 3: $\ln(M3) = \ln 12.04 = 2.488$

   Stage 4: $\ln(M4) = \ln 7.67 = 2.037$

   Stage 5: $\ln(M5) = \ln 4.58 = 1.522$

   Stage 6: $\ln(M6) = \ln 2.33 = 0.846$

   Stage F: $\ln(Mf) = \ln 0.39 = -0.942$

6. Calculate values $TWi \times ln(Mi)$ for each stage and summarise them:

   Stage 1: $TW1 \times \ln(M1) = 15.47 \times 3.484 = 53.902$

   Stage 2: $TW2 \times \ln(M2) = 16.67 \times 2.876 = 47.949$

   Stage 3: $TW3 \times \ln(M3) = 4.87 \times 2.488 = 12.118$

   Stage 4: $TW4 \times \ln(M4) = 0.44 \times 2.037 = 0.896$

   Stage 5: $TW5 \times \ln(M5) = 0.26 \times 1.522 = 0.396$

   Stage 6: $TW6 \times \ln(M6) = 0.14 \times 0.846 = 0.118$

   Stage F: $TWf \times \ln(Mf) = 0.16 \times (-0.942) = -0.151$

   $$\sum_{i=1}^{7} TWi \times \ln(Mi) = 53.902 + 47.949 + 12.118 + 0.896 + 0.396 + 0.118 - 0.151 = 115.229$$

7. Calculate the MMAD value:

$$MMAD = exp\left(\frac{\left(\sum_{i=1}^{7}(TWi \times \ln(Mi))\right)}{TWS}\right)$$

$$= exp\left(\frac{115.229}{38.01}\right)$$

$$= exp\,(3.03) = 20.7$$

8. Calculate the standard deviation for the MMAD value:

   Calculate values for $TW1 \times \left(\ln\left(\frac{M1}{MMAD}\right)\right)^2$ and summarise them:

   Stage 1:

$$TW1 \times \left(\ln\left(\frac{M1}{MMAD}\right)\right)^2 = 15.47 \times \left(\ln\left(\frac{32.6}{20.7}\right)\right)^2 = 15.47 \times 0.206 = 3.187;$$

   Stage 2:

$$TW2 \times \left(\ln\left(\frac{M2}{MMAD}\right)\right)^2 = 16.67 \times \left(\ln\left(\frac{17.75}{20.7}\right)\right)^2 = 16.67 \times 0.024 = 0.400;$$

   Stage 3:

$$TW3 \times \left(\ln\left(\frac{M3}{MMAD}\right)\right)^2 = 4.87 \times \left(\ln\left(\frac{12.04}{20.7}\right)\right)^2 = 4.87 \times 0.294 = 1.432;$$

   Stage 4:

$$TW4 \times \left(\ln\left(\frac{M4}{MMAD}\right)\right)^2 = 0.44 \times \left(\ln\left(\frac{7.67}{20.7}\right)\right)^2 = 0.44 \times 0.986 = 0.434;$$

   Stage 5:

$$TW5 \times \left(\ln\left(\frac{M5}{MMAD}\right)\right)^2 = 0.26 \times \left(\ln\left(\frac{4.58}{20.7}\right)\right)^2 = 0.26 \times 2.275 = 0.591;$$

   Stage 6:

$$TW6 \times \left(\ln\left(\frac{M6}{MMAD}\right)\right)^2 = 0.14 \times \left(\ln\left(\frac{2.33}{20.7}\right)\right)^2 = 0.14 \times 4.771 = 0.668;$$

   Stage F:

$$TWf \times \left(\ln\left(\frac{Mf}{MMAD}\right)\right)^2 = 0.16 \times \left(\ln\left(\frac{0.39}{20.7}\right)\right)^2 = 0.16 \times 15.775 = 2.524;$$

   Sum for all stages:

$$\sum_{i=1}^{7} TWi \times \left(\ln\left(\frac{Mi}{MMAD}\right)\right)^2 \ldots$$

$$= 3.187 + 0.400 + 1.432 + 0.434 + 0.591 + 0.668 + 2.524 = 9.236$$

   Then the standard deviation will be:

$$GSD = exp\left(\sqrt{\frac{\left\{\sum_{i=1}^{7}\left(TWi \times \left(\ln\left(\frac{Mi}{MMAD}\right)\right)^2\right)\right\}}{TWS}}\right)$$

$$GSD = exp\left(\sqrt{\frac{9.236}{TWS}}\right)$$

   Therefore the *Mass Median Aerodynamic Diameter (MMAD) is* 20.7 ± 1.6.

3.1.2. AMAD and associated calculations

Before the calculation the *minimum detection limit* (MDL) of the equipment in use must be established. MDL value is expressed in milliBecquerel (mBq).

The MDL for each impactor stage is calculated as follows:

$$MDLi = \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{Bc}{(Bt \times 60)}} \times (Ct \times 60) \times (1 + (\frac{Ct}{Bt})\right)\right)}{Eff \times Ct \times 60} \right\} \times 1000$$

where:

$MDLi$ = minimum detection limit of the equipment in use for the stage i for the counting time Ct;

Bc = number of counts from background for the background counting time Bt;

Bt = background count time (usually 900 minutes);

Ct = counting time (e.g. 60 minutes for stages 1–4, 100 minutes for stages 5 and 6 and 200 minutes for the stage F);

Eff = efficiency of the alpha-spectrometer.

3.1.2.1. Calculation example – minimum detection limits

Data Impactor stages will be counted in two different alpha-spectrometer chambers.

Background counting results are:

Chamber 'A': 42 counts in 900 minutes

Chamber 'B': 37 counts in 900 minutes

Efficiency was determined:

Chamber 'A' Eff = 35.9%

Chamber 'B' Eff = 31.5%

Stages will be counted for 60, 100 and 200 minutes.

Solution MDL should be determined for each chamber for three different counting periods:

Chamber 'A', 60 minutes count:

$$MDLi = \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{Bc}{(Bt \times 60)}} \times (Ct \times 60) \times (1 + (\frac{Ct}{Bt})\right)\right)}{Eff \times Ct \times 60} \right\} \times 1000$$

$$= \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{42}{(900 \times 60)}} \times (60 \times 60) \times (1 + (\frac{60}{900})\right)\right)}{0.359 \times 60 \times 60} \right\} \times 1000$$

$$= \left\{ \frac{(3 + (3.29 \times \sqrt{2.986}))}{1292.4} \right\} \times 1000 \approx 7\,mBq$$

Chamber 'A', 100 minutes count:

$$MDLi = \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{Bc}{(Bt \times 60)}} \times (Ct \times 60) \times (1 + (\frac{Ct}{Bt})\right)\right)}{Eff \times Ct \times 60} \right\} \times 1000$$

$$= \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{42}{(900\times60)} \times (100 \times 60) \times (1 + (\frac{100}{900})}\right)\right)}{0.359 \times 100 \times 60} \right\} \times 1000$$

$$= \left\{ \frac{(3 + (3.29 \times \sqrt{5.185}))}{2154} \right\} \times 1000 \approx 5\,mBq$$

Chamber 'A', 200 minutes count:

$$MDLi = \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{Bc}{(Bt\times60)} \times (Ct \times 60) \times (1 + (\frac{Ct}{Bt})}\right)\right)}{Eff \times Ct \times 60} \right\} \times 1000$$

$$= \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{42}{(900\times60)} \times (200 \times 60) \times (1 + (\frac{200}{900})}\right)\right)}{0.359 \times 200 \times 60} \right\} \times 1000$$

$$= \left\{ \frac{(3 + (3.29 \times \sqrt{11.407}))}{4308} \right\} \times 1000 \approx 3\,mBq$$

Chamber 'B', 60 minutes count:

$$MDLi = \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{Bc}{(Bt\times60)} \times (Ct \times 60) \times (1 + (\frac{Ct}{Bt})}\right)\right)}{Eff \times Ct \times 60} \right\} \times 1000$$

$$= \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{37}{(900\times60)} \times (60 \times 60) \times (1 + (\frac{60}{900})}\right)\right)}{0.315 \times 60 \times 60} \right\} \times 1000$$

$$= \left\{ \frac{(3 + (3.29 \times \sqrt{2.631}))}{1134} \right\} \times 1000 \approx 7\,mBq$$

Chamber 'B', 100 minutes count:

$$MDLi = \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{Bc}{(Bt\times60)} \times (Ct \times 60) \times (1 + (\frac{Ct}{Bt})}\right)\right)}{Eff \times Ct \times 60} \right\} \times 1000$$

$$= \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{37}{(900\times60)} \times (100 \times 60) \times (1 + (\frac{100}{900})}\right)\right)}{0.315 \times 100 \times 60} \right\} \times 1000$$

$$= \left\{ \frac{(3 + (3.29 \times \sqrt{4.568}))}{1890} \right\} \times 1000 \approx 5\,mBq$$

Chamber 'B', 200 minutes count:

$$MDLi = \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{Bc}{(Bt\times60)} \times (Ct \times 60) \times (1 + (\frac{Ct}{Bt})}\right)\right)}{Eff \times Ct \times 60} \right\} \times 1000$$

$$= \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{\frac{37}{(900\times60)} \times (200 \times 60) \times (1 + (\frac{200}{900}))}\right)\right)}{0.315 \times 200 \times 60} \right\} \times 1000$$

$$= \left\{ \frac{\left(3 + \left(3.29 \times \sqrt{10.049}\right)\right)}{1134} \right\} \times 1000 \approx 4\,mBq$$

Therefore, minimum detection limits are shown in Table 3.2 :

Table 3.2.: Minimum Detection Limits (mBq)

	60 minutes count	100 minutes count	200 minutes count
Chamber 'A'	7	5	3
Chamber 'B'	7	5	4

The following parameters are required for further calculations:

- Background counts for the each impactor stage i;
- Efficiency for the each impactor stage i;
- Number of counts for the each impactor stage i; and
- Sampling time.

1. The *volume (V)* in cubic metres (m^3) of the sample was calculated previously.

   The 'net counted' *activity* (in mBq) is calculated for each stage as follows:

$$Ai = \left(\frac{\left(\frac{Cc}{Ct\times60}\right) - \left(\frac{Bc}{Bt\times60}\right)}{Eff} \right) \times 1000$$

where:

Ai = activity of the stage i (in milliBecquerels);
Cc = number of counts from the stage i for the counting time Ct;
Ct = counting time for the stage i;
Bc = number of counts from background for the background counting time Bt;
Bt = background count time (usually 900 minutes);
Eff =efficiency of the alpha-spectrometer.

1. The value obtained must be then compared with the respective 'Minimum Detection Limit'. If the sample count does not exceed the MDL then the MDL must be substituted for the sample count in the calculation. In other words, if the stage 'net counted' activity will be 5 milliBecquerel (with the MDL = 7 mBq), the value of 7 mBq should be used in all following calculations. If the 'net counted' activity on three or more stages is less than MDL, the sample is invalid.
2. The activity of the sample is calculated as follows:
3. Then the dust activity concentration is determined as follows:

$$Ac\,(mBq/m^3) = \frac{A\,(mBq)}{V(m^3)}$$

3.1.2.2. Calculation example – activity concentration

Data The sample was worn for 480 minutes and the flow rate of the sampler was 2 litres per minute.

A set of counting results are listed in Table 3.3:

Table 3.3.: Counting results

Stage No	Backgrd. counts (Bc)	Backgrd. time (Bt)	Efficiency (Eff)	Counts (Cc)	Count time (Ct)
1	42	900	0.359	775	60
2	37	900	0.315	291	60
3	42	900	0.359	162	60
4	42	900	0.359	57	60
5	42	900	0.359	45	100
6	42	900	0.359	19	100
f	37	900	0.315	43	200

Solution

1. The volume of the sample is: 480 min×2 litres per min = 960 litres = 0.96 m^3.
2. 'Net counted' activity for each stage is:

$$A1 = \left(\frac{\left(\frac{Cc}{Ct\times 60}\right) - \left(\frac{Bc}{Bt\times 60}\right)}{Eff}\right) \times 1000 = \left(\frac{\left(\frac{775}{60\times 60}\right) - \left(\frac{42}{900\times 60}\right)}{0.359}\right) \times 1000 = 597\, mBq$$

$$A2 = \left(\frac{\left(\frac{Cc}{Ct\times 60}\right) - \left(\frac{Bc}{Bt\times 60}\right)}{Eff}\right) \times 1000 = \left(\frac{\left(\frac{291}{60\times 60}\right) - \left(\frac{37}{900\times 60}\right)}{0.315}\right) \times 1000 = 254\, mBq$$

$$A3 = \left(\frac{\left(\frac{Cc}{Ct\times 60}\right) - \left(\frac{Bc}{Bt\times 60}\right)}{Eff}\right) \times 1000 = \left(\frac{\left(\frac{162}{60\times 60}\right) - \left(\frac{42}{900\times 60}\right)}{0.359}\right) \times 1000 = 123\, mBq$$

$$A4 = \left(\frac{\left(\frac{Cc}{Ct\times 60}\right) - \left(\frac{Bc}{Bt\times 60}\right)}{Eff}\right) \times 1000 = \left(\frac{\left(\frac{57}{60\times 60}\right) - \left(\frac{42}{900\times 60}\right)}{0.359}\right) \times 1000 = 42\, mBq$$

$$A5 = \left(\frac{\left(\frac{Cc}{Ct\times 60}\right) - \left(\frac{Bc}{Bt\times 60}\right)}{Eff}\right) \times 1000 = \left(\frac{\left(\frac{45}{100\times 60}\right) - \left(\frac{42}{900\times 60}\right)}{0.359}\right) \times 1000 = 19\, mBq$$

$$A6 = \left(\frac{\left(\frac{Cc}{Ct\times 60}\right) - \left(\frac{Bc}{Bt\times 60}\right)}{Eff}\right) \times 1000 = \left(\frac{\left(\frac{19}{100\times 60}\right) - \left(\frac{42}{900\times 60}\right)}{0.359}\right) \times 1000 = 7\, mBq$$

$$Af = \left(\frac{\left(\frac{Cc}{Ct\times 60}\right) - \left(\frac{Bc}{Bt\times 60}\right)}{Eff} \right) \times 1000 = \left(\frac{\left(\frac{43}{200\times 60}\right) - \left(\frac{37}{900\times 60}\right)}{0.315} \right) \times 1000 = 9\, mBq$$

Table 3.4 shows the comparison with MDL for each stage (MDL values were calculated previously for both chambers and all counting times):

Table 3.4.: Comparison with MDL for each stage.

Stage	1	2	3	4	5	6	f
‘Net counted’ activity (mBq)Ai	597	254	123	42	19	7	9
MDL (mBq)	7	7	7	7	5	5	4
Comparison	Ai > MDL	Ai > MDL	Ai > MDL	Ai > MDL	Ai > MDL	Ai > MDL	Ai > MDL

Therefore, this sample is valid for the AMAD calculation.

3. The activity of the sample is:

$$\sum_{i-1}^{7} Ai = 597 + 254 + 123 + 42 + 19 + 7 + 9 = 1051\, mBq$$

4. *The dust activity concentration* is determined as follows:

$$Ac\,(mBq/m^3) = \frac{A\,(mBq)}{V(m^3)} = \frac{1051 mBq}{0.96 m^3} = 1095 mBq/m^3 = 1.095 Bq/m^3$$

In order to determine AMAD the following calculations should be carried out:

1. Determine a *cumulative % ‘less than’* for each stage:

   Stage 1:

$$Cum.\% < size = \left(\frac{\sum_{i=2}^{7} Ai}{A} \right) \times 100$$

   Stage 2:

$$Cum.\% < size = \left(\frac{\sum_{i=3}^{7} Ai}{A} \right) \times 100$$

   Stage 3:

$$Cum.\% < size = \left(\frac{\sum_{i=4}^{7} Ai}{A} \right) \times 100$$

Stage 4:

$$Cum.\% < size = \left(\frac{\sum_{i=5}^{7} Ai}{A} \right) \times 100$$

Stage 5:

$$Cum.\% < size = \left(\frac{\sum_{i=6}^{7} Ai}{A} \right) \times 100$$

Stage 6:

$$Cum.\% < size = \left(\frac{Af}{A} \right) \times 100$$

Stage F:

$$Cum.\% < size = 0$$

2. Since all median values are known, calculate the natural logarithm of M for each stage:

   Stage 1: ln(M1) = ln32.6 = 3.484

   Stage 2: ln(M2) = ln17.75 = 2.876

   Stage 3: ln(M3) = ln12.04 = 2.488

   Stage 4: ln(M4) = ln7.67 = 2.037

   Stage 5: ln(M5) = ln4.58 = 1.522

   Stage 6: ln(M6) = ln2.33 = 0.846

   Stage F: ln(Mf) = ln0.39 = − 0.942

3. Calculate values Ai× ln(Mi) for each stage and summarise them:

$$\sum_{i=1}^{7} Ai \times \ln(Mi)$$

4. Then the AMAD value could be calculated as follows:

$$AMAD = exp \left(\frac{\left(\sum_{i=1}^{7} Ai \times \ln(Mi) \right)}{A} \right)$$

5. Geometric standard deviation (GSD) for the AMAD value should also be calculated:

$$GSD = exp \left(\sqrt{\frac{\left\{ \sum_{i=1}^{7} \left(Ai \times \left(\ln\left(\frac{Mi}{AMAD} \right) \right)^2 \right) \right\}}{A}} \right)$$

3.1.2.3. Calculation example – AMAD and GSD

Data The following activities were calculated for each stage:

A1 = 597 mBq

A2 = 254 mBq

A3 = 123 mBq

A4 = 42 mBq

A5 = 19 mBq

A6 = 7 mBq

Af = 9 mBq

Therefore the total activity of the sample equals 1052 mBq.

Solution

1. Determine a *cumulative % less than* for each stage:

   Stage 1:

$$Cum.\% < size = \left[\frac{(A2 + A3 + A4 + A5 + A6 + Af)}{A}\right] \times 100 = \left[\frac{454}{1052}\right] \times 100 = 43.16\%$$

   Stage 2:

$$Cum.\% < size = \left[\frac{(A3 + A4 + A5 + A6 + Af)}{A}\right] \times 100 = \left[\frac{200}{1052}\right] \times 100 = 19.01\%$$

   Stage 3:

$$Cum.\% < size = \left[\frac{(A4 + A5 + A6 + Af)}{A}\right] \times 100 = \left[\frac{77}{1052}\right] \times 100 = 7.32\%$$

   Stage 4:

$$Cum.\% < size = \left[\frac{(A5 + A6 + Af)}{A}\right] \times 100 = \left[\frac{35}{1052}\right] \times 100 = 3.33\%$$

   Stage 5:

$$Cum.\% < size = \left[\frac{(A6 + Af)}{A}\right] \times 100 = \left[\frac{16}{1052}\right] \times 100 = 1.52\%$$

   Stage 6:

$$Cum.\% < size = \left[\frac{Af}{A}\right] \times 100 = \left[\frac{9}{1052}\right] \times 100 = 0.86\%$$

   Stage F:

$$Cum.\% < size = 0.00\%$$

2. Natural logarithms for median values were calculated previously:

   Stage 1: ln(M1) = ln32.6 = 3.484

   Stage 2: ln(M2) = ln17.75 = 2.876

   Stage 3: ln(M3) = ln12.04 = 2.488

   Stage 4: ln(M4) = ln7.67 = 2.037

   Stage 5: ln(M5) = ln4.58 = 1.522

   Stage 6: ln(M6) = ln2.33 = 0.846

   Stage F: ln(Mf) = ln0.39 = −0.942

3. Calculate values Ai × ln(Mi) for each stage and summarise them:

   Stage 1: A1 × ln(M1) = 597 × 3.484 = 2079.948

   Stage 2: A2 × ln(M2) = 254 × 2.876 = 730.504

   Stage 3: A3 × ln(M3) = 123× 2.488 = 306.024

   Stage 4: A4 × ln(M4) = 42 × 2.037 = 85.554

   Stage 5: A5 × ln(M5) = 19 × 1.522 = 28.918

   Stage 6: A6 × ln(M6) = 7 × 0.846 = 5.922

   Stage F: Af × ln(Mf) = 9 × (−0.942) = −8.478

   $$= Ai \times \ln(Mi) = 2079.948 + 703.504 + 306.024 + 85.554 + 28.918 + 5.922 - 8.478 = 3228.392$$

4. Calculate the $AMAD$ value:

   $$AMAD = exp\left(\frac{\left(\sum_{i=1}^{7} Ai \times \ln(Mi)\right)}{A}\right)$$

   $$= exp\left(\frac{3228.392}{1052}\right) = 21.5$$

5. Calculate the standard deviation for the AMAD value:

   Calculate values for:

   $$\sum_{i=1}^{7} Ai \times \left(\ln\left(\frac{Mi}{AMAD}\right)\right)^2$$

   and then summarise them:

   Stage 1:

   $$A1 \times \left(\ln\left(\frac{M1}{AMAD}\right)\right)^2 = 597 \times \left(\ln\left(\frac{32.6}{21.5}\right)\right)^2 = 597 \times 0.173 = 103.281$$

   Stage 2:

   $$A2 \times \left(\ln\left(\frac{M2}{AMAD}\right)\right)^2 = 254 \times \left(\ln\left(\frac{17.75}{21.5}\right)\right)^2 = 254 \times 0.037 = 9.398$$

Stage 3:

$$A3 \times \left(\ln\left(\frac{M3}{AMAD}\right)\right)^2 = 123 \times \left(\ln\left(\frac{12.04}{21.5}\right)\right)^2 = 123 \times 0.336 = 41.328$$

Stage 4:

$$A4 \times \left(\ln\left(\frac{M4}{AMAD}\right)\right)^2 = 42 \times \left(\ln\left(\frac{7.67}{21.5}\right)\right)^2 = 42 \times 1.062 = 44.604$$

Stage 5:

$$A5 \times \left(\ln\left(\frac{M5}{AMAD}\right)\right)^2 = 19 \times \left(\ln\left(\frac{4.58}{21.5}\right)\right)^2 = 19 \times 2.391 = 45.429$$

Stage 6:

$$A6 \times \left(\ln\left(\frac{M6}{AMAD}\right)\right)^2 = 7 \times \left(\ln\left(\frac{2.33}{21.5}\right)\right)^2 = 7 \times 4.938 = 34.566$$

Stage F:

$$Af \times \left(\ln\left(\frac{Mf}{AMAD}\right)\right)^2 = 9 \times \left(\ln\left(\frac{0.39}{21.5}\right)\right)^2 = 9 \times 16.077 = 144.693$$

Sum for all stages :

$$\sum_{i=1}^{7} Ai \times \left(\ln\left(\frac{Mi}{AMAD}\right)\right)^2$$

$$= 103.281 + 9.398 + 41.328 + 44.604 + 45.429 + 34.566 + 144.693 = 423.299$$

Then the standard deviation will be:

$$GSD = exp\left(\sqrt{\frac{\left\{\sum_{i=1}^{7}\left(Ai \times \left(\ln\left(\frac{Mi}{AMAD}\right)\right)^2\right)\right\}}{A}}\right)$$

$$= exp\left(\sqrt{\frac{423.299}{A}}\right) = exp\left(\sqrt{\frac{423.299}{1052}}\right) = 1.9$$

Therefore the *Activity Median Aerodynamic Diameter (AMAD) is 21.5±1.9*

3.2. Excel spreadsheet for data processing

An Excel spreadsheet has been developed in order to the simplify calculations and minimise errors. Data should be entered into the appropriate fields to calculate the values. The program user interface and formulae are shown in Figures B.2 on page 27, B.3 on page 28, B.4 on page 29, and B.5 on page 30.

The sample Excel Spreadsheet is embedded in the electronic version of this document and may be run from here or saved onto your computer. *This spreadsheet is free software; you can redistribute it and/or modify it. The software is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.*

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4. DMP AMAD approval policy

4.1. Evaluation of impactor program results by the Regulator

Data generated from the impactor program must be submitted to DMP for approval. The data is compared with data generated by the personal air sampling (PAS) data in the Boswell Database to gain an indication of whether the impactor data is representative of the dust being encountered by workers. Often the dust levels collected by impactors in a plant measure higher concentrations than what is reported in Boswell. It is well known that impactors sample more dust that personal samplers. This is more evident in the gravimetric analysis data where the impactor data indicates that workers would be exposed to dust close to or above the recommended limit for nuisance dust, 10mg/m^3. This higher loading of dust would affect the detection of alpha particles in the evaluation of radiometric impactor data. Better results can be achieved by specifically instructing employees on the method of wearing an impactor and how to avoid coarse particles (mineral spillage entering the sampler. Where care is taken by employees wearing an impactor, mass concentrations of dust measured with a personal impactor can be compatible with the levels obtained by the PAS program.

For the impactor data to be used as a means for determining the AMAD of the dust for converting the results of the dust for converting the results of the PAS to an internal dose, the two sampling methods should be representative of the same dust distributions. It is also important to be aware that impactors are not approved by the Australian Standard [4].

However, the policy is that when it is apparent that the dust in a work area has an AMAD in excess of 10 μm, a default particle size AMAD value of 10 μm is approved for use in the assessment of the committed effective dose for a period of 12 months. Otherwise, the default AMAD is set at 5 μm as recommended by ICRP 66 [5].

A. Appendix with a typical procedure for setting up a seven-stage impactor

1. All parts for the impactor assembly should be present — seven stages, the impactor unit, the metal filter holder, inlet cowl and two screws.
2. All internal surfaces of the impactor and impactor stages should be free of dirt:
    a) Each stage and impactor should be thoroughly wiped with detergent or alcohol, then brushed, wiped clean and completely dried;
    b) The stages should be held onto a light to make sure that all slots are free of dirt and dust.
3. Plastic substrates should be put in the template and sprayed with silicone grease several hours before setting up to allow solvent to evaporate completely.
4. The filter used for the last stage should be placed in a clean container and left with lid slightly ajar overnight to come to equilibrium with the atmosphere.
5. The metal filter holder should be placed onto the bottom of the impactor unit.
6. The filter must be weighed to an accuracy of ±0.01mg and placed on the top of the metal filter holder. The bottom impactor stage (typically – ‘F’) should be placed on the top of this.
7. The plastic substrate, previously sprayed with silicon grease, should be weighed to an accuracy of ±0.01mg and placed on the bottom stage (‘F’) so the holes match up. Then the stage No.6 should be placed on the top of this.
8. This process should continue for each stage, until the stage No.1, where, instead of the substrate, the inlet cowl is placed on the top.
9. The impactor should be tightened with two screws and assembled with the dust pump. The impactor is then worn in the same manner as ordinary dust sampling heads.
10. After the sampling impactor must be disassembled, each stage should be weighed to an accuracy of ±0.01mg and placed in the plastic petri dish for the radiometric analysis.
11. The following data should be recorded: number of the sample, date and time of sampling, wearer’s name and occupation, and weight of each stage before and after sampling.
12. Each stage should be analysed in the same manner as ‘ordinary’ dust samples for alpha activity concentrations. Usually each stage is counted for 100 minutes. Counting times may increase to 300 minutes with decrease in dust concentrations.

B. Appendix with Excel spreadsheet views

Figure B.1.: The user interface of the Excel spreadsheet.

	A	B	C	D	E	F	G	H	I	J
1	SAMPLE No...									
2	Stage No.	1	2	3	4	5	6	F	Σ	
3	Pre-weight (mg)	28.58	27.27	27.25	27.33	26.75	26.53	10.31		
4	Post-weight (mg)	44.05	43.94	32.12	27.77	27.01	26.67	10.47		
5	Total weight [W] (mg)	15.47	16.67	4.87	0.44	0.26	0.14	0.16	38.01	
6	Cum.% < size	59.30	15.44	2.63	1.47	0.79	0.42	0.00		
7	Size range (nm)	50 - 21.3	21.3 - 14.8	14.8 - 9.8	9.8 - 6.0	6.0 - 3.5	3.5 - 1.55	1.55 - 0.1		
8	Median [M] (nm)	32.6	17.75	12.04	7.67	4.58	2.33	0.39		
9	ln[M]	3.484	2.876	2.488	2.037	1.522	0.846	-0.942		
10	Background count	42	37	42	42	42	42	37		
11	Background time (min)	900	900	900	900	900	900	900		
12	Efficiency	0.359	0.315	0.359	0.359	0.359	0.359	0.315		
13	Count time (min)	60	60	60	60	100	100	200		
14	Min.Detect. Act (mBq)	7	7	7	7	5	5	4		
15	Counts	775	291	162	57	45	19	43		
16	Net counted Activity (mBq)	597	254	123	42	19	7	9		
17	Is net activity <MDL (NO)?									
18	Activity [A] (mBq)	597	254	123	42	19	7	9	1052	
19	Cum.% < size	43.18	18.99	7.28	3.29	1.51	0.87	0.00		
20	{[A]*ln[M]}	2081.852	731.863	306.505	85.440	28.494	5.629	-8.663	3231.120	
21	AMAD=	21.6								
22	{[A]*@SQ{ln([M]/[AMAD])}	101.335	9.785	42.048	44.939	45.032	32.991	148.247	424.377	
23	GSD=	1.9								
24	{[W]*ln[M]}	53.902	47.949	12.118	0.896	0.396	0.118	-0.151	115.229	
25	MMAD=	20.7								
26	{[M]*@SQ{ln([M]/[MMAD])}	3.171	0.401	1.438	0.435	0.593	0.669	2.526	9.232	
27	GSD=	1.6								
28										
29	NAME	WORK	SHIFT	TIME (min)	FLOW (lpm)	SAMPLE	COUNT	Tot mBq/m3	Tot mg/m3	
30	J.Smith	D.P.O.	NGT	480	2	31-Jan	11-Feb	1095	40	
31										
32	M.D.L.Stages -	none								
33										
34										
35										
36										
37										
38				MANUALLY ENTERED DATA						
39										
40										

Figure B.2.: Spreadsheet calculations for Stage: 1 & 2.

	A	B	C
2	*Stage No.*	1	2
3	*Pre-weight (mg)*	28.58	27.27
4	*Post-weight (mg)*	44.05	43.94
5	*Total weight [W] (mg)*	=(B4-B3)	=C4-C3
6	*Cum.% < size*	=((C5+D5+E5+F5+G5+H5)/I5)*100	=((D5+E5+F5+G5+H5)/I5)*100
7	*Size range (nm)*	50 - 21.3	21.3 - 14.8
8	*Median [M] (nm)*	32.6	17.75
9	*ln[M]*	=LN(B8)	=LN(C8)
10	*Background count*	42	37
11	*Background time (min)*	900	900
12	*Efficiency*	0.359	0.315
13	*Count time (min)*	60	60
14	*Min.Detect. Act (mBq)*	=(3+3.29*SQRT(B10/(B11*60)*(B13*60)*(1+(B13/B11))))/(B12*B13*60)*100(	=(3+3.29*SQRT(C10/(C11*60)*(C13*60)*(1+(C13/C11))))/(C12*C13*60)*1000
15	*Counts*	775	291
16	*Net counted Activity (mBq)*	=((B15/(B13*60)-(B10/(B11*60)))/B12)*1000	=((C15/(C13*60)-(C10/(C11*60)))/C12)*1000
17	*Is net activity <MDL (NO)?*	=IF(B16>B14," ","NO")	=IF(C16>C14," ","NO")
18	*Activity [A] (mBq)*	=IF(B16>B14,B16,0)	=IF(C16>C14,C16,0)
19	*Cum.% < size*	=((C18+D18+E18+F18+G18+H18)/I18)*100	=((D18+E18+F18+G18+H18)/I18)*100
20	*{[A]*ln[M]}*	=B18*B9	=C18*C9
21	***AMAD=***	=EXP(I20/I18)	
22	*{[A]*@SQ{ln([M]/[AMAD])}*	=+(B18*(LN(B8/$B$21))^2)	=+(C18*(LN(C8/$B$21))^2)
23	***GSD=***	=EXP(SQRT(I22/I18))	
24	*{[W]*ln[M]}*	=B5*B9	=C5*C9
25	***MMAD=***	=EXP(I24/I5)	
26	*{[M]*@SQ{ln([M]/[MMAD])}*	=+(B5*(LN(B8/$B$25))^2)	=+(C5*(LN(C8/$B$25))^2)
27	***GSD=***	=EXP(SQRT(I26/I5))	
28			
29	***NAME***	***WORK***	***SHIFT***
30	***J. Smith***	***D.P.O.***	***NGT***
31			
32	***M.D.L.Stages -***	***none***	
33			
34		CALCULATIONS DESCRIBED IN THE PROCEDURE	
35			
36			
37			
38			

Figure B.3.: Spreadsheet calculations for Stage: 3 & 4.

	D	E
2	3	4
3	27.25	27.33
4	32.12	27.77
5	=(D4-D3)	=(E4-E3)
6	=((E5+F5+G5+H5)/I5)*100	=((F5+G5+H5)/I5)*100
7	14.8 - 9.8	9.8 - 6.0
8	12.04	7.67
9	=LN(D8)	=LN(E8)
10	42	42
11	900	900
12	0.359	0.359
13	60	60
14	=(3+3.29*SQRT(D10/(D11*60)*(D13*60)*(1+(D13/D11))))/(D12*D13*60)*1000	=(3+3.29*SQRT(E10/(E11*60)*(E13*60)*(1+(E13/E11))))/(E12*E13*60)*1000
15	162	57
16	=((D15/(D13*60)-(D10/(D11*60)))/D12)*1000	=((E15/(E13*60)-(E10/(E11*60)))/E12)*1000
17	=IF(D16>D14," ","NO")	=IF(E16>E14," ","NO")
18	=IF(D16>D14,D16,0)	=IF(E16>E14,E16,0)
19	=((E18+F18+G18+H18)/I18)*100	=((F18+G18+H18)/I18)*100
20	=D18*D9	=E18*E9
21		
22	=+(D18*(LN(D8/$B$21))^2)	=+(E18*(LN(E8/$B$21))^2)
23		
24	=D5*D9	=E5*E9
25		
26	=+(D5*(LN(D8/$B$25))^2)	=+(E5*(LN(E8/$B$25))^2)
27		
28		
29	TIME (min)	FLOW (lpm)
30	480	2
31		
32		
33		
34		
35		
36		
37		
38		

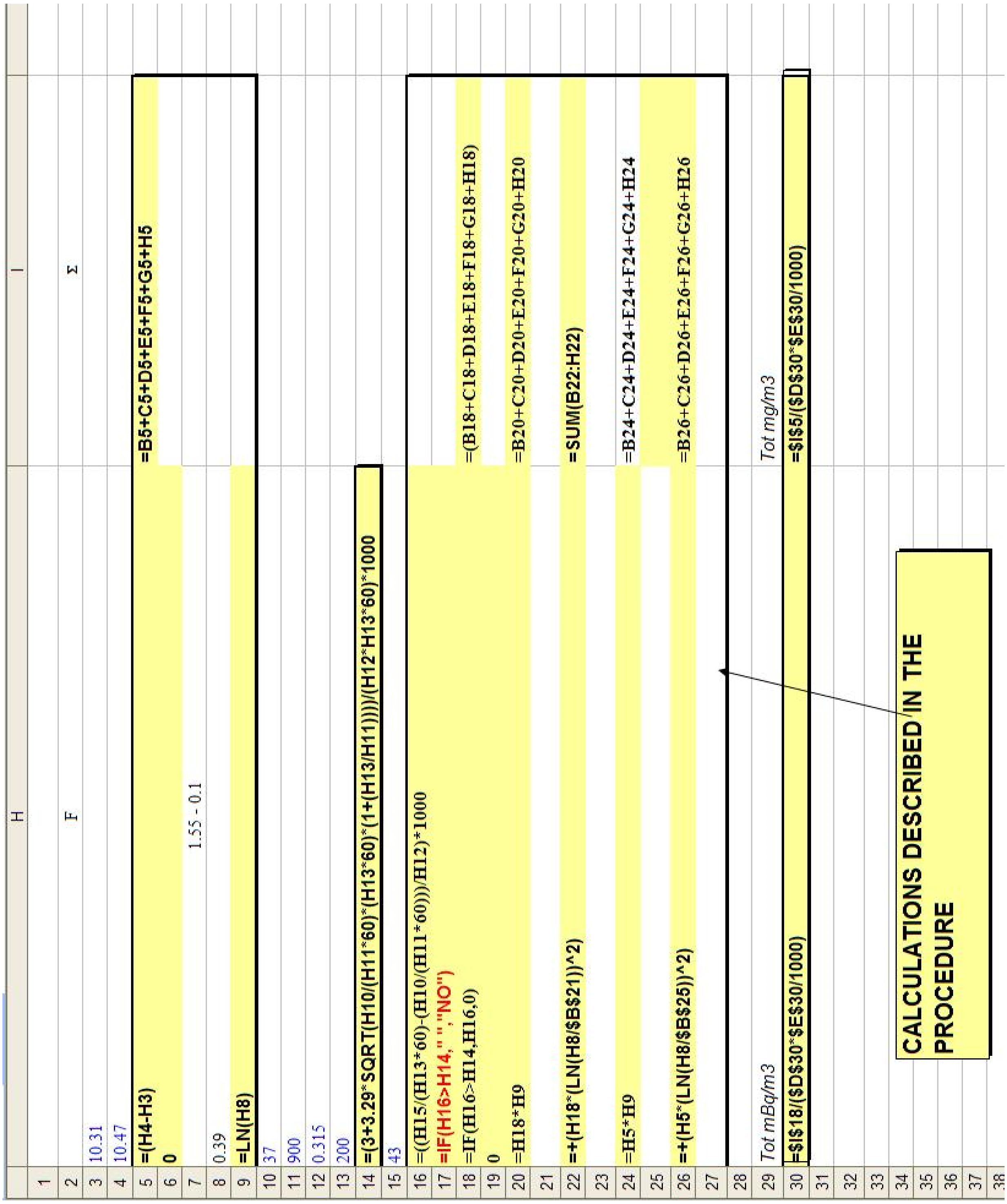
CALCULATIONS DESCRIBED IN THE PROCEDURE

Figure B.4.: Spreadsheet calculations for Stage: 5 & 6.

	F	G
2	5	6
3	26.75	26.53
4	27.01	26.67
5	=(F4-F3)	=(G4-G3)
6	=((G5+H5)/I5)*100	=((H5)/I5)*100
7	6.0 - 3.5	3.5 - 1.55
8	4.58	2.33
9	=LN(F8)	=LN(G8)
10	42	42
11	900	900
12	0.359	0.359
13	100	100
14	=(3+3.29*SQRT(F10/(F11*60)*(F13*60)*(1+(F13/F11))))/(F12*F13*60)*1000	=(3+3.29*SQRT(G10/(G11*60)*(G13*60)*(1+(G13/G11))))/(G12*G13*60)*1000
15	45	19
16	=((F15/(F13*60)-(F10/(F11*60)))/F12)*1000	=((G15/(G13*60)-(G10/(G11*60)))/G12)*1000
17	=IF(F16>F14," ","NO")	=IF(G16>G14," ","NO")
18	=IF(F16>F14,F16,0)	=IF(G16>G14,G16,0)
19	=((G18+H18)/I18)*100	=((H18)/I18)*100
20	=F18*F9	=G18*G9
21		
22	=+(F18*(LN(F8/$B$21))^2)	=+(G18*(LN(G8/$B$21))^2)
23		
24	=F5*F9	=G5*G9
25		
26	=+(F5*(LN(F8/$B$25))^2)	=+(G5*(LN(G8/$B$25))^2)
27		
28		
29	*SAMPLE*	*COUNT*
30	*31-Jan*	*11-Feb*
31		
32		
33		
34		
35		
36		
37		
38		

CALCULATIONS DESCRIBED IN THE PROCEDURE

Figure B.5.: Spreadsheet calculations for Stage: F & Sum of all stages .



	H	I
1		
2	F	Σ
3	10.31	
4	10.47	
5	=(H4-H3)	=B5+C5+D5+E5+F5+G5+H5
6	0	
7	1.55 - 0.1	
8	0.39	
9	=LN(H8)	
10	37	
11	900	
12	0.315	
13	200	
14	=(3+3.29*SQRT(H10/(H11*60)*(H13*60)*(1+(H13/H11))))/(H12*H13*60)*1000	
15	43	
16	=((H15/(H13*60)-(H10/(H11*60)))/H12)*1000	
17	=IF(H16>H14," ","NO")	
18	=IF(H16>H14,H16,0)	=(B18+C18+D18+E18+F18+G18+H18)
19	0	
20	=H18*H9	=B20+C20+D20+E20+F20+G20+H20
21		
22	=+(H18*(LN(H8/$B$21))^2)	=SUM(B22:H22)
23		
24	=H5*H9	=B24+C24+D24+E24+F24+G24+H24
25		
26	=+(H5*(LN(H8/$B$25))^2)	=B26+C26+D26+E26+F26+G26+H26
27		
28		
29	Tot mBq/m3	Tot mg/m3
30	=$I$18/($D$30*$E$30/1000)	=$I$5/($D$30*$E$30/1000)
31		
32		
33		
34		
35		
36		
37		
38		

Bibliography

[1] Part 16 – Radiation Safety, Mines Safety & Inspection Regulations, 1995.

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

[3] Series 290 Marple Personal Cascade Impactors Instruction Manual P/N 100065–00 Thermo Electron Corporation Environmental Instruments 27 Forge Parkway Franklin Massachusetts 02038, 1 Dec 2003.
www.thermo.com

[4] AS 3640: 2004. Workplace atmospheres — Method for sampling and gravimetric determination of inhalable dust, 2004.

[5] ICRP Publication 66: Human Respiratory Tract Model for Radiological Protection Annals of the ICRP Volume 24/1-3A International Commission on Radiological Protection, January 1995.

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