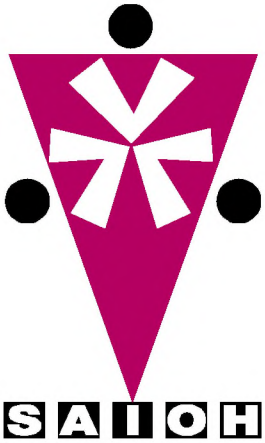
An industry guide to

AIR MONITORING STRATEGIES FOR HAZARDOUS SUBSTANCES

A strategic approach to assessing occupational exposure to Airborne Hazardous Chemical Substances (including Lead and Asbestos)



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FOREWORD

This document has been developed to provide a single guideline to facilitate the implementation of a monitoring strategy to assess occupational exposure to airborne hazardous chemical substances.

The guide supports the air monitoring requirements of the Hazardous Chemical Substances Regulations, the Asbestos Regulations and the Lead Regulations.

CHIEF INSPECTOR OCCUPATIONAL HEALTH AND SAFETY

This guideline is based on the UK Health and Safety Executive (HSE) Document No. HSG 173: Monitoring Strategies for Toxic Substances and the US National Institute for Occupational Safety and Health (NIOSH) Publication No. 77-173: Occupational Exposure Sampling Strategy Manual (OESSM).

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Introduction

1. This guideline is intended to assist you to protect the health of employees who might be exposed to airborne hazardous chemical substances.

2. You can use it both as an introduction to the design of inhalation exposure monitoring strategies in general and more specifically to understand your duties in terms of The Hazardous Chemical Substances (HCS) Regulations, Asbestos Regulations (AR) and the Lead Regulations (LR) which were published under the Occupational Health and Safety Act of 1993 [(1)].

3. You can use these procedures to investigate employee exposure, by inhalation, to hazardous chemical substances. They will help you investigate the nature, extent and control of employee exposure.

4. The guide will also help you to understand any information or advice that you may receive from consultants and others.

5. Health and safety professionals may also use this guide as an introduction to the subject.

6. The HCS Regulations state that a hazardous chemical substance includes any toxic, harmful, corrosive, irritant or asphyxiant substance, or a mixture of such substances for which –

- an occupational exposure limit (OEL) is prescribed, or
- an OEL is not prescribed, but which creates a hazard to health.

7. The Asbestos Regulations and the Lead Regulations respectively prescribe an:

- OEL for regulated asbestos fibres;
- OEL for lead other than for tetra-ethyl lead; and an
- OEL for tetra-ethyl lead

8. The information in this guide is not suitable for:

- assessing exposure to micro-organisms;
- assessing exposure from non-inhalation routes (ie skin absorption and ingestion); and
- assessing safety issues such as flammability or explosive hazards.

9. You need to be aware that substances hazardous to health can enter the body by ingestion (ie swallowing the substance) and skin absorption (ie through the skin) as well as by inhalation. In this case air monitoring by itself is inadequate to measure employee exposure and a technique called biological monitoring may also be used for certain substances.

10. Biological monitoring is outside the scope of this guide. For further information on this topic see section 4 of Annexure 1 of the HCS Regulations.

11. With regard to biological monitoring for lead see Medical Surveillance in the Lead Regulations.

Legislative requirements

12. The principles of occupational health and safety risk management as laid down in section 8 of the Occupational Health and Safety (OHS) Act, 1993 are also followed in the occupational hygiene regulations for substances hazardous to health. The central requirements under the OHS Act are:

- Assessment of potential exposure – you should carry out a health risk assessment[(2)] of the potential exposure of employees to hazardous chemical substances;
- Air monitoring – if the assessment indicates that any of your employees could be exposed to a hazardous chemical substance then you are required to set up a measurement programme to determine the airborne concentrations of that substance; and
- Control of exposure – you should ensure that exposure is prevented or, when this is not reasonably practicable, adequately controlled.
  - For a substance with a Recommended Limit, control of exposure is regarded as adequate when it is below the recommended limit or if the relevant area is zoned and the level of exposure is reduced to below the limit by means of adequate personal protective equipment.
  - For a substance with a Control Limit, exposure is only regarded as adequate when the exposure is at a level as low as reasonably practicable below the limit.

13. The procedures for inhalation exposure monitoring are not given in detail in the regulations but you are required to consult your health and safety representatives and obtain their comments before carrying out the monitoring programme. Measurements to demonstrate legal compliance (see Compliance Testing, paragraphs 81 to 91) are also required to be carried out, or verified, by an Approved Inspection Authority [(3)].

Exposure limits

14. A number of hazardous chemical substances including asbestos and lead and its compounds have been given OEL's. There are in general two types of OEL, a TWA OEL averaged over an 8-hour period and a short term exposure level (STEL) averaged over a 15 minutes reference period (In the case of asbestos a four hour OEL and 10 minute STEL is stipulated).

15. An Occupational Exposure - Control Limit (OEL-CL) is the maximum concentration of an airborne substance, which:

- your employees may be exposed to by inhalation; and
- should not be exceeded.

16. You should also ensure that exposure is maintained 'as low as reasonably practicable' below the Control Limit. OEL-CL's are specified in Table 1 of the HCS Regulations[4].

17. An Occupational Exposure - Recommended Limit (OEL-RL) is the concentration of an airborne substance at which there is no current evidence of likely harm to employees who are exposed day after day by inhalation. OEL-RL's are specified in Table 2 of the HCS Regulations.

18. A large number of chemical substances used in industry have not yet been given OEL's, but this does not mean they are safe. In these circumstances you need to ensure that exposure is controlled to a level at which nearly all the working population could be exposed, day after day, without adverse effects on their health.

19. To judge whether there is a risk to the health of your employees in these circumstances, you may be able to use limits produced by other bodies, such as Threshold Limit Values[5] from the American Conference of Governmental Industrial Hygienists (ACGIH).

20. You can also use the information provided by your manufacturer or supplier to set in-house standards[6].

Inhalation exposure monitoring

Why you should develop a monitoring strategy

21. As an employer, you may wish to develop a monitoring strategy. There are a number of good reasons to do this, including:
- to use in health risk assessment;
- to check compliance with OEL's;
- to design exposure control measures;
- to check the effectiveness of your control measures;
- to inform your employees of the pattern of exposure and level of risk;
- to indicate the need for health surveillance;
- to establish in-house exposure standards, where necessary;
- for insurance purposes; and
- to contribute to epidemiological studies.

Personal monitoring

22. Measuring your employees' personal exposure, by inhalation, to hazardous chemical substances is not the same as measuring the amount at a particular fixed site in the workplace. Fixed sites can be either:
- at the source of emission of a hazardous chemical substance; or
- at another area in the workplace, away from the source.

23. Personal monitoring is used to establish the concentration of an airborne substance within the breathing zone of the employee. This is explained in more detail in Appendix 2, paragraphs 10-13 of this guide. It should be noted that OEL's primarily relate only to personal exposure.

24. You will need to consider whether personal exposure monitoring will be useful when assessing the risks to your employees from working with hazardous chemical substances.

25. Remember, exposure monitoring is not an alternative to the adequate control of exposure and monitoring programmes can be time consuming, labour-intensive and expensive. Therefore it is important that you establish:
- a clear need for monitoring;
- an understanding of the factors likely to influence the exposure; and
- a strategy which is fit for the purpose.

Static monitoring

26. OEL's refer to personal monitoring. You can however use fixed site or static monitoring to obtain information on the likely sources contributing to the exposure. Static monitoring does not usually reflect the amount that employees could breathe in, which determines the risk to health.

27. You may take static samples:
- to check the effectiveness of your control measures;
- to identify emission sources;
- to determine background workplace environmental contaminant concentrations;
- if there are no suitable personal monitoring methods available;
- when wearing personal monitoring equipment may introduce additional hazards; and
- when continuous monitoring alarm systems are installed.

28. A limited number of OELs are based on static air sampling rather than personal sampling. These include the 8 hour TWA OEL-RL for cotton dust and the annual average OEL-CL for vinyl chloride.

Approaches to inhalation exposure assessment and monitoring

29. Because of variations in plant, process, work and other conditions it is difficult to draw conclusions about long-term exposure patterns on the basis of a single measurement of exposure at one point in time (see Appendix 1 and 2).

30. You will need to make sure that the monitoring strategy you devise and the way you interpret the results allows you to draw conclusions with confidence about the risks to the health of your employees.

31. Exposure monitoring can be time-consuming and expensive. But, if you follow the advice outlined in this guide you will get the most out of a monitoring exercise, at a reasonable cost.

32. Each stage in the industrial manufacture and use of hazardous chemical substances involves different tasks. Each of them can present different exposure conditions. Figures 1a – 1e show how exposure can vary, often over short periods of time, during a shift.

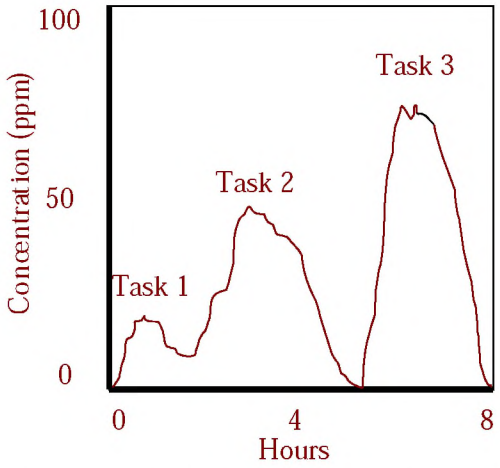


Figure 1a An exposure pattern for a working shift (8 hours)

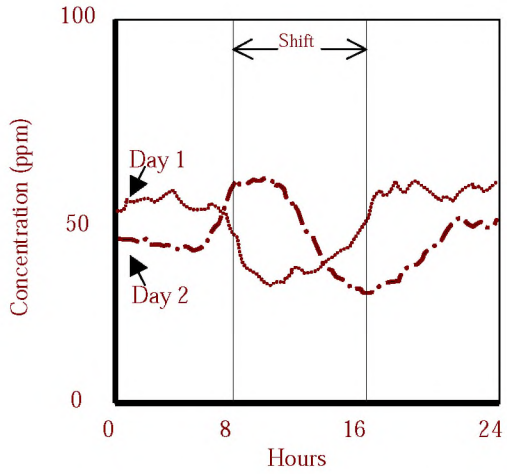


Figure 1b Variations in exposure over a 24 hour period

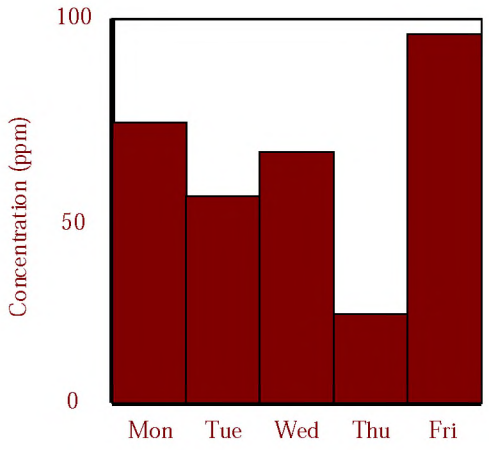


Figure 1c Daily variations in shift averages (8-hour TWA's)

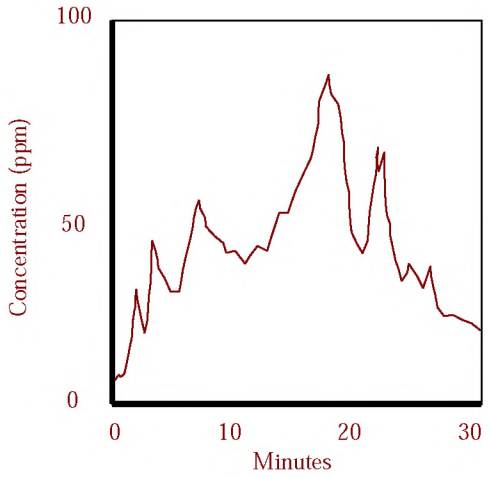


Figure 1d Continuous monitoring trace (eg paint spraying showing intermittent nature of job)

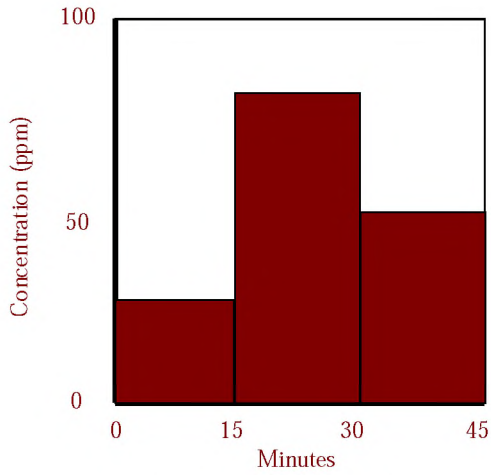


Figure 1e 15 minute time weighted average exposure

33. The design of a monitoring strategy will be greatly influenced by the:
- aims of the survey; and
- conditions presented by the process.

34. The scope of the exposure assessment will depend on how complicated the process is. However, in many situations it may be possible to determine the likely level of exposure without taking measurements. Figure 2 illustrates a structured approach for evaluating exposure by inhalation.

35. The following paragraphs outline this approach to monitoring inhalation exposure to hazardous chemical substances.

36. Not every situation is complex enough to warrant such a structured approach, for example monitoring exposure to solvent vapours during hand painting in a well-ventilated room. In these situations you could select or combine different aspects of the structured approach.

37. You may consider combining aspects of the basic and detailed surveys. This may involve the simultaneous use of smoke tubes, air velocity meters, chemical indicator tubes and personal sampling equipment.

Approaches to inhalation exposure assessment and monitoring

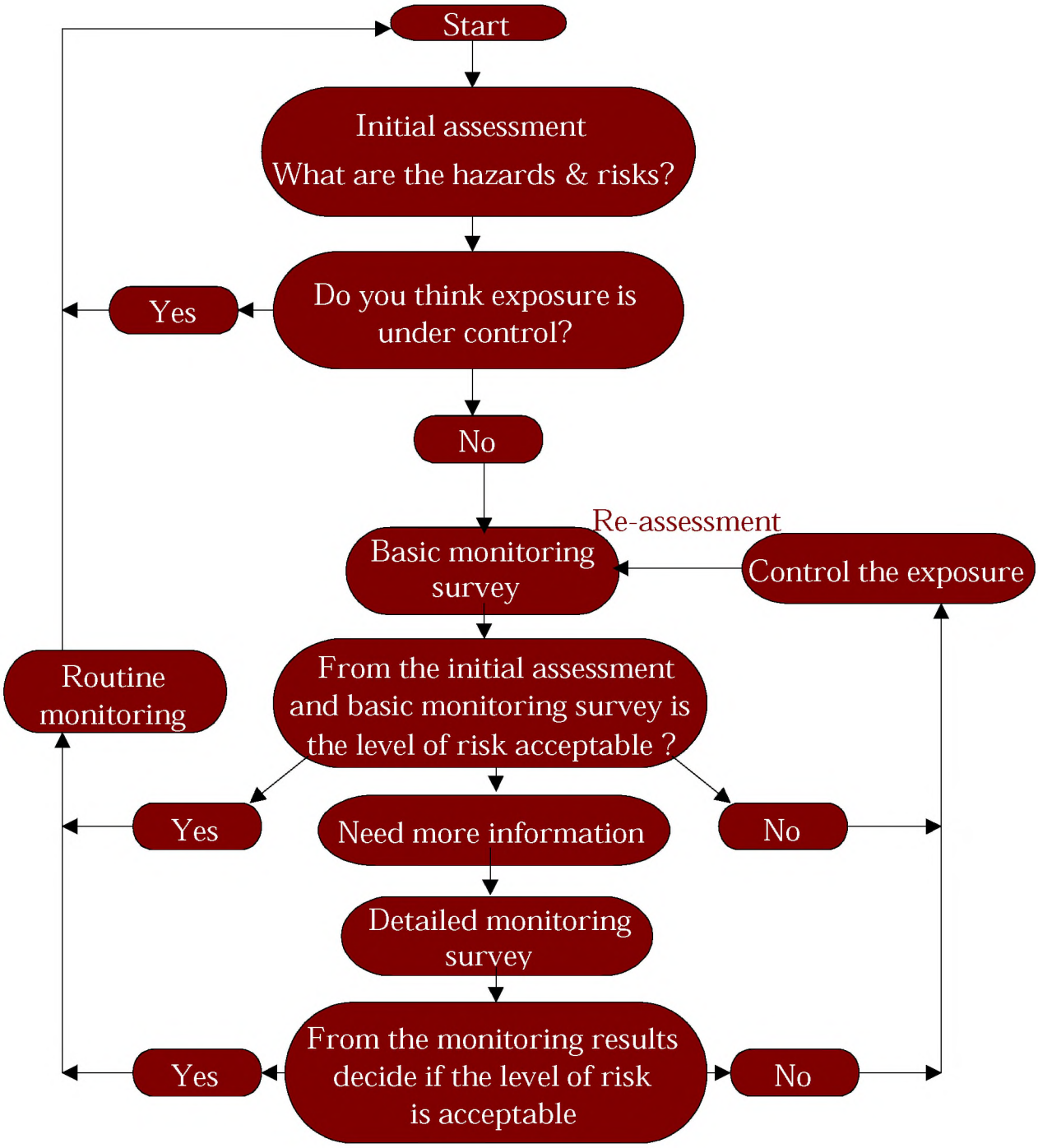


Figure 2 A structured approach for assessing inhalation exposure to hazardous chemical substances

Approaches to inhalation exposure assessment and monitoring

Initial assessment

38. The initial assessment is an important part of the strategy described in Figure 2. It helps you establish the need for, and the extent of, exposure monitoring. This will help you decide on:

- the hazards;
- the potential risks; and
- whether more information is needed (eg do you need to carry out monitoring to determine the exposure of your employees?).

39. The first stage of the initial assessment requires you to find out information on a variety of factors, for example:

- the hazardous chemical substances that your employees are exposed to;
- the effects that these substances can have on your employees;
- where the substances may be present and the airborne forms of those substances;
- the nature of the processes or operations where exposure could occur;
- the number, type and position of the sources from which the substances could be released;
- which groups of employees are most likely to be exposed;
- the pattern and duration of exposure;
- work practices;
- the means by which the substances are controlled and the effect of reasonable deterioration in, or failure of, such controls;
- whether respiratory protective equipment and/or other personal protective equipment are worn and their effectiveness; and
- what are the OELs, limits from other standard setting bodies or in-house standards for the substances involved.

40. You can obtain this information from a number of sources, for example:

- labels on containers and packages;
- manufacturers' and suppliers' data sheets;
- publications from the Department of Labour or other health and safety organisations;
- technical literature from trade associations; and
- past experience.

41. When you have this information, you can use simple qualitative tests to help you decide whether there may be a risk to the health of your employees, for example:

- smoke tubes can illustrate the movement of air under the influence of draughts, general and local ventilation systems, and show what the effects are;
- a dust lamp allows you to see very fine airborne particles which are invisible under normal light. This helps you identify emission sources and watch the movement of airborne dust.
- Smell can also be used as an indicator of contamination if the concentration exceeds the odour threshold limit. But remember this is an unreliable method.

42. Based on the information collected during the initial appraisal you may conclude that the level of exposure, by inhalation, is acceptable. If this is the case, it might not be necessary to carry out exposure monitoring except where this is required by legislation (see paragraph 85).

43. Remember, the level of exposure of your employees to a hazardous chemical substance can change. This means that your initial assessment may no longer be valid. You should always be aware of the need for exposure monitoring.

Basic monitoring survey

44. You will need to proceed to a basic monitoring survey when:

- the initial assessment suggests there is an exposure risk but the extent of the risk is uncertain;
- major changes have been made to the process, procedures or control measures since the last assessment;
- unusual or periodic operations are planned;
- a new process is being commissioned; or
- a new OEL or in-house standard has been set.

45. The basic monitoring survey estimates your employees' personal exposure and provides an indication of the efficiency of process and engineering controls.

46. In the case of a basic monitoring survey it is best to look at worst-case situations, such as the 'dirtiest' processes, or situations your employees make the most complaints about.

47. Before monitoring you need to identify those employees likely to be at significant risk of exposure along with the conditions giving rise to them. Appendix 1 sets out the factors that influence airborne concentrations and Appendix 2 outlines the variables which influence the design of monitoring strategies. This information will help you decide what needs to be done.

48. You can use semi-quantitative methods to estimate personal exposure. These give you a rough numerical estimate of exposure. Some semi-quantitative methods are comparatively inexpensive and easy to use.

Approaches to inhalation exposure assessment and monitoring

49. Semi-quantitative methods range from simple techniques, such as chemical indicator tubes (where the absorbent granules in the tube change colour when a known amount of air, containing a chemical, is drawn through) to more complex methods which require specialist knowledge, including:

- computer exposure modelling; and
- organic vapour analysers such as photoionisation detectors, portable gas chromatographs and infra-red analysers.

50. Alternatively, validated laboratory based sampling and analytical techniques can be used (see paragraph 28 of Appendix 2). If you are unsure how to use such techniques, you could consult an occupational hygienist. If the monitoring is required to demonstrate compliance with legal standards then an Approved Inspection Authority must be consulted beforehand.

51. Air velocity meters can be used to assess local exhaust ventilation systems to ensure that they are performing in accordance with the design specification. Also, the qualitative methods used in the initial assessment can be used here.

52. The basic survey may highlight defects and deficiencies in control strategies. Based on this and information gathered during the initial assessment you may conclude that the control of inhalation exposure is acceptable. If the conclusion is not certain, you have two choices:

- carry out a detailed survey and take remedial action as necessary; and
- take direct action to control exposure.

Detailed monitoring survey

53. You can use this approach when:

- the extent and pattern of exposure cannot be confidently assessed by a basic survey;
- exposure is highly variable between employees doing similar tasks;
- carcinogenic substances or respiratory sensitisers are involved;
- the initial appraisal and basic survey suggest that:
  - the time-weighted personal exposure may be very close to the OEL, limits from another body or in-house standard; and
  - the cost of additional control measures cannot be justified without evidence of the extent of exposure variability; and
- undertaking major maintenance and one-off jobs such as plant decommissioning.

54. A detailed monitoring survey is likely to involve techniques already mentioned for the initial appraisal and basic survey. This will be in conjunction with more detailed monitoring of your employees' potential exposure to hazardous chemical substances.

55. A detailed monitoring survey is most suited to complex processes and will require an in-depth investigation of the process and its environment, for example:

- procedures involved in the process;
- work practices;
- maintenance procedures including the type and frequency;
- control measures in use, their suitability and effectiveness;
- protective equipment provided to your employees and its suitability;
- previous monitoring results;
- results of health surveillance programmes;
- information and instruction provided to your employees for carrying out the tasks involved; and
- the extent of the training provided to your employees.

56. A detailed monitoring survey usually requires more specialist knowledge than an initial appraisal or basic survey. It is beyond the scope of this guideline to describe such a procedure in full, especially as detailed surveys vary with the situation in each workplace.

57. For further information you can see the references at the end of this guideline or consult an Approved Inspection Authority.

58. For certain substances a detailed monitoring survey may need to include the use of biological monitoring. You can find out more about biological monitoring and how to go about it in Annexure 1 of the HCS Regulations.

Reassessment

59. Monitoring for the basic and detailed surveys may highlight deficiencies in control measures or poor work practices.

60. Once you have carried out remedial action you will need to see if the changes have had a positive effect. You can usually do this by a brief reassessment of the situation.

61. If the risks to health are judged to be high, additional monitoring may be advisable. For example when:

- carcinogens or teratogens are used; or
- there is a very variable pattern of exposure.

Approaches to inhalation exposure assessment and monitoring

Routine monitoring

62. When the risk to your employees has been adequately controlled, Regulations under the OHS Act still require a routine monitoring programme to ensure that the control measures stay effective.

63. Routine monitoring can be time-consuming and expensive over the long term. Consequently, if you think that you may not be complying with an OEL it can be more cost-effective for you to invest in better control measures. This reduces the:

- need for expensive routine monitoring; and
- health risks for your workforce.

64. Remember there are some simple and inexpensive instruments available which can provide information on the continued performance of your control methods, for example:

- pressure sensing devices fitted to ventilation systems;
- smoke tubes; or
- dust lamps.

65. For the results of a routine monitoring programme to be effective in protecting the health of your employees you need to be able to compare them with those obtained from previous monitoring exercises. This requires that the programme is well planned. You need to consider:

- the similarity of processes and tasks monitored;
- where and at what stage of the process the monitoring was carried out; and
- the method of collecting and analysing the samples.

66. If a programme is not well planned it can produce a large volume of results and paperwork without being of any actual use in making sure that your employees' health is being protected.

67. Representative monitoring at least every 12 months must be carried out for substances which have been designated with a Control Limit, i.e. asbestos, lead and the substances listed in Table 1 of the Hazardous Chemical Substances Regulations. Substances with a Recommended Limit, i.e. listed in Table 2 of the Hazardous Chemical Substances Regulations, must be monitored at least every 24 months.

Interpretation of results

68. OELs are set down as eight-hour time weighted averages (TWAs) and/or 15-minute TWAs. This means that you need to ensure that each result has been converted to the specified TWA reference period.

69. The approved methodology for calculating TWAs is given in Annexure 2 of the HCS Regulations. When you are converting the results to TWAs, you need to give careful consideration to the accuracy and precision of the sampling and analytical methods used.

70. You can do this by consulting the manufacturer of the equipment or by seeking specialist advice, for example from the laboratory that carried out the analysis.

71. When comparing the results with OELs, limits from other bodies or in-house standards, you will need to take account of other relevant workplace information you have collected (see Appendix 3).

72. If you have used relatively unsophisticated techniques, such as chemical indicator tubes during an initial appraisal, do not place too much confidence when an employee's exposure is between 50 & 150% of the OEL.

73. In these circumstances you should conclude that the level of exposure is uncertain and a more detailed investigation is required.

74. When the exposure is less than 50% of the OEL you can however be confident that no further action is necessary. As the strategies and techniques that you use become more refined, you can place greater confidence in the results.

75. In most situations you will not need to carry out a statistical treatment of the results. However, you may decide to apply a simple analysis such as a group average and range.

76. If you have taken a large number of samples, for example during representative (see Appendix 2) and routine monitoring, a more detailed statistical analysis may be carried out. This will require a knowledge of statistics.

Approaches to inhalation exposure assessment and monitoring

77. Using statistics to analyse the results will give you a better indication of the variability in exposure and extent of compliance with OELs. More information on statistical techniques can be found in the references at the end of this guideline [7 - 9].

78. From the exposure monitoring results you may conclude that:

- the data are/are not adequate and/or representative of all those exposed;
- compliance with OELs, limits from other bodies or in-house standards has/has not been achieved;
- further actions are/are not necessary to prevent or reduce exposure; or
- more monitoring is/is not needed.

79. When interpreting the results and reaching your conclusion you need to remember that the OHS Act requires that protection is given to all employees. If you have carried out group based, similarly exposed group (SEG) monitoring you need to show that the conclusion drawn for one employee is equally applicable to others in the same exposed group (see Appendix 2, paragraphs 5 to 9).

80. The higher the result is above the OEL the greater the priority you will need to give to reducing exposure.

If you are comparing your results with limits from other bodies or in-house standards you need to consider the basis behind the number in order to decide whether there is a risk to health of your employees.

Compliance testing

81. Compliance testing is the minimum amount of monitoring required to demonstrate that you are meeting your legal obligations. It is only one part of an effective monitoring programme.

82. Compliance monitoring means taking measurements according to the procedures laid down in the applicable regulations and comparing your results with the relevant OELs.

83. It is important to note that these measurements must be carried out, or verified, by an Approved Inspection Authority.

84. Where your initial appraisal, or risk assessment, has indicated that any employees could be exposed to a hazardous chemical substance by inhalation then you are required to implement a monitoring programme to measure the airborne concentrations of those substances.

85. Measurements which are representative of typical exposure should be carried out on each and every employee who could be exposed at or above the OEL of any substance. Measurements must be taken at least annually for a substance with a Control Limit and at least every two years for a substance with a Recommended Limit.

86. If the specific employees in any workforce who could be exposed at or above the relevant OELs are not readily apparent and cannot be reliably identified in the initial appraisal then a group measurement can be taken.

87. For a substance with a Control Limit, Table 1 should be used to select a representative sample of the workforce which, with a confidence level of 95%, will contain at least one of the top 10% exposed employees.

Size of group (N)	12	13-14	15-16	17-18	19-21	22-24	25-27	28-31	32-35	36-41	42-50	∞
Required no. of measured employees (n)	11	12	13	14	15	16	17	18	19	20	21	29

Table 1 Sample size for top 10% and confidence 0.95 (Use n = N if N ≤ 11)

For a substance with a Recommended Limit Table 2 should be used to select a representative sample of the workforce which, with a 90% confidence level, will contain at least one of the top 10% of exposed employees.

Size of group (N)	8	9	10	11-12	13-14	15-17	18-20	21-24	25-29	30-37	38-49	50	∞
Required no. of measured employees (n)	7	8	9	10	11	12	13	14	15	16	17	18	22

Table 2 Sample size for top 10% and confidence 0.90 (Use n = N if N ≤ 7)

88. After having determined the appropriate number of employees to sample, it is necessary to select those employees at random. Appendix 4 provides a simple method for carrying this out.

89. It should be noted that Tables 1 & 2 are only tools to identify the "high-risk employee" or a group of "high risk employees". Appendix 2, paragraphs 5 to 9 give more detail on grouping similarly exposed employees to determine those most at risk.

90. If the exposure of the "high risk worker" is above the OEL then it is necessary to investigate further to identify whether there are any other employees whose exposure could be above the OEL.

91. Once the exposed, or potentially exposed, employees have been identified, you must then ensure that every one of them is regularly monitored on the appropriate schedule as given in paragraph 85.

Statistical analysis

92. For legal purposes it is important to know:
- was an employee exposure result in compliance with the relevant OEL on a particular day?;
- what is an employee's long-term exposure estimate based on several exposure measurements?; and
- should engineering controls be installed to reduce those exposures?

93. When an employee is sampled and an average exposure is calculated, this result will rarely be exactly the same as the true average exposure.

94. The discrepancy will be due to:
- Random sampling errors i.e. variations in the sampling rate, analysis inaccuracies, handling losses etc.; and
- Random fluctuations in the workplace air due to air currents, temperature differences, or the processes occurring during the workshift.

95. It is not the purpose of this guideline to give a detailed tutorial on statistical techniques. It is however important for you to realise that all measurements of airborne substances are subject to some degree of uncertainty. This variability can be of a considerable nature in real work situations. This is of particular significance when there is a possibility that you could be prosecuted for non-compliance with legislation and when you are considering implementing, or not implementing, expensive engineering controls.

96. The result of exposure sampling is referred to as an average exposure estimate. Statistical methods allow you to calculate limits, with a selected confidence level, that will contain the true value. The numerically larger limit is known as the upper confidence limit (UCL), and the numerically smaller limit is known as the lower confidence limit (LCL).

97. Figure 3 provides a graphic example of a LCL and UCL for an average exposure limit. The practical interpretation of a 95% one-sided LCL is that you can be 95% confident that the true average exposure is greater than the LCL (thus the arrow points up). Conversely for a 95% one-sided UCL, you can be 95% confident that the true average exposure is less than the UCL (thus the arrow points down).

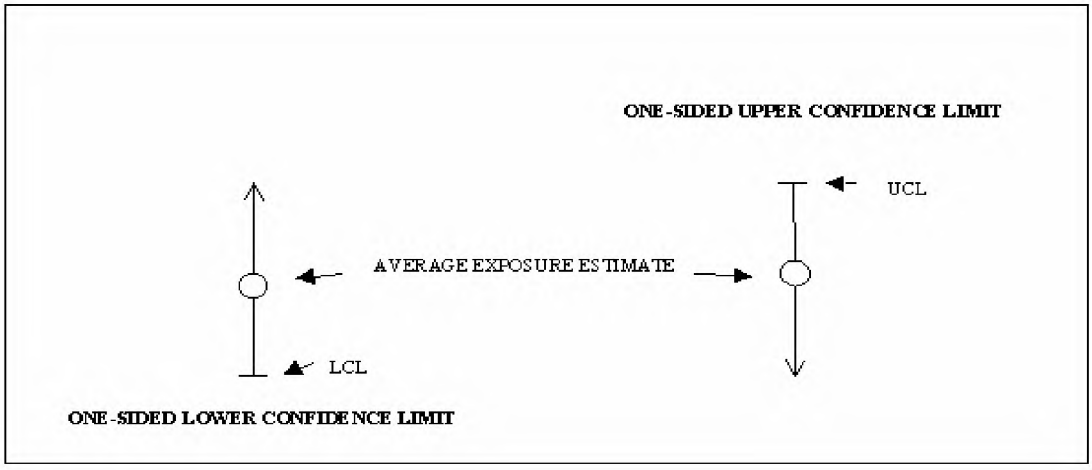


Figure 3 Example of one-sided LCL and UCL.

98. A one-sided confidence limit (LCL or UCL) can be used to classify average exposures into one of three possible exposure categories. The use of the LCL (by an Inspector) would result in a decision of either Non-compliance Exposure or Possible Overexposure. The use of the UCL (by the employer) would result in a decision of either Compliance Exposure or Possible Overexposure. Table 3 displays the three-way classification relative to the OEL. Figure 4 is a graphical representation of Table 3.

Classification	Definition	Statistical criterion
A. Non-compliance exposure	There is 95% confidence (based on measurements) that an employee's exposure is above the OEL.	LCL (at 95%) > OEL
B. Possible Overexposure	Any employee who cannot be classified in A or C.	
C. Compliance exposure	There is 95% confidence (based on measurements) that an employee's exposure is below the OEL.	UCL (at 95%) ≤ OEL

Table 3 Classification system for employee exposure to hazardous chemical substances

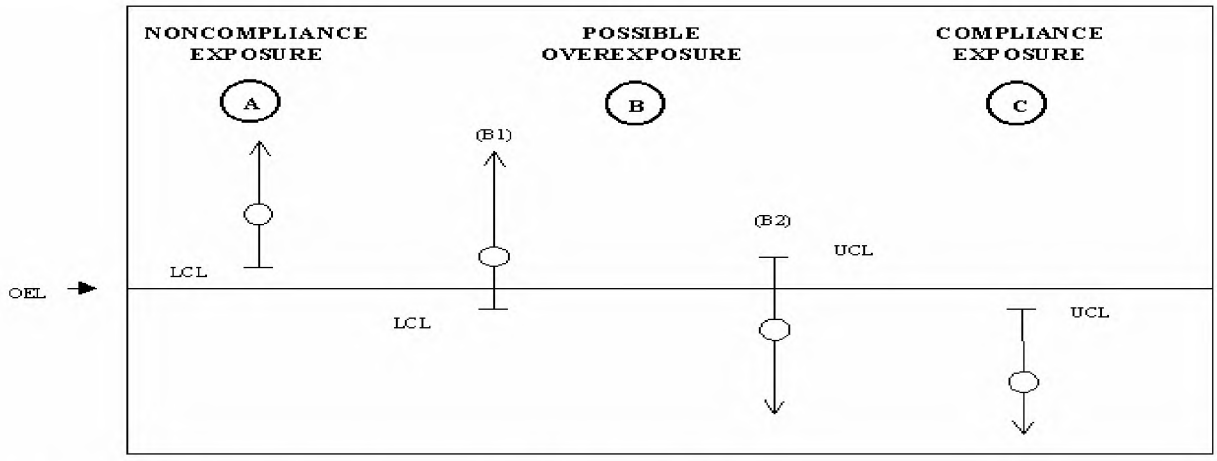


Figure 4 Classification according to one-sided confidence limits.

99. The definition of an "exposed" employee deserves further explanation. Case B1 represents an employee whose average exposure estimate on a day was greater than the OEL (overexposure in the conventional sense). But, the LCL did not exceed the OEL, and a statistically definitive statement could not be made since there was a possibility that the true average exposure was under the OEL in the region down to the LCL and thus not overexposed.

100. Conversely, Case B2 represents an employee whose average exposure estimate was less than the OEL (safe exposure in conventional terms). But, the UCL was not lower than the OEL and a statistically definitive statement could not be made regarding compliance since there is a possibility that the true average exposure is in fact greater than the OEL (up to the UCL).

101. The procedure for determining the LCL or UCL is:

- determine the full period sample value (V);
- obtain the relevant 8-hour OEL;
- obtain the coefficient of variation (CV_T) for the sampling/analytical method used. This should be available from the Approved Inspection Authority or laboratory carrying out the analysis;
- determine the standardised concentration (i.e. concentration of hazardous chemical substance is given as a ratio relative to the exposure standard and therefore unitless) –

  $Vs = V/OEL$;

- calculate LCL or UCL as follows –

  (a) Factory Inspector's test for non-compliance

  $LCL(95\%) = Vs - (1.645)\ (CV_T)$

  (b) Employer's test for compliance

  $UCL(95\%) = Vs + (1.645)\ (CV_T)$

- Classify the exposure average as follows –

  (a) Factory Inspector's test for non-compliance
  - If LCL > 1, classify as Non-compliance Exposure;
  - If Vs > 1 and LCL ≤ 1, classify as Possible Overexposure;
  - If Vs ≤ 1, no statistical test for non-compliance would be made.

  (b) Employer's test for compliance
  - If UCL ≤ 1, classify as Compliance Exposure;
  - If UCL > 1, classify as Possible Overexposure;
  - If Vs > 1, no statistical test for compliance would be made.

Classifying exposures as compliance or non-compliance (overexposure) is a legal requirement under the OHS Act. An example of statistical analysis for a full period single sample has been outlined above. For statistical analysis of full period consecutive samples, partial period consecutive samples and grab samples refer to Chapter 4 of the OESSM[7] document.

Approaches to inhalation exposure assessment and monitoring

Adequate control

102. For substances with a Control Limit, you can regard inhalation exposure as being adequately controlled when exposure is:

- reduced so far as is reasonably practicable; and
- below the OEL.

103. For a substance with a Recommended Limit, you can regard inhalation exposure as being adequately controlled when exposure is:

- at or below the relevant OEL; or
- above the OEL but you have identified the reason and are taking action to put it right as soon as is reasonably practicable. The relevant area has been zoned and exposure is reduced to below the limit by means of adequate respiratory protective equipment.

104. Reducing exposure 'as far as reasonably practicable' means that:

'you must reduce exposure to the point where there is a big difference between, on the one hand, the sacrifice (in money, time or trouble) that would be involved in further measures and, on the other hand, the risks from exposure (which should be insignificant)'.

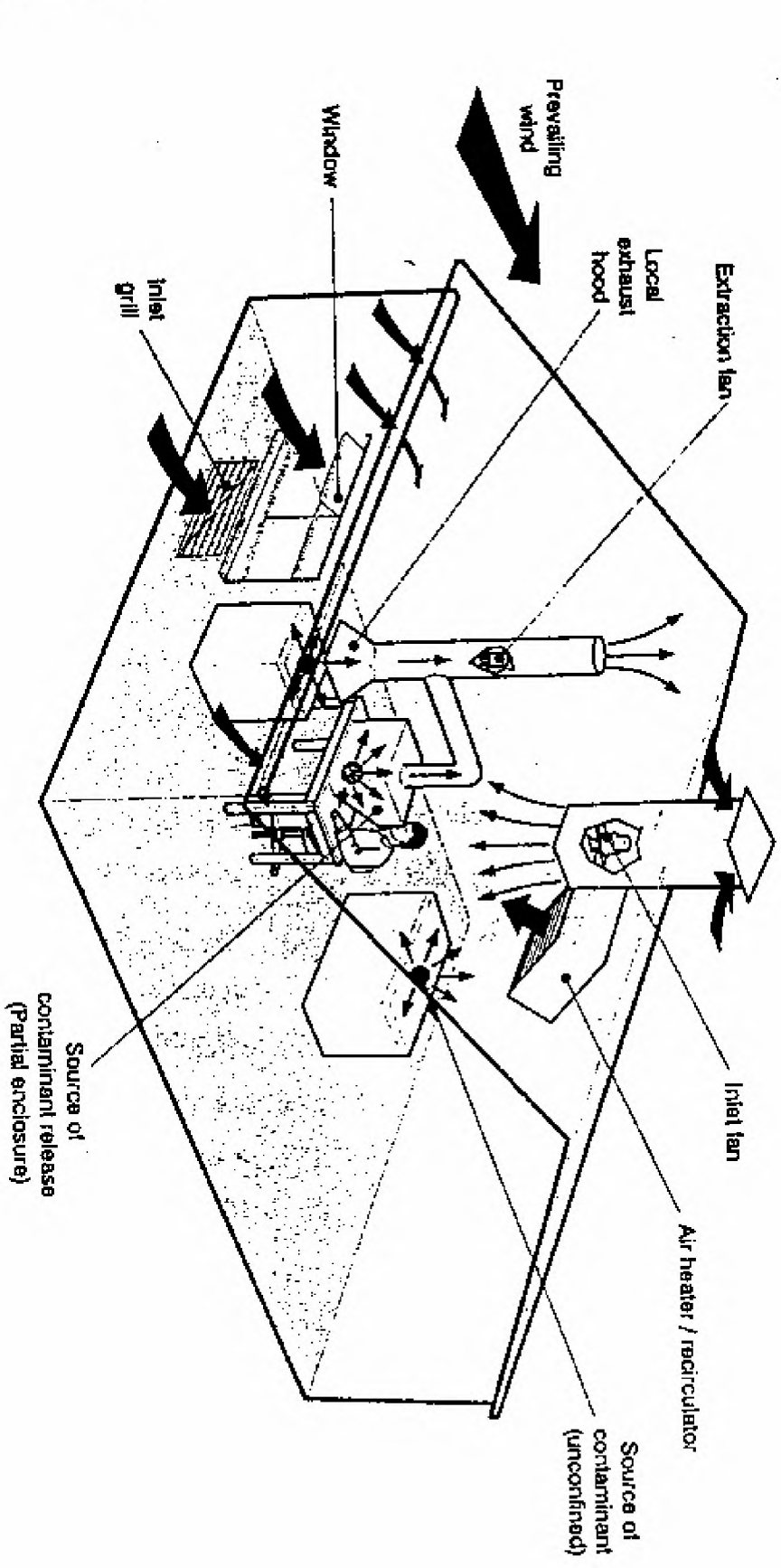
Appendix 1: Factors influencing airborne contaminant concentrations

1. It is important to understand the variability of the workplace environment before designing a monitoring strategy. Factors which influence the release and airborne concentration of substances include:
    - physical and chemical properties of the substance such as the vapour pressure, boiling point and particle size;
    - the number of sources from which the substance is released;
    - rate, duration and speed of release from each source;
    - arrangement of the process, temperature and design of the control measures;
    - variations in the process, job and tasks being carried out. These can be by the hour, day or even week;
    - dispersion or mixing of the substance in the workplace air due to general or local ventilation; and
    - ambient conditions (temperature, pressure and humidity).

2. These factors may produce rapid fluctuations in the concentrations of the substances over small distances. Figure 1 shows a workplace where plant and process conditions as well as local and general ventilation characteristics may vary from day to day or display a seasonal pattern.

3. As well as the factors outlined in paragraph 1, your employees can also influence the level and pattern of exposure, for example:
    - the type and position of each source relative to the employee;
    - the length of time the employee spends in the vicinity of the source;
    - whether the employee has:
        - direct control over the task or process; and
        - a poor appreciation of the risks leading to poor work practices.

Appendix 1



Appendix 1, Figure 1 Factors influencing airborne contaminant concentrations

Appendix 2: Variables influencing the design of monitoring strategies

1. This appendix outlines a number of variables which you will need to consider when designing a monitoring strategy. Further information can be found in the references at the end of this guideline.

Health effect

2. The type of health effect that could be induced by the substance will influence the monitoring procedure. For a substance with acute effects such as eye irritation, the monitoring techniques need to be sensitive enough so that peak and short term (15-minute TWA) measurements can be taken.

3. In the case of chronic effects the monitoring strategy will mainly focus on long term (eight-hour TWA) exposures. This is because, in general, the development of health effects depends on exposure over a prolonged period of time.

4. You may need to consider substances which have the potential to induce both acute and chronic effects. The monitoring strategy will need to take this into account.

Grouping of individuals

5. The OHS Act require that you protect the health of all your employees. While you may wish to have information on the exposure of all your employees, in many workplaces the numbers involved may make the monitoring exercise prohibitively expensive. So monitoring strategies usually focus on groups of employees who do similar jobs in similar ways. These groups are described as similarly exposed groups (SEGs). The grouping of potentially exposed employees can be made by careful observation of such common factors as:

- similarity of the tasks performed (not necessarily the same job);
- exposure to the same range of airborne contaminants; and
- similarity of environment (process, exposure source and control measures).

6. If you have carried out group sampling the results need to be carefully analysed to make certain that they are equally valid for all employees in the SEG. A wide difference in the results from different individuals indicates considerable variation within the SEG.

7. In these circumstances you need to further sub-divide the group or reassign employees to a more appropriate SEG. Repeated measurements from the same employee can help you decide whether that employee needs to be reassigned or a SEG further sub-divided.

8. As a useful guide:
when an individual's exposure is less than half or greater than twice the group average, then the individual needs to be reassigned to a more appropriate SEG.

9. You can then focus your risk control strategies and further monitoring on those employees most at risk from excessive exposure.

Types of exposure measurement

10. As indicated in paragraphs 22 to 37 in the main text, there are two main types of monitoring, personal and fixed site (static). The purpose of personal monitoring is to establish the concentration of the airborne substance within the breathing zone of the employee.

11. The breathing zone is the space within 20-30 cm of the person's nose and mouth. This convention permits the placing of personal samplers on the employee's lapel. However, airflows and activities are variable. This means that the positioning of the sampler (right lapel, left lapel or helmet) may cause an over or under estimate of the average concentration inhaled by the employee. For example, the fume generated during soldering operations will rise straight upwards because of thermal currents. This may miss a sampler placed on the employee's lapel.

12. Therefore, you need to give careful consideration to the process, task and work practices before placing the sampler and during the monitoring exercise so that the results can be correctly interpreted.

13. There are two distinct types of personal measurement; representative and worst-case:

- representative measurements that take into account all possible workplace influences including the variables described in this Appendix and Appendix 1; and
- worst-case measurements that can be taken where you can clearly identify employees who are subject to periods of high exposure. The monitoring period can then be selected to cover these events. For the purposes of determining the eight-hour TWA exposure, you can consider the exposures found in these circumstances as applying to the whole of the working period. This presumption will err on the side of safety once acted on.

Appendix 2

Number of samples

14. The minimum number of samples required to be taken for legal compliance purposes is defined in the applicable regulations and is covered in the section on Compliance Testing (paragraphs 81 to 91) in the main section of this guideline.

15. Taking one or a few samples on one day however is unlikely to provide you with sufficient information on which to base conclusions about long term exposures. In reality the number of samples that you can take is usually constrained by the resources available to you. You need to use your judgement when deciding on sample size, especially when small groups are concerned.

16. For worst-case monitoring, as a rule of thumb, at least one employee in five needs to be monitored from a properly selected SEG, unless a smaller number can be justified.

For representative measurements:

- if there are less than ten employees in the SEG only five need to be included in the monitoring exercise;
- for complex situations involving more than ten employees in the SEG, or for legal compliance purposes, see Tables 1 and 2 in the main section of this guideline.

Monitoring period and duration

17. If the process is continuous and has minimal variation, the choice of monitoring period is not of great importance. However, if the process is cyclic it is critical that you carry out the monitoring at the time your employees are being exposed.

18. The choice of monitoring period is also closely linked to the type of health effect associated with the substance (see Appendix 2, paragraphs 2 - 4). The duration of the monitoring has to be sufficient to:

- give results which are representative of the whole range of exposures, including peak exposures; and
- allow the relevant TWA exposure to be calculated.

19. You also need to ensure that start-up procedures at the beginning of shifts and end of shift tasks such as clean-down operations are included.

20. In the case of continuous, well controlled processes with minimum variability you can use a monitoring duration of less than the full shift (or eight hour reference period). In such circumstances the monitoring period should cover at least 25% of the working shift and include periods of high exposure.

21. If there is considerable variation in the work pattern you may need to monitor on a number of days to cover all anticipated variations.

22. Remember, unsampled time represents a serious weakness in the credibility of any exposure measurement. Consequently, during this time, you need to make careful observation of work practices, etc.

Sampling and analysis equipment

23. The monitoring equipment and method of analysis that you choose have to fit the requirements of the strategy and not vice versa. However, the practicalities of the workplace may require you to make a compromise.

24. The sampling technique you choose needs to be appropriate for the given work situation and not influence the employee's behaviour by being:

- too heavy;
- obstructive; or
- noisy.

25. The equipment needs to:

- be robust enough to cope with the demands of the work environment;
- have sufficient battery life; and
- be certified for use in flammable or explosive atmospheres, if necessary.

26. The errors in the sampling and analysis equipment need to be determined and supported when appropriate by quality control protocols.

27. Examples of national quality schemes include the:

- South African National Accreditation System (SANAS);
- UK Workplace Analysis Scheme for Proficiency (WASP); and
- US Proficiency Analytical Testing (PAT) Program.

28. Specific information on sampling and analytical techniques for many substances and processes can be found in the NIOSH Manual of analytical methods [10] and the HSE's Methods for the determination of hazardous substances (MDHS) series [11]. You can also get information from Approved Inspection Authorities, equipment manufacturers and analytical laboratories.
For sampling and evaluation of airborne asbestos refer to SAIOH-3 Asbestos fibres in air and for lead SABS SM 1164.

Appendix 3: Core information

1. A set of monitoring results in isolation is rarely sufficient to permit conclusions to be made with confidence on the level of exposure and the necessary control measures. Additional essential information, often referred to as 'core information'[12], is required.

2. Collecting core information at the time you carry out the monitoring will allow you to make reliable decisions about:
- the level of exposure; and
- the need or adequacy of controls.

3. Table 1 lists the information which you may need to collect when carrying out exposure monitoring.

Key categories	Data element
Premises	This section includes details on the name of your premises, address and what type of work you do.
Workplace	This section gives information on the department, work area and process.
Worker activity	Details of the employee eg name, ID number, male/female, profession, job title and tasks carried out are included in this section.
Product	This is the name of the product your employees are using.
Chemical substance	This is the substance which you are monitoring for. Chemical identification numbers can be noted if you know them (CAS number etc.). The current OEL or other standard can be noted.

Exposure modifiers	These are important factors which will help you interpret the monitoring results. You can note the things which affect your employees' exposure, for example:
	- is exposure continuous throughout the day or does it occur in occasional periods;
	- what type of controls do you use:
	  - local/general ventilation
	  - maximising the distance of the employees from the process
	  - minimising the time spent at the process
	  - the use of respirators;
	- is the area where the employee works:
	  - indoors or outdoors
	  - an open or enclosed space.

Measurement strategy	Note the strategy that you used in the survey in this section, eg was it a worst-case or representative situation.
Measuring procedure	Describe the procedure you used to carry out the monitoring, eg type of sample, duration of exposure and monitoring.
Result	Detail the sample result, the TWA result and the units.
References	Note the report reference number, the name of the person who carried out the survey and the date.

Appendix 3, Table 1 Core information

Appendix 4: Random number table

10	15	01	02	81	91	69	14	62	36	20	99	91	90	22
46	25	85	30	89	27	53	93	34	52	19	39	99	24	48
22	97	76	64	15	24	49	32	30	19	63	58	42	93	06
61	07	16	39	53	71	57	00	74	97	16	37	39	81	16
06	91	60	81	49	60	14	06	01	54	77	06	11	42	27
53	18	70	90	15	21	81	44	42	99	72	56	69	98	31
71	18	44	48	63	21	10	12	96	91	05	07	18	20	94
56	69	60	18	84	42	32	89	14	63	10	17	18	57	84
25	12	58	44	05	56	85	36	53	53	53	59	38	62	08
17	16	11	18	64	28	69	88	33	70	79	56	05	90	31
01	85	91	78	63	40	48	03	49	69	18	72	52	20	12
90	33	90	09	93	52	92	88	33	36	17	30	08	84	27
30	74	10	61	87	85	48	52	67	93	01	26	85	20	29
89	07	97	71	08	77	13	47	81	97	85	29	74	28	90
51	12	51	51	77	16	60	92	49	53	70	63	75	40	02
21	52	60	89	19	55	44	01	65	64	44	05	55	01	54
33	94	31	04	18	29	71	85	51	01	92	64	52	53	46
58	23	14	83	98	23	64	94	17	35	35	07	97	33	09
42	06	76	13	51	46	88	19	25	58	48	91	85	14	09
30	90	04	59	22	30	61	99	32	54	58	22	74	47	25
76	26	58	06	21	15	96	11	32	32	05	24	13	38	94
28	35	06	17	64	18	22	29	27	87	87	58	00	45	15
46	41	10	07	36	18	02	33	28	07	19	92	60	61	50
67	32	86	50	94	13	16	74	92	24	36	00	22	02	51
07	79	97	45	21	00	30	03	94	89	41	17	27	63	41
49	82	24	99	47	81	64	66	80	65	83	34	13	30	97
35	91	00	50	98	38	87	94	39	57	67	77	44	11	71
11	60	06	28	37	07	98	98	27	31	80	44	97	70	95
14	50	35	59	87	48	02	00	48	04	21	20	92	90	12
35	01	38	28	68	10	10	54	06	50	65	79	53	10	21
72	77	56	55	87	69	45	00	25	00	96	30	47	23	39
56	20	21	51	33	72	32	41	76	91	21	36	27	73	20
37	63	71	84	52	22	78	17	96	18	70	66	99	72	01
42	11	20	54	36	70	23	65	59	99	94	11	18	81	80
90	52	02	85	88	47	00	82	72	15	43	99	10	76	25
03	21	83	43	90	22	44	34	65	85	55	38	59	13	35
01	39	76	22	83	32	79	29	04	16	15	12	66	38	22
73	88	09	82	05	92	82	27	32	17	27	98	63	11	34
88	56	34	57	23	25	40	67	12	02	14	23	35	99	37
11	35	85	09	96	05	97	28	14	00	80	70	75	76	88
37	40	59	33	26	62	69	76	50	43	86	70	79	93	28
19	68	69	88	49	46	63	56	00	73	91	15	06	57	54
17	00	64	60	88	61	99	30	26	11	44	34	60	60	71
60	63	71	05	43	58	26	32	63	35	57	10	07	54	93
85	64	29	44	14	55	78	34	30	48	51	09	25	27	11
65	52	50	22	05	99	73	85	29	70	60	18	19	42	08
43	47	42	45	00	20	14	49	94	56	59	09	58	29	44
45	70	05	49	26	57	99	24	74	75	28	39	52	62	72
98	67	72	01	13	14	87	89	13	77	69	70	35	34	15
81	58	35	94	75	00	97	96	86	96	86	54	86	55	41

Appendix 4, Table 1 Random number table

1. To use the table, start at any location on the table; then, moving in any given direction (across, down or up), identify the employees to be monitored.

2. For example to select 17 out of 45 employees for monitoring, designate each employee with a number from 1 to 45, then moving along in the direction chosen, choose 17 employees.

3. Assuming you start in the left-hand corner of the table, and move down, your first employee is number 10; the second employee is number 22; the third employee is number 06; etc. If you get a duplicate or a number outside the desired range, ignore it. Stop when you have obtained the 17 numbers.

Appendix 5: References

1. Occupational Health and Safety Act (No 85 of 1993) and its Regulations. South Africa

2. A Guide to Conducting an Occupational Health Risk Assessment Institute of Occupational Hygienists of Southern Africa (IOHSA) 1997.

3. Approved Inspection Authorities: Occupational Hygiene, Information Brochure No.1 Chief Directorate of Occupational Health and Safety; Department of Labour Revised 9 June 1998.

4. Occupational Exposure Limit for a Hazardous Chemical Substances as listed in Tables 1 and 2 of Annexure 1 of the Hazardous Chemical Substances Regulations.

5. 2000 TLV's® and BEI's®: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists 2000 ISBN 1-882417-36-4.

6. Whylie D., Setting exposure limits: what to do when there's no standard. Occupational Health and Safety Canada 1993 9(6) 58-60.

7. Occupational exposure sampling strategy manual NIOSH Publication No. 77-173 1977, USA

8. Dewell P Some applications of statistics in occupational hygiene British Occupational Hygiene Society (BOHS) Technical Handbook No. 1. H and H Scientific Consultants 1989 ISBN 0 9059 2718 4.

9. Sampling strategies for airborne contaminants in the workplace British Occupational Hygiene Society (BOHS) Technical Guide No.11. H and H Scientific Consultants 1993 ISBN 0 9482 3714 7.

10. Manual of analytical methods 4th edition NIOSH Publication No 94-113 1994, USA.

11. Methods for the determination of hazardous substances MDHS in series, HSE , UK.

12. Occupational exposure databases: a proposal for core information for workplace exposure measurements on chemical agents European Foundation for the Improvement of Living and Working Conditions 1996 ISBN 9 2827 7355 8.

Appendix 6: Internet Resources

1. Extensive information for use in air sampling is available via the Internet. Analytical methods (e.g. NIOSH, OSHA, EPA), the OESSM document and information on proficiency schemes can be located via the Chemicals page of the Association of Societies for Occupational safety and Health (ASOSH) web site (http://www.asosh.org/WorldLinks/chemicals.htm).

2. South African health and safety legislation can be accessed via Acts Online (http://www.acts.co.za/).

Appendix 7: Acknowledgements

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