12. Skin/Dermal Exposure Monitoring

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12.1 Introduction

Dermal hazards refer to chemical substances that can cause dermatitis or otherwise damage the skin, as well as to chemicals that can enter the body through intact skin and cause other toxic effects. The meaning of the "skin" notation for approximately 98 Schedule 22.9(2)(a) listed chemical substances refers primarily to the latter. Use of the "skin" notation is intended to alert the reader that air sampling alone is insufficient to accurately quantify exposure and that measures to prevent significant skin contact and/or absorption may be required. Evaluating dermal exposure can be difficult and warning signs are limited. However, being aware of the substances in work environments and applying basic scientific principles along with some regularly used tests can be useful. The information contained in this chapter is provided to help evaluate dermal exposure. This chapter provides a description of the techniques commonly used to measure dermal exposure via dermal dosimetry.

12.2 Legislation

Section 11 of the MHSA requires employers to "assess and respond to risk." To this purpose, dermal exposure monitoring can be used to evaluate employee exposure. It is also useful in assessing the effectiveness of control measures, including proper work practices.

12.3 Principles and outline of procedure

Dermal exposure data can be used in conjunction with concurrently gathered ambient chemical dissipation data to establish chemical transfer coefficients. These transfer coefficients can be used in the exposure and risk assessment process to predict exposures for specific activities using ambient residue concentration data in the absence of scenario-specific exposure data.

12.3.1 Dermal dosimetry

In comparison to air sampling and even biological monitoring, dermal dosimetry is not a sampling or routine procedure. Thus far, its use is limited to research and to specially designed studies. Individuals applying dermal dosimeters should be thoroughly trained regarding the placement and retrieval of the dosimeters and recording of observations and other information about the activity. In addition to objective parameters, observed work practices can also have statistically significant important influences on dermal exposure and close observation is therefore necessary.

While dermal dosimetry mostly involves the patch technique, whole body dosimeters have also been used. Whole body dosimeters are typically a set of long cotton underwear (a one-piece set is sometimes called a union suit) that minimizes the effect of non-uniform depositions within a body part, but suffers from the lack of a barrier between the skin and dosimeter and may add heat stress to the wearer. After use, the whole body dosimeter may still be dissected into portions covering individual body parts.

12.3.2 Principle of operation

The patch dermal dosimeter method measures dermal exposure via absorbent patches that are attached to specified areas of a workers body, either inside or outside the clothing. Patches of predetermined size serve as collection media for the chemical substance for measuring the amount of chemical contacting the clothing or skin. Subsequent to the performance of post-application exposure activities, the patches are removed and analysed for content. The quantities of chemical on patches from a specified location on the body are used in conjunction with standard body surface area data for those body parts to estimate potential dermal exposure. Differences between chemical deposition on inside and outside patches can be use to determine clothing penetration factors.

12.4. Dosimeters and patches

12.4.1 Composition and size

The composition and size of the patches used in dermal dosimetry studies are important considerations and should be based on the physical/chemical characteristics of the chemical and the exposure scenario. A high quality alpha-cellulose will absorb a considerable amount of residue without disintegrating. Another material, that is satisfactory and more readily available in small lots, is preparative chromatography paper. Other appropriate materials include surgical gauze, clothing material and blotter paper. In extremely dusty environments, investigators should consider patch materials that are porous enough to collect dusts or dried residues. Surgical gauze is suggested as an appropriate material for dry formulations. Typically, patch materials should not require pre-extraction to remove substances that interfere with residue analysis. This should, however, be determined before beginning exposure tests using such patches. Patches should be approximately 1mm thick and backed with an impermeable material such as aluminium foil, polyethylene or glassine paper. These materials will reduce the potential for contamination of the patches by materials on the skin or clothing and prevent seepage of collected residues through the patch to the skin or clothing. Multi-layered patches are not considered to be suitable for determining penetration. Instead, evaluation of penetration of work clothing should be conducted using inside and outside patches, as described below. Patches should be constructed or used in multiples per sampling location so that the exposed area is approximately 10cm x 10cm (100cm^2). The use of smaller patch areas is generally inappropriate and should be avoided.

Each patch dosimeter is a sandwich holding a passive matrix (like a cotton gauze sponge) flat and to protect it from skin perspiration. Either one or two sets of patch dermal dosimeters can be used. The most important is the set placed against the skin under the clothing. It is believed that errors will result from using patch dosimeters attached to the inside of clothing that is free to move relative to the skin; such dosimeters will neither collect contaminants reaching the skin via penetration through openings (such as the neck, sleeves, or cuffs) nor be affected by the air motion carrying contaminant through the weave of the fabric. A second set of dosimeters may be placed outside of any clothing; it is also important that no inner dosimeter is placed beneath an outer dosimeter.

It is implicit in any use of dosimeters that the chemical to be assessed is stable on the matrix, that it can be efficiently extracted, and that there is no background or interference with its analysis. While such assurance should be established before sampling, field spikes prepared

from spiking solutions and field blanks are usually prepared, handled and analysed at about a 1:10 ratio with field samples to further assure dosimeter accuracy for the particular compound.

12.4.2 Location and attachment

Dermal patch dosimeters often consist of 8x8 cm or 10x10 cm 12-ply, square sponges, backed with four to six sheets of polyethylene; placing this sandwich in a commercially available protective aluminised paper envelope with a circular open collecting area is a convenient way to protect the dosimeter from mechanical damage and minimize cross contamination while handling. Such a 8x8 cm dosimeter would have a collecting area of 25.65 cm^2; a 10x10 cm dosimeter, 42.03 cm^2.

There are no standard procedures for attaching the dosimeters. Some examples are given below.

- One scheme for dermal dosimeters worn under normal work clothes is to pre-attach those for the torso and upper arms to a tight fitting T-shirt; those for the lower arms and legs to a pre-attached elastic bands with a Velcro release; and as an alternative those for the legs may be attached to net chaps.

- Dosimeters worn over normal work clothes are pre-attached to a 3.8 cm open net smock covering the chest, back, upper arms, and upper legs; those placed on the head, lower arms, lower legs may be pinned or attached via duct tape to the wearer's clothing.

- The dermal dosimeters are to be put in place before exposure begin and remain in place throughout the duration of exposure.

Patches should be attached, according to the exposure situation, to collect residues representative of those impinging on all regions of the body. Normally, a complete set for each exposure period will consist of 10 and 12 patches. Patches should be attached under the test subjects' clothing on the skin or to the inner clothing. The patches should not be attached to the inside of the outer clothing because these pads would not collect chemicals or residues penetrating through the openings of the clothing. Patches should be attached at the following locations: top of the shoulders, back of the neck just below the lower edge of the collar, the upper chest near the jugular notch, back of the forearms and front of the thighs and lower legs. Inside patches must be centred under seams as well as under un-seamed material, because seams are often the areas of maximum penetration. If the workers are engaged in some activity that is likely to result in extraordinary exposure to regions of the body that are not well represented by the usual patch locations, extra patches must be included to assess such exposure. If the determination of actual penetration of work clothing is desired in the field study, additional patches can be attached to the workers' outer garments. The use of multi-layered inside patches is not suitable. Care must be taken to ensure that any patches attached to the outer clothing are near, but not covered by, patches under the clothing. Patches may be attached to the skin using material such as surgical tape, which will hold the patches during vigorous activities. Patches may be attached to clothing using safety pins, staples or tape. Some investigators have utilised specially designed harnesses or lightweight vests fitted with open-fronted pockets to hold the shoulders, chest, and back patches. These

alternative attachment methods have been used successfully and are acceptable. The patches should be evaluated for potential contamination or losses from/to adhesives or holders.

12.4.3 Removal and handling

The procedure for handling exposed patches will depend on the stability of the chemical(s) being studied. If the pre-field study results indicate that the chemical is stable on moist exposure patches, then the patch should be placed in a pre-labelled protective envelope or bag in a manner that avoids both cross-contamination with its holder and residue loss from contact with the envelope. All bags containing exposed patches from one exposure of a single test subject should be grouped together. Care should be taken to not contaminate the patches in handling. If the pre-field study results indicate that the chemical is unstable, the investigator needs to provide a method of handling the patches that is documented prior to the study.

12.4.4 Storage

Samples should be stored in a manner that will minimise deterioration and loss of collected chemical between collection and analysis. The study investigator is responsible for demonstrating the stability of the samples under the storage duration and conditions used.

12.4.5 Analytical methods

Validated methods of appropriate or sufficient sensitivity are needed for all sample analyses. It is implicit in any use of dosimeters that the chemical to be assessed is stable on the matrix, that it can be efficiently extracted, and that there is no background or interference with its analysis. While such assurance should be established before sampling, field spikes prepared from spiking solutions and field blanks are usually prepared, handled and analysed at about a 1:10 ratio with field samples to further assure dosimeter accuracy for the particular compound.

12.4.6 Data presentation

Individual body locations and total residue data should be reported in tabular form. The residues should be reported as μg or mg of chemical per surface area basis (i.e. normalised on patch sample surface area; μg/cm² or mg/cm²). Distributional data should be provided, to the extent possible.

12.5 Data acquisition and analysis

After dosimeters have been in place throughout an activity involving exposure, they are carefully prepared for extraction (the quantitative removal of the chemical from the collection matrix) and analysed for the mass of chemical. The resulting measured levels of contaminant can be used in several ways. Most of the following calculations would apply equally well to pads placed either outside of clothing or inside. Various calculations can be made to determine the deposited chemical (mg) and perhaps the dose density (μg/cm2) and the dose rate (mg/hr).

The first example is to calculate the dermal deposition density. To do this, the total mass of contaminant found during analysis, is divided by the surface area of the pad(s), at each body location.

$$\text{Dermal deposition density } (\mu g/cm^2) = \text{Chemical mass} \div \text{Dosimeter area}$$

To calculate someone's total dermal deposition, it is necessary to assume that the deposition density on the local body part is accurately represented by the deposition density measured on the dosimeter. A set of standard body surface areas is typically used. Such an assumption allows the local dermal deposition to be calculated by the following proportion:

$$\text{Dermal deposition (mg)} = \text{Chemical mass x (Anatomic area} \div \text{Dosimeter area)}$$

The validity of this assumption can be qualitatively judged based on observation of the setting. There is as yet no quantitative test for deposition uniformity. A semi-quantitative test for deposition uniformity. A semi-quantitative judgment can be made by comparing the proportion of dose measured at each location among different users dong nominally similar tasks. Some variation is expected in both the distribution and total of all locations.

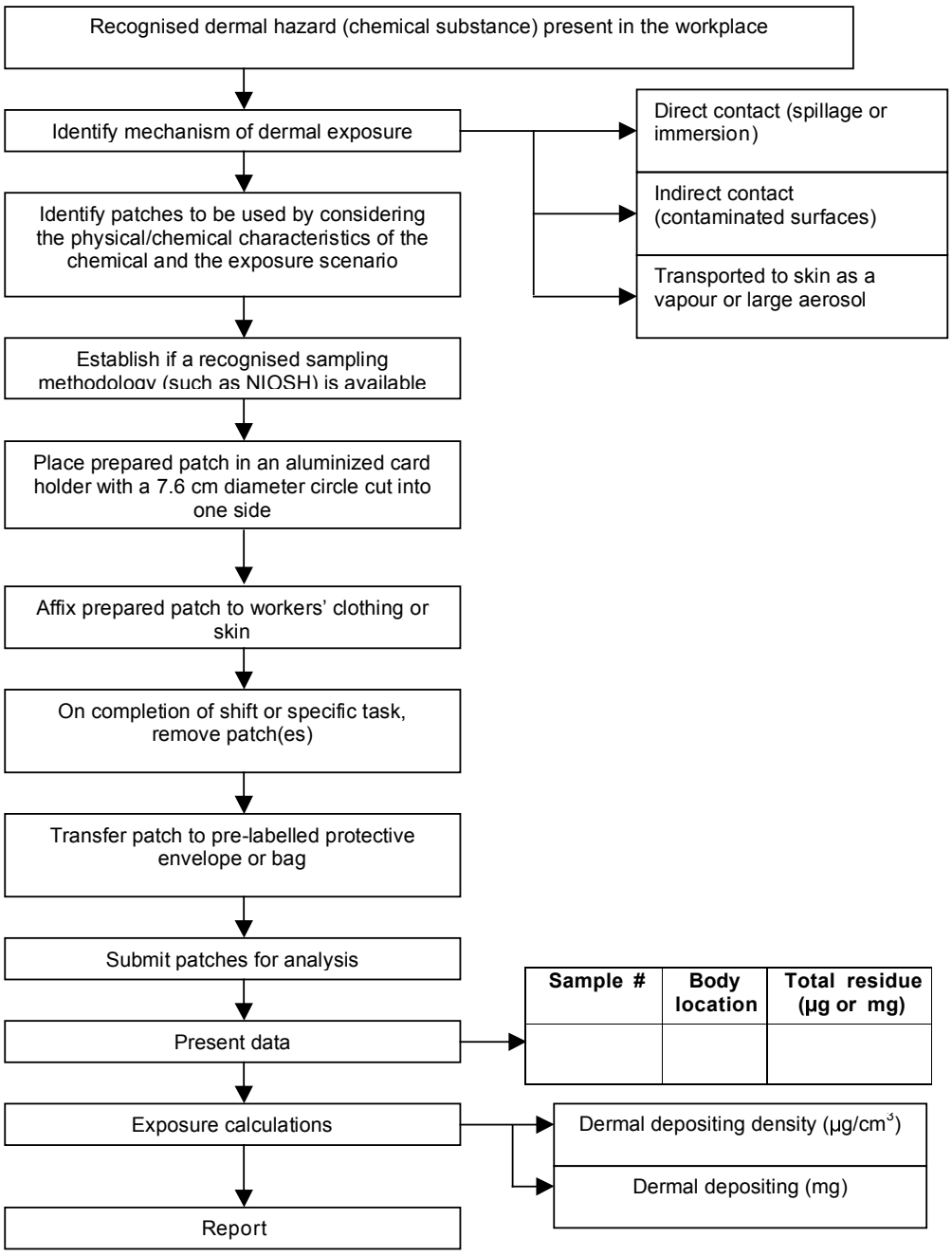
If dosimeters were only placed outside the clothing, then an assumption would also need to be made as to how much of that "potential dose" would have penetrated the worker's clothing. The inter-location distribution of the dermal dose will allow one to interpret the impact of hypothetical changes in work practices or protective clothing on the user's total dose. It is also only at this stage and beyond that the set of dermal deposition at each location can be meaningfully added to yield a total.

One additional common step is to compare the dermal dose to the airborne dose. This comparison can include adjustment factors for both dermal adsorption and/or for respiratory retention that which is usually also well less than 100% either for particles (where the site of deposition and retention varies by particle size) or for gases and vapours (where retention varies by chemical).

As with all other approaches to assessing dermal exposures, there are limitations to the use of dermal dosimeters. Among the most important of these limitations (not restricted to dermal dosimeters) is the difficulty in accurately collecting depositions of volatile chemicals. An alternative type of pad was designed to retain a high fraction of volatile chemicals, either agricultural or industrial; but adjusting dermal measurements for ambient vapours complicates its use. In order for a pesticide to be efficacious for a long time, volatile pesticides are rare.

12.6 Dermal exposure sampling

Figure 1 depicts a summary of the said evaluation procedure.



12.7 Reports

During application, the Field Investigator should record information on

- the site: its location, indoors or out, amount of product used, type of equipment being used.
- the environment: temperature, humidity, air velocity and direction with respect to applicator and work, exposure time,
- the clothing worn: work clothing (coveralls, jacket, hat or cap, etc.) and protective clothing (gloves, goggles, face shield, respirator, etc.), and
- any occurrence of visible skin wetting or saturation and the surfaces and approximate areas involved.

This information must also be contained within the report.

Individual body locations and total residue data should be reported in tabular form in the results section of the report. The residues should be reported as µg or mg of chemical per surface area basis (i.e. normalised on patch sample surface area; ug/cm² or mg/cm²). Distributional data should be provided, to the extent possible.

All the findings of measurements must be recorded. Reports serve many purposes e.g. communication, triggering an emergency and (very important) an input to risk management. Whatever format the reports, it must be easily accessible to employees, their representatives and to inspectors.

Appropriate systems should be put in place to ensure that the results and findings of occupational hygiene surveys are reported to management and to the Occupational Medical Practitioner. Adequate information should be kept to enable reporting on the management of occupational health risks and the reporting on occupational hygiene surveys must enable management to take appropriate and preventative action.

12.8. Bibliography

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5. NIOSH Analytical Method No. 9201 Chlorinated and Organonitrogen Herbicides (Patch). NIOSH, USA.

Appendix A: Example procedures

Chlorinated or Organonitrogen Herbicides (agricultural pesticide)

NIOSH 9201

Equipment

- Dermal patch

  (Polyurethane foam (PUF) pads, 10 x 10 cm, 3 to 4 mm thick)

- Passive exposure

  Place pad in an aluminised card holder with 7.6 cm diameter circle cut in one side.
  Affix to worker's clothing or skin

Made of polyurethane (PUF), these specially cleaned squares are available in a medical-grade aluminised holder or individually for attachment to clothing or skin for the sampling of herbicides according to NIOSH Method 9201.

Figure 2: SKC Dermal PUF Patches for Chlorinated or Organonitrogen Herbicdes

Analysis

- After sampling, transfer pads to 120 ml wide-mouthed glass jars with PTFE-lined caps
- Desorbed patch with 40 ml isopropanol
- Analyse by gas chromatography, electron capture detector (GCECD)

13. Surface Contamination

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13.1 Purpose

To assess surface contamination on the skin, work surfaces, and PPE surfaces (e.g. gloves, respirators, aprons, etc.).

13.2 Principle

Where inadvertent ingestion or skin absorption of hazardous chemical substances could be a significant exposure route, sampling techniques and strategies should always take into consideration the potential for the worker to be exposed through handling contaminated equipment, wearing contaminated clothing and touching contaminated surfaces. Dermal exposure normally occurs by one of three pathways, namely immersion, deposition or surface contact. Surface contact occurs when the skin touches a contaminated surface. This can be a major source of skin exposure, particularly during cleaning and maintenance operations. Transfer of these residues to other parts of the worker's body and to other surfaces in the workplace exacerbates the problem.

Skin exposure to chemicals in the form of liquids and dust is a daily occurrence in many industries. Chemicals have the potential to cause skin damage, which results in dermatitis, while some dusts may mechanically irritate the skin. Although the skin is a very effective barrier, some chemicals can be directly absorbed through this route. Also, dust may be indirectly ingested or inhaled, particularly if work-clothing contamination becomes severe. Biological agents have a wide range of health effects and are outside the scope of these methods. A strategic approach is therefore essential for controlling occupational skin exposure.

There are no health-based occupational exposure limits for skin exposure and therefore a judgement has to be made concerning the potential for health damage based on information from various sources. Product labels may give an indication of whether a chemical is hazardous to the skin.

Wipe sampling is an important tool of worksite analysis for both identifying hazardous conditions, and in evaluating the effectiveness of personal protective equipment, housekeeping, and decontamination programs. As described below, wipe sampling is an important tool for assessing compliance with certain legal requirements even though there are few specific criteria for acceptable surface contamination amounts.

The terms wipe sampling, swipe sampling and smear sampling are synonyms that describe the techniques used to assess surface contamination on the skin, work surfaces, and PPE surfaces (e.g. gloves, respirators, aprons, etc.) The term "wipe sampling" will be used in this chapter.

13.3 Methodology

The surfaces that should be monitored are

- those frequently touched by workers,
- those that may come in contact with food or other materials ingested or placed in the mouth,
- those where cross-contamination can occur, such as canteen tabletops and office desktops,
- those where workers change in and out of their clothing, and
- the surfaces in 'clean' and 'dirty' changing rooms.

Surface monitoring should be targeted at substances/processes for which ingestion/skin absorption is potentially significant. The data collected from surface monitoring must be normalised to the specific area as accurately as possible. Sampling should in the first instance be focused on surfaces that can be easily sampled. However, surface characteristics such as porosity or impermeability, smoothness or roughness and the presence or absence of moisture will have an effect on the efficiency of the sampling, and professional judgement will have to be applied. Sometimes it may be necessary to sample unsuitable surfaces because they are regularly touched. If so, suitable allowances should be made.

The measurement of surface contamination can be an effective way of showing that a cleaning or segregation policy is working. Also, surface monitoring can be used to promote improved standards of housekeeping and hygiene in the workplace and help reduce workers developing skin problems.

13.4 Classification of work areas

13.4.1 Controlled work areas requiring PPE

These are areas where it has been determined (e.g. from an employer's risk assessment) that PPE is necessary to prevent dermal exposures to a surface contaminant in spite of an aggressive, yet feasible cleaning regimen. Many production areas and specific job tasks fall into this category. Dermal exposure to contaminants such as mercury, nickel and soluble platinum is preventable through the correct PPE.

Wipe sampling can be used in assessing the effectiveness of the PPE program. Many elements of PPE programs are intended to prevent contamination to certain locations, such as the use of gloves to prevent contamination to the skin of the hands. Surface contamination found in those "protected" locations usually indicates a problem with the program. For example, the presence of surface contamination inside a glove is normally the result of either PPE failure (e.g. the contaminate soaked through the glove material or a tear in the glove), and/or an improper work practice for using the PPE, such as the worker inserting a contaminated hand inside the glove. Additional sampling and observation can be used to determine the specific source of the program failure and possible abatement (e.g. changing gloves more often, checking for tears before donning, cleaning hands before donning, etc.).

Sampling after abatement measures are implemented can be used to show the effectiveness of abatement.

It is important to recognise that this sampling is not attempting to assess the health risk resulting from the contamination inside the glove; rather, it is to identify failures in the PPE program. Therefore, the criteria for concluding that contamination exists do not have to be quantitative. Criteria and reproducible procedures should be selected in such a way that they provide confidence that contamination has been adequately controlled, i.e. contaminant levels are below background levels. The use of wipe pads that change colour upon contact with the contaminant is ideal both in locating contamination and as a visual tool in training workers on the consequences of poor work practices.

13.4.2 Controlled work areas requiring special cleaning

Wipe sampling in these areas can show that a feasible and practical regimen of special cleaning and/or decontamination precludes the need for PPE or additional cleaning. The cleaning of lunchroom tables and the decontamination of equipment before being removed from a restricted area are examples of this category. Other examples include cleaning surfaces to reduce accumulation of toxic materials (e.g. asbestos, lead, and beryllium) that may become re-suspended in air and thus contribute to airborne exposures.

Wipe sampling is used in these areas as a quality control test of the specialised cleaning (or decontamination) regimen. Therefore, samples are taken to assess contamination levels of those surfaces for which the special cleaning is required. Samples found in excess of an acceptable, task-specific, surface contamination limit indicate a failure in the cleaning or decontamination program. More aggressive training and supervision of the cleaning procedures and/or scheduling may need to be implemented.

Again, it is important to recognise that this sampling is not attempting to assess the health risk resulting from the contamination. Rather, it is to ensure that the cleaning and decontamination regimen is being effectively implemented. Establishing an acceptable contamination limit will depend on the purpose of the cleaning, and what is feasible for the procedures utilized. For example, periodic vacuuming of floor surfaces in a lead production area may be used to reduce the amount of lead dust available for re-entrainment, but significant lead contamination of the floor would still be expected. An acceptable surface contamination limit for this type of cleaning would be set much higher than a limit used to evaluate cleaning of tables in the break room.

13.4.3 Non-controlled work areas

These are work areas for which no special cleaning or PPE are required by the Safety and Health Program. Examples of this category are office areas that are physically separated from the production areas. These areas are often “assumed” to have no significant contamination. Wipe sampling is useful in demonstrating the lack of contamination. If samples do show contamination, further investigation would be needed to determine the cause. Consistent positive results would require a re-assessment of whether the area requires controls.

As with sampling to evaluate PPE programs described above, procedures and criteria for sampling non-controlled areas need to provide confidence that contamination has not occurred (i.e. surface concentrations are not above background). Again, the use of wipe pads, which change colour upon contact with the contaminant, is ideal. The "direct reading" capability makes it possible to quickly screen an entire work area (and a single pad may be used for multiple locations within the area).

Sampling should be aimed at those locations within the non-controlled area that accumulate dust (e.g. tops of filing cabinets) and surfaces that have potential for contamination from production areas (e.g. paper work brought in from the production areas).

Additional surfaces to consider for sampling include those that may come into contact with food and other materials that are ingested or placed in the mouth (e.g. chewing tobacco, gum, cigarettes).

13.5 Sampling techniques and procedures

The methods described in this section are not "reference" methods as current international classification of sampling methodologies do not address or include surface sampling. There are however several invalidated methods available for the sampling of surface contamination that are deemed acceptable.

A location for the assessment of surface contamination should be chosen using the scenarios listed below.

- On-site activities that generate sufficient airborne particles that deposit on surfaces, or cause spillage, or other forms of direct contact occurring, or the location is regularly and frequently associated with liquid handling.
- The location could be a potential dermal contact site, e.g. work bench, tables, drinking machines, showers, changing rooms, tea making facility, tools, door handles and taps.

Individual sampling locations should be sufficiently large to accommodate a sample area of 5 cm^2 for the wipe sampling method. The size of the sample area, i.e. at least 5 cm^2, is based on research in the field of surface contamination evaluation. However, as long as the sampled area is accurately known, it does not have to be fixed. What is important is the representativeness of the area sampled.

The methods described in this chapter are suitable for the sampling of surface contamination from a variety of surface types found in the workplace.

Porous surfaces such as unsealed wood and concrete can provide highly inaccurate results when sampled. However, it is the removable fraction that is of significance. Therefore, if it is an 'important surface', then it should be wiped and the results will be > 'x', x being the measured value. If a surface is rough and likely to be contaminated, consideration should be given to replacing it with one that can be easily cleaned, or it should be covered.

The efficiency and variability of surface sampling can be affected by a number of factors, namely

- concentration and particle size distribution of the surface contaminant,
- surface roughness and porosity,
- area of surface sampled,
- wipe pressure,
- collection efficiency of the sampling media, and
- recovery efficiency from the sampling media.

The first two are site-related and should be dealt with by the sampling strategy. The second two should be standardised to reduce variation. The last two need to be established by sampling known levels of contamination.

Professional judgement has to be applied when sampling from rough and porous surfaces and the reasons for sampling from these surfaces should be documented.

13.6 Surface sampling

The contamination on a known area of surface is removed by one of the methods and then analysed for quantity and composition.

Of the various techniques used for sampling surface contamination, the wipe and adhesive sampling methods are most commonly used. The wipe sampling method involves using a suitable absorbent but resistant medium, such as 'absorbwipe'. The wipe is drawn across a known area of contaminated surface and then sampled, releasing some of the contamination. The adhesive sampling method involves a medium such as adhesive tape. The adhesive tape is pressed onto the contaminated surface. Both materials are then analysed to produce an assessment of the level and nature of the deposit.

(a) Reagents

Wipes can be moistened with distilled water or a suitable solvent such as methanol, ethanol, isopropyl alcohol or trim ethylpentane (iso-octane). The amount of water/solvent used should be enough to make the wipe wet and not merely damp.

Suitable wipes are listed below

- Glass fiber filters (GFF), 37 mm in diameter as used in air sampling, are recommended for many chemicals that are analysed by gas chromatography (GC), or high-performance liquid chromatography (HPLC). These may be used dry, or wetted with an appropriate solvent.
- Paper filters are generally used for collection of metals. Mixed cellulose ester filter discs or smear tabs, or their equivalent, are most often recommended.
- Polyvinyl chloride filters are available for substances which are unstable on paper-type filters.
- Charcoal-impregnated pads may be used for collection of volatile solvents from surfaces. They work by trapping the solvent on activated charcoal, similar to air sampling charcoal tubes.

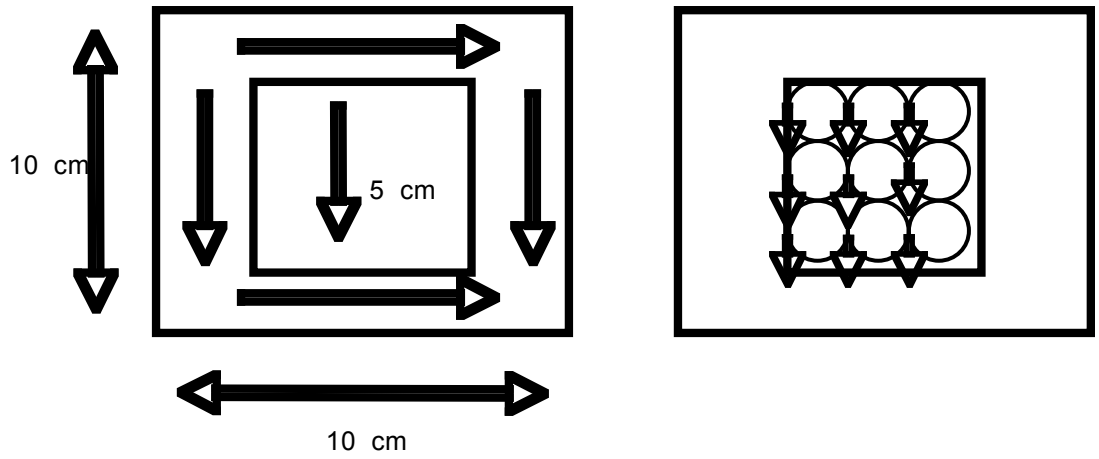
(b) Sample pattern

A surface area of 10 x 10 cm should be chosen as the region from which a sample is drawn. A consistent sampling area should be maintained by use of a window-like template. The template should be cleaned prior to sampling. When wipe samples are taken from discrete objects, such as taps, a consistent wiping pattern should be employed.

The wipe material should be removed from its storage bag just prior to use. Disposable gloves should be worn when handling the wipe material to avoid contamination or excessive skin contact. Pre-moistened wipes are ready for use. Dry wipes must be moistened with at least one millimeter of distilled water/solvent before wiping the surface.

Taking the wipe between the fingers and thumb, the same pattern of wiping should be consistently adhered to, applying maximum operator pressure. A possible wipe pattern consists of wiping once round the edge of the sample region in an anti-clockwise direction and then wiping across a number of times in parallel. The wipe material should be folded in half two times and the region wiped again using a motion consisting of nine consecutive circles (Figure 13.1).

Figure 13.1 Wipe sampling pattern



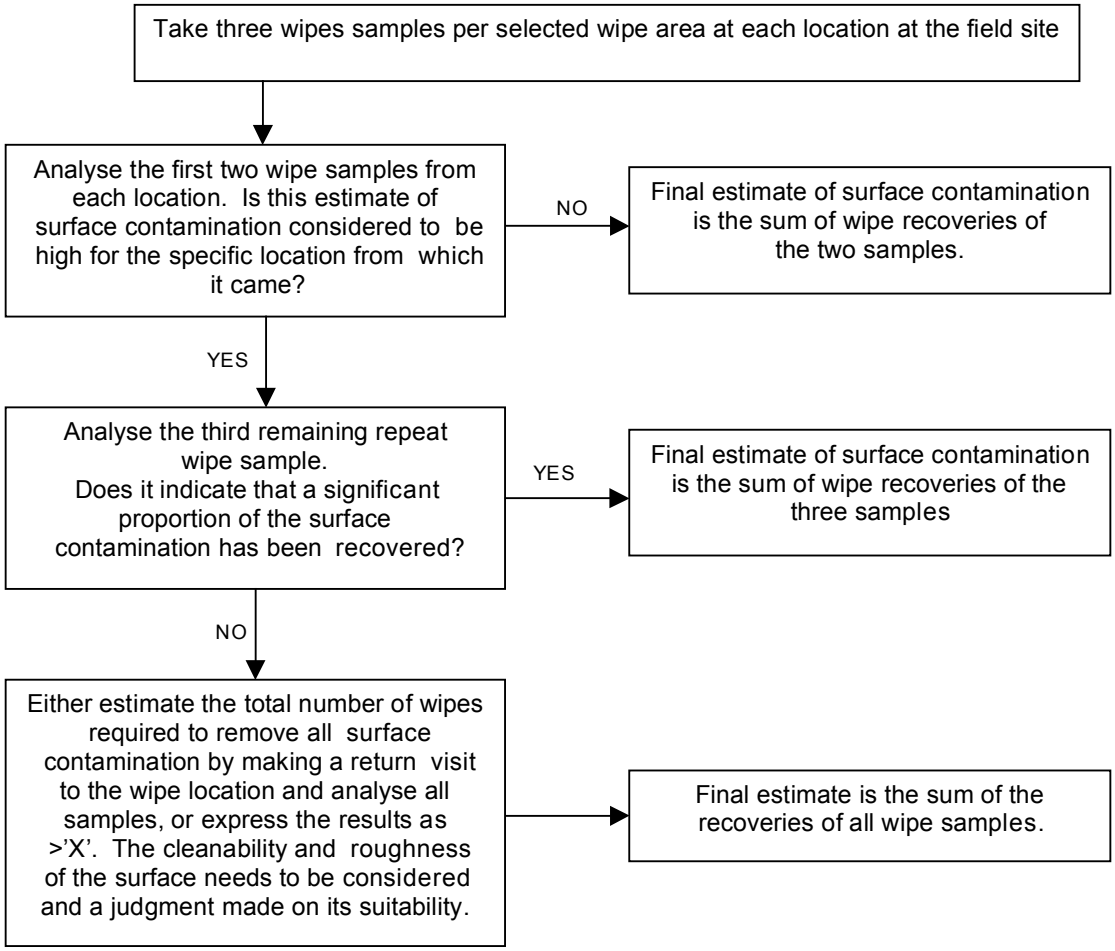
A total of three consecutive wipe samples should be taken at the same location. Initially only the first two wipe samples need be too analysed. If it is found that the second wipe sample is 50% or less than the first wipe sample taken, then the third wipe sample does not have to be analysed. If the second wipe sample has a similar concentration to the first or greater than 50%, then the third wipe sample will have to be analysed. In areas of high contamination it is essential that a third sample be taken, as the first two may become saturated. The final estimate of contamination on the surface is the sum of the first two wipes.

In extreme contamination, it may be necessary to take even more than three wipe samples. It is important to consider whether the estimated concentration of contamination on the surface, after the analysis of the three samples, is feasible. If it is feasible, then the concentration on the surface is the sum of the three wipe samples. However, if the second and third wipe samples are all similar to the first, further sampling could be required.

If a return visit has to be made to wipe a surface, care should be taken to avoid the areas originally wiped, while sampling as close as is practical to the original site.

The samples can now be sent to the laboratory for analysis (see Figure 13.2).

Figure 13.2 A strategy for wipe sampling liquid residue surface contamination



13.7 Skin sampling

Techniques and media for wipe sampling of skin contamination vary with the agent and purpose of the sample. It is important to appreciate that there are concerns related to direct wipe sampling of the skin, including the possibility of promoting skin absorption with the use of certain solvents.

Before any skin wipe is taken, explain to the particular employee why you wish to sample his skin and ask the employee about possible skin allergies to the chemicals in the sampling medium or wetting solution. Employees may elect not to allow sampling of their skin. As an

alternative to direct skin sampling, an indirect measurement of skin contamination as well as PPE failure, can be assessed by wipe sampling surfaces that workers can touch e.g. table tops, handles, control knobs or the inside surfaces of protective equipment.

Classic wipe sampling techniques, as described earlier, employing glass fibre filters, mixed cellulose ester filters or smear tabs, or gauze squares, charcoal impregnated pads, may be used for sampling contaminants on the skin. If it is deemed desirable to moisten the collecting medium to improve collection efficiency, procedures will normally utilise either de-ionised water, or 50% solution of isopropyl alcohol in water.

Hand washes may be appropriate in some cases. Twenty millilitre of distilled or de-ionised water, or a dilute solution of mild soap, may be added to a zipper-style sandwich bag. The hand to be sampled is inserted, and the bag held tightly closed around the wrist. After a few seconds of agitation, the hand is carefully removed, and the wash solution is poured back into a scintillation vial for shipment to the laboratory.

13.8 Storage and transportation

(a) Sample storage

The adhesive samples should be carefully removed from the contaminated surface, if necessary with the aid of a pair of tweezers. Once removed from the contaminated surface, the sample should be stored in individually labelled clean containers. The wipe samples should be folded over on themselves. The individual samples should be stored in individually labelled clean containers. Glass, screw-topped vials are suitable. Once firmly sealed in the vials, the samples will not degrade. The sample identity and all relevant sampling data should be carefully recorded.

(b) Personal protection: hands

When surface sampling for particle/dust or liquid contamination, care should be taken to avoid cross-contamination from the hands. Nitrile or other suitable non-absorbent gloves should be worn.

(c) Transportation

Surface wipe material should be transported to the laboratory in a container which has been designed to prevent damage to the samples in transit and which has been labelled to assure proper handling.

(d) Sample analysis

Validated methods of appropriate or sufficient sensitivity are needed for all sample analysis. In practice, recognised analysis methodology should be applied by an accredited laboratory.

13.9 Evaluation of sampling results

Surface sampling results should be interpreted carefully and competently. The main interest is the level of contaminant (per unit area) on surfaces routinely touched by people. However, the investigator may also be interested in whether contamination has spread to areas outside production, for instance, to test the effectiveness of clean side, dirty-side changing facilities and procedures.

It is important to put surface sampling results in context. Where uptake of a potential toxic substance is the concern, inadvertent ingestion or skin absorption may be making a significant contribution to total absorption if control measures and training are inadequate. The proportionate contribution compared with other main routes of absorption, inhalation of airborne contaminant will vary with the substance and circumstances. Judgement will need to be made on a case-by-case basis.

13.10 Reports

It is vitally important that the findings of measurements are recorded. Reports serve many purposes e.g. communication, triggering an emergency and (very important) an input to risk management. Whatever format the reports, it must be easily accessible to employees, their representatives and to inspectors. Although the recording and reporting of occupational hygiene measurements is important, the generation of a paper system is not. The documentation system should not detract from the major purpose of the measurements; that is, to improve the management of risks and thereby ensure the health and safety of employees.

Appropriate systems should be put in place to ensure that the results and findings of occupational hygiene surveys are reported to management and the Occupational Medical Practitioner. Adequate information should be kept to enable reporting on the management of occupational health risks and the reporting on occupational hygiene surveys must enable management to take appropriate and preventive action.

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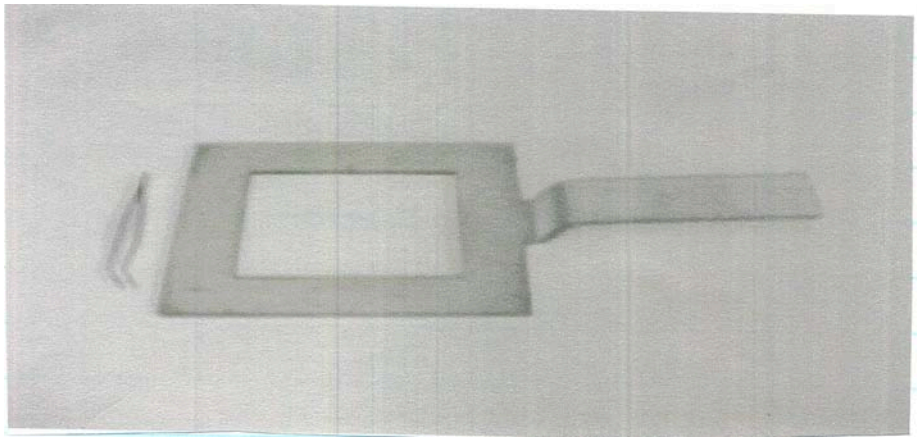
Appendix A: Example Procedures

Soluble platinum

Equipment

- Whatman 540 ashless paper
- Distilled water
- Wipe sample template (100 cm³ surface)
- Tweezers
- PPE (cotton & rubber gloves, FFP2 particulate mask)



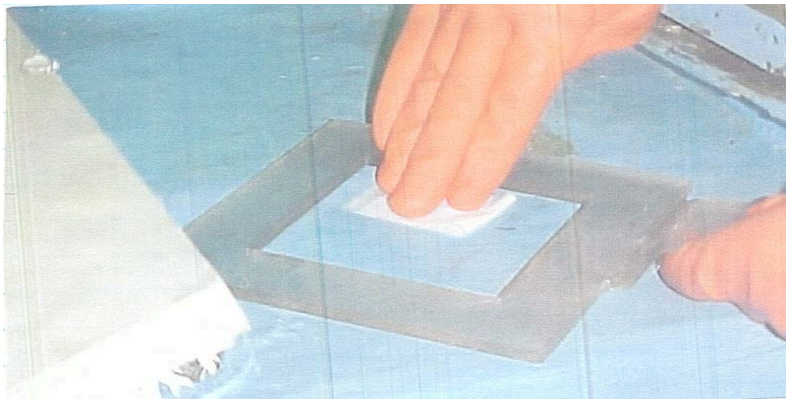
Wipe sample template with 100 cm² sample grids.

Procedure

- The whatman paper is cut into narrow strips (40 mm x 100 mm) and moisten with distilled water.

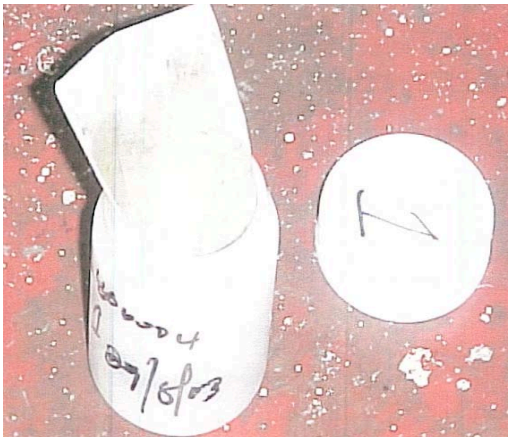
Moisten Whatman paper strips

- The moisten filter paper is then used to wipe inside the surface of the template.



Sampling in progress

- The used filter paper is then sealed in a sample bottle and sent to the laboratory for analyses.



Sample is placed and sealed in a container

Sample analysis

- Soluble platinum is leached in 0.007 molar Hydrochloric acid by allowing a suitable sample to stand at room temperature for twenty minutes.

- The platinum content of the filtrate is then determined by ICP.

14. Stack Emissions and Isokinetic Sampling

Author: Dave Unsted, Consultant.

14.1 Introduction

Stack emissions generally may not be seen in terms of an occupational hygiene problem. However, when it is considered that the discharge from a stack may return back to ground level within the mining/plant operation's boundary (or back to ground level on a neighbouring property), and re-enter the working environment the link can more readily be made.

Particulate contaminants include dust, fume, mist and smoke. Small particles will not settle from the air (particles that are of a diameter of less than 30 to 40 micrometers). On the other hand, large particles will settle from the air unless the conveying velocity of the air in the system overcomes the gravitational attraction of these particles.

These sources of contaminants include smelters, fuel burning equipment, incinerators, ferrous cupola foundry operations, chemical and mineral kilns, asphalt paving plants, cement manufacture, iron ore palletising, fertiliser plants, and exhaust systems serving material handling equipment

Toxic contaminants in the air being exhausted from some process in a plant can present potential hazards to the plant and neighbouring property and community. The presence of an atmospheric inversion (a cold layer of air blanketing the ground and preventing the rise of pollutants to the upper atmosphere and subsequent dispersion) may result in a potential hazard. Even though only small quantities of the contaminant may be released and normally diluted by air movement in the atmosphere, they may become "locked into" low levels above the ground and in this way become a potential problem. Under severe temperature inversion conditions a plume can travel long distances without gaining height and with only little dissipation.

Generally, toxic contaminants require high air cleaner efficiencies at the particular or relevant process in the plant to prevent any potential hazard arising from discharge into the atmosphere.

Stack testing, or sampling, and performance testing refer to tests that provide a means to determine the concentration of emissions. Whereas modelling may provide estimates of the ground level concentration some distance from the point of release, stack testing is a direct measurement of emission concentration at the point of release.

Apart from the need to establish emission levels there are other reasons to conduct duct or stack sampling. These include:

7. Performance and efficiency of emission control equipment
8. The need for emission control equipment.
9. Discharge of product of economic interest

While the test may be manpower and equipment intensive, the results of tests may be of significance to both the regulatory authority and the mine or plant (source). The results often determine a course of action and it is therefore important that the test be performed in a valid representative manner. The complex nature of the various sampling methods place a responsibility on testing personnel to ensure that each test is an accurate representation of a source's actual emissions.

14.2 The Effects of Air Pollution

The presence of air pollution can result in many harmful effects. Among the most important of these effects are

Health Effects. It has been claimed that cancer is related to industrial pollutants. Although the accuracy of such statements may be questionable, there are documented cases where acute air pollution has resulted in excessive deaths. Certain chronic effects have been studied. These studies appear to indicate that a cause/effect relationship between air pollution and health does exist. Further studies are being conducted. It is likely that this subject will be controversial for 1. quite a while. Nevertheless, bronchitis, other respiratory disorders, asthma, allergies and general feeling of ill health are claimed to be the effects of exposure to airborne pollutants.

Community Relations. Excessive air pollution can be harmful to community relations for the industry involved. The workers may react to the dangers that threaten their families' health if they live in the immediate area. Airborne pollutants can soil washing on a line and also be deposited on clean vehicles and even cause damage to vehicles. Community groups may form to put pressure on the management concerned to reduce the amount of pollution present. In addition, the public relations image obtained by the operation may be harmed.

Property Damage. Observations in a heavily industrialised area can indicate damage to property that can occur as a result of air pollution. The economic effects of this damage are difficult to determine. Equipment may have a shorter operating life because of corrosion caused by pollution. Buildings may need to be cleaned more often and exterior surfaces may be subject to excessive ageing.

Plant Life. Studies on the effects of air pollution on various types of plant life have been conducted and a direct cause and effect relationship discovered for certain types of pollution.

Animal Life. As in the case of health factors affecting humans, certain acute pollution problems have been shown to exist in animals. As part of the natural food chain pollutants that affect plant life are often carried over to animals and thus to humans. The chronic effects of this type of transfer are not yet well known or understood.

If the discharge of noxious or offensive gases or particulates cannot be prevented then it is important to render these harmless and inoffensive. One way of achieving this is by suitable dispersion from a tall stack.

14.3 Determining the extent of stack emissions (air pollution).

There are two methods that are available to determine the extent of air pollution. The first method concerns the measuring pollutant concentrations in the ambient air to determine the extent and dispersion of pollution in the surrounding area. This aspect will not be addressed here. (See chapter on particulates).

The second method to determine the extent of the pollution is to measure the pollution that is resulting from a single source, for example a stack. This provides information concerning pollution that may be being discharged from a plant or operation into the atmosphere. Here again there are two methods of doing this. Duct velocity may be measured and the sampler velocity adjusted to the isokinetic velocity. Or a null-balance probe can be used to match the static pressures, thereby matching velocities without measuring duct velocity.

14.4 Isokinetic sampling

The determination of particulate concentrations in a stack requires particulate matter inside the stack to be withdrawn isokinetically from the source and collected on solid filtering media. Isokinetic testing refers to taking a sample in which a representative sample of the gases and aerosols in that portion of the gas stream being tested is obtained by withdrawing it from the host stream in the stack at the same velocity as the stack gas. The sample is drawn into a probe at the same linear velocity as the gas flowing at that point. Under such conditions that there is no change in particle momentum, so that the sample will be representative.

After the sampling is completed, the particulate mass collected on the filter is determined by mass, or gravimetrically.

Stack gas parameters are very important in the selection of the appropriate test method. There are two methods of sampling viz. out-stack and in-stack. The principle of out-stack testing is that the particulate matter is withdrawn isokinetically from the source and collected on solid filtering media maintained at a temperature in the range of 120 ± 14°C. A reference point of 120°C has been established based on the chemical and physical characteristics of particulate matter. The rule of thumb for selecting the appropriate method is that when the stack temperature is below 120°C, then the in-stack testing method can be used. If the stack temperature is above the reference point or high stack moisture exists, then the out-stack method is used.

14.5 Equipment (sampling train)

The various components for isokinetic sampling are seen in Figure 14.1.

14.5.1 Method

The place where the sample is to be taken must be determined. It may be taken in the exhaust system ahead of and close to the fan or it may be taken elsewhere in the stack. The sampling position selected will depend on the particular situation involved. In some cases it may be difficult to sample at the “ideal” site, in which case an alternative site will have to be used.

The next step is to determine the velocity of the gas stream travelling within the duct or in the stack at the desired measuring point. A Pitot tube is usually used for this purpose. Using the average velocity obtained and a measurement of the diameter of the duct or stack the rate of flow at which the pollutant is entering the surrounding atmosphere can be determined.

A determination should be made of the pressure, gas, temperature and moisture content that are present in the emission at the test site. These factors will affect the rate of flow if significantly different from standard conditions.

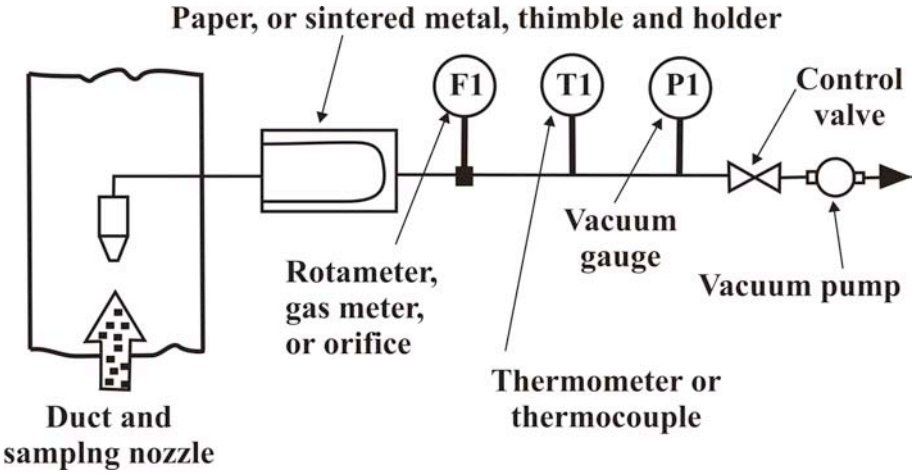


Figure 14.1 Schematic of isokinetic sampling arrangement

14.5.2 Pitot Measurements

(This section should be read in conjunction with the chapter on Pitot measurements).

Isokinetic sampling is attained by firstly traversing the stack or duct by means of a Pitot tube to obtain the air velocity profiles. A special type of Pitot tube, Type S, has been developed for use in very dusty air/areas where a standard Pitot will not function satisfactorily. The Type S Pitot tube has enlarged static pressure and total pressure holes that greatly reduce the tendency of these holes to block in a dusty atmosphere. The static holes are sometimes replaced with slots. This Pitot tube gives higher readings than a standard tube and therefore requires a correction factor, supplied by the manufacturer.

Velocity is not constant within a duct. Because of obstructions and because of the frictional drag that occurs at the sidewalls, the velocity contour is not fixed or uniform. Therefore, it is necessary to obtain measurements across the contour to obtain an estimate of the velocity through the system. The point of stable airflow in a duct system is 6 to 10 diameters or more downstream and two to four diameters upstream from any major disturbance. Any measurements of velocity pressure using a Pitot tube should be taken at these distances from any obstruction.

The procedure for conducting the Pitot traverse is to divide the duct into cross sections of small, equal areas (see chapter on Pitot tube)

A Pitot tube traverse is then conducted and gas stream velocities calculated. After calculating velocities, each velocity is multiplied by the area it represents and these individual flow rates, m3/s, are added to obtain the total flow rate.

14.5.3 Isokinetic Sample Collection

From a chart or software relating duct velocity, probe diameter and sampling rate, taking into consideration density differences in the stack and at the meter, the appropriate nozzle is selected whereby the sample will be withdrawn at the same rate as the flow in the duct. It is usual to sample at a rate that ensures that the fluid in the limb of an inclined manometer will fall at a convenient position on the limb, usually the midpoint. Alternatively, the operating position of a dial type gauge will also be at its relevant midpoint.

Suction to the probe is provided by a suitable vacuum pump. The sampling train usually includes a dry gas meter to indicate the total volume of air sampled from “before” and “after” readings. An electronic flow meter may also be used to give an airflow rate (ℓ/min) and when this is multiplied by the sampling time the total amount of air sampled can be calculated. This value can be compared with that obtained from the dry gas meter. Significant differences could indicate leakages in the sampling system which would cast doubt on the results. In addition to all the above equipment there is also some means of indicating the pressure differential over the sampling filter or pad. When the limit of pressure, according to the suppliers, is being approached, the filter media should be changed. Failure to take this action could result in a burst filter and consequent loss of sample. Where there are large differences in temperature between conditions inside the duct or stack and outside conditions condensation may take place in the probe. This will also result in the loss of the sample and can be avoided by wrapping the portion of the probe on the outside of the duct or stack with a heating tape, usually powered by an electric mains supply. (See also In-Stack Sampling above).

Particulate samples are then collected via a probe in the duct at each of the flow measuring points and the sampling rate adjusted to provide isokinetic sampling. The amounts are collected and weighed together in proportion to the individual flow rates found at the corresponding points.

Lack of equipment and personnel generally means that samples are collected successively from each sampling point rather than simultaneously. A single filter can be used for the entire sample collection the probe is simply moved to each sampling position and the sampling rate adjusted for each position.

The following should be recorded:

1. Time and date.
2. Sample location.
3. Sample collection rate
4. Sample pressure.
5. Sample temperature
6. Dew point
7. Plant operating conditions

8. Flow rates and variability
9. Production rates and variability
10. Pressures
11. Temperatures

The vacuum pump draws the particulate laden gas through the selected nozzle and through the filter medium – 55 mm diameter, 110 mm diameter filters with suitable holders, usually of the "quick-release" type or fiberglass pads. Before measurements begin an adequate number of filters should be prepared by drying them in their canisters together with the retaining screens, in an oven for 60 minutes at a temperature of 110°C, 5 °C, cooling in a desiccator and then weighing to an accuracy of 2 mg. A similar drying and weighing process is with the used filters to determine the mass of solids collected.

A cyclone separator may also be used ahead of the filter to remove large particles. A rotameter or orifice controls the flow rate through the probe and nozzle. The flow rate indicated on the rotameter, usually ℓ/min, can be converted to a gas velocity in the nozzle. This velocity is then matched to the velocity in the stack/duct and the flow rate in the nozzle adjusted until it matches that in the stack/duct. The sampling line is also equipped with a temperature measuring device (thermometer, thermo-couple, thermistor) and vacuum gauge. These devices are necessary for checks on sampling temperature and pump pressure. It is essential that the velocity of air in the sampling head matches that of the duct or stack – i.e. isokinetic conditions prevail. This may be accomplished by using a static balanced tube or probe, or, usually, by adjusting the sampling rate and nozzle size to match the gas velocity in the duct or stack. If these precautions are not taken and the duct or stack velocity differs significantly from that or the sampling equipment, then either too much or too little air will be sampled. Frequent checks by Pitot measurement and on temperature and pressure will indicate any need to adjust the sampling flow rate and/or the filter.

A dry gas meter (not shown in the figure) may also be used to measure the total volume of gas sampled. This can be used to check against the calculated flow derived from nozzle flow rate and time.

After the required sampling is completed the filters with their load and any field filters are transported in their designated containers for gravimetric and other analyses.

Even when precautions are taken there can be several reasons why the sample is not truly representative:

1. The probe always has a finite wall thickness that disturbs the flow.

2. The point sampled may not be representative of the whole gas stream.

3. If the flow is turbulent at the point of sampling there is no way to get a truly isokinetic sample. The sample will contain smaller portions of the larger particles, or sample may be lost by deposition or changed by agglomeration in the sample line before it enters the main sampling device.

It is known that failure to sample isokinetically yields inaccurate results which may vary from as low as half of the correct value if the sampling is too rapid, to as high as two or three times the correct value if sampling is too slow.

Unless the most elaborate precautions are taken and the sampling conditions are virtually ideal, it is not possible to measure the concentration of solids in the air stream of a stack to a better accuracy of five to ten percent. It is therefore rarely necessary to express the final result to more than two significant figures.

Notes on isokinetic sampling:

(a) Sample velocity and alignment are both important parameters
(b) Under isokinetic sampling conditions all particle sizes are collected efficiently
(c) Small particle sizes, under 3µm diameter, do not require isokinetic sampling for efficient collection since their small mass minimises inertial effects.

14.5.4 Null Method

Null Probe.

This probe is shown in Figure 14.2.

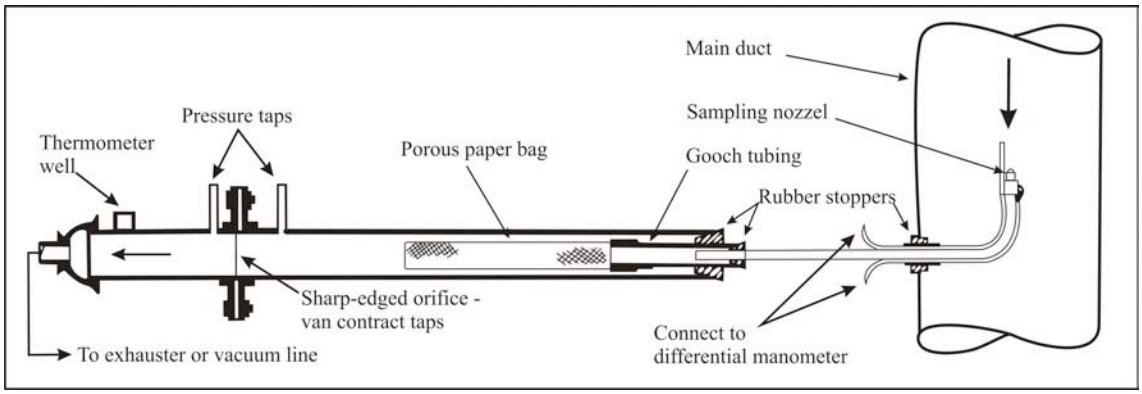


Figure 14.2 Null Balance Sampling Probe

In this method a null-balance probe is used to match the static pressures, thereby matching velocities without measuring duct velocity.

The location of static tappings on the probe, the probe shape, the difference in turbulence in proximity of the duct and probe tappings plus other factors affect the relationship between balanced static pressure and isokinetic flow. A null probe must therefore be calibrated. This can be done by comparing Vs (sample velocity) to Va (actual velocity inside duct or stack) at the sampling point. A fan testing column, a Pitot tube, the sampling train and flowmeter could be used for such a test.

The graph shown in Figure 14.3 shows a calibration of a null probe similar to the one shown in Figure 14.2. Note that these probes are not suitable for use outside a specific velocity range, which in this case should not be lower than 10m/s, as shown by the dotted line.

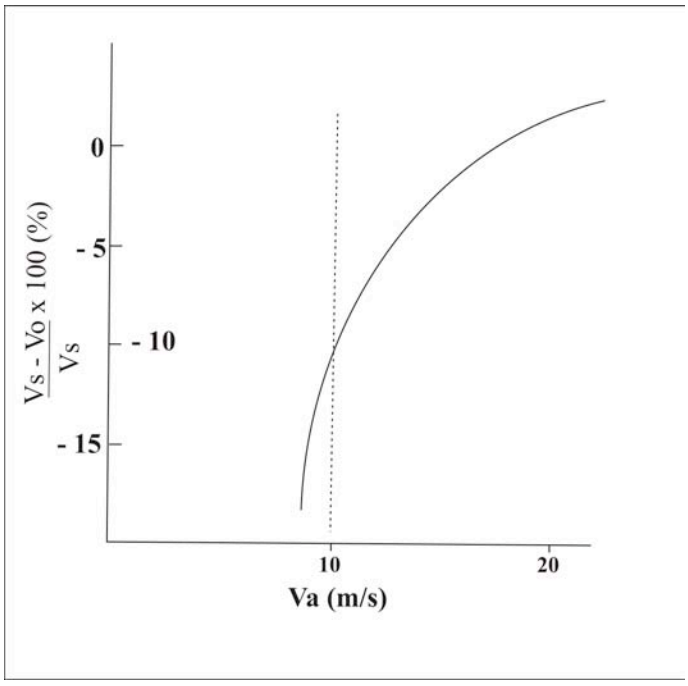


Figure 14.3 Relationship Between Sampling Velocity error and Free Stream Velocity

14.6 Planning and preparation

The quality and applicability of the test can be assured by taking a few preliminary steps and formulating a test plan.

A test plan is more than just specifying a test procedure. A complete test plan must include such items as sampling and analytical methodology, quality assurance procedures for sampling and analysis, source operating parameters, source parameters to be recorded, when the test will take place, and who will be present.

1. Identification and a brief description of the source to be tested. The description should include:
   (a) Type of industrial process or combustion facility.
   (b) Type and quantity of raw and finished materials used in the process.
   (c) Description of any cyclical or batch operations which would tend to produce variable emissions with time.
   (d) Basic operating parameters used to regulate the process.
   (e) Rated capacity of the process.

2. A brief description of any air pollution control equipment associated with the process, including:
   (a) Type of control device
   (b) Operating parameters
   (c) Rated capacity and efficiency

It is essential to study the test site prior to any sampling to ensure smooth operation and also to assist with the selection of instrumentation and to make all necessary arrangements. Criteria and factors that could influence the selection of the sampling point are:

(a) Can sampling take place at the point of greatest interest – such as the stack discharge?

(b) Will be the sampling position be In a straight section of pipe or duct six to ten diameters upstream and two to four diameters downstream from any bends or flow disturbances?

(c) Is the site accessible to sampling personnel and equipment?

(d) Availability of electricity, extension leads, water and compressed air, if needed.

(e) Ensure that at the sampling position– scaffolding, platforms etc are safe.

(f) It is important to establish what temperatures maybe expected. Very high temperatures, such as may be present when an oxygen lance is used, may melt the probe. Also, the temperature in the duct largely determines whether the sample will in- or out-duct.

(g) The final part of the smelt when fluxing takes place, is also very important because temperatures become substantially elevated and the particulate content of the air stream also becomes highly elevated.

(h) Arrangements need to be made for the necessary permits to enter the premises and for permission to take equipment onto site and to remove the equipment at the completion of the work.

(i) The position of sampling ports is very important. Wherever possible existing sampling ports should be made use of. Where there are no existing ports their positions should be selected as discussed above. The ports should readily permit the passage of the sampling probe and nozzle and where necessary the passage of a filter (in-duct sampling)

(j) Furthermore, the importance of liaising with several departments and organisations when a stack is being planned or built to ensure that sampling ports be taken care of at an early stage is emphasised. Very often stack walls are very thick and engineers are reluctant to "drill" or make holes in the wall once it has been built since the structural strength could be jeopardised.

(k) The means to transport equipment, usually very heavy, to the sampling ports, which may be on top of scaffolding, need to be arranged. The services of a rigger may be necessary.

(l) Another aspect to be considered in planning the sampling is the number of shifts worked, their duration and similarity of operations over all shifts.

(m) Over what portion of the shift the sample should be collected. In the case where the possible loss of precious metal or valuable product is being investigated a full shift sample is always be desirable.

(n) The importance of discussing any special requirements of the analytical laboratory for collecting and transporting samples must also be taken into consideration.

(o) It is also important to know the maximum temperature expected in the duct or stack as very high temperatures could melt the sampling probe.

3. Identification of all pollutants to be measured.
4. A description of the sampling train(s) to be used, including schematic diagrams, if appropriate.
5. Detailed sampling and analysis procedures. Reference standard methods, if applicable. Justify any proposed modifications.

6. The number and length of sampling runs which will constitute a complete test.
7. A dimensioned sketch showing all sampling ports in relation to breeching and to
8. Upstream and downstream disturbances or obstructions of gas flow.
9. Estimated stack gas conditions such as temperature, moisture, and velocity.
10. Projected process operating conditions during which the tests will be run (e.g., production rate).
11. A description of any process or control equipment data to be collected during the test period.
12. A description of any monitoring data to be collected during the test period and subsequently reported (e.g., stationary continuous emission monitor data).
13. Field quality assurance/quality control procedures (e.g., field blanks, sample storage and transport methods).
14. Laboratory quality assurance/quality control procedures (e.g., manner and frequency of blanks, spikes, and standards).
15. Names and titles of personnel performing the tests.

14.7 Data Recorded during sampling

1. Time and date
2. Sample location.
3. Sample collection rate
4. Sample pressure
5. Sample temperature
6. Dew point
7. Plant operating conditions
8. Flow rates and variability
9. Production rates and variability
10. Pressures
11. Temperatures

14.8 Calculation of results.

1. Determine the total amount of air that flowed in the duct or stack during the period of measuring. This determined from the flow rate multiplied by the total time of sampling and from the difference in readings on the dry gas meter for isokinetic sampling
2. Determine the amount of air sampled from the flows through the nozzle for the duration of the sampling period.
3. From laboratory results of the mass of contaminant collected calculate the mass concentration of the sample collected (mg/m^3).
4. Multiply the answer from item 3 by the answer for item 1. This will give the total mass of contaminant in the duct or stack during the observation period. This should be converted to grams or kg and then, if required the amount of kg/h calculated. When there are emissions of economic interest this can provide very useful information.
5. For the null method the amount of air flowing in the duct or stack during sampling is determined from Pitot readings.

14.9 Reporting

1. Summary of results

2. Full results should cover:
   (a) Operating data (e.g., production rate, fuel type or composition).
   (b) Results expressed in units consistent with the emission limitation applicable to the source.
   (c) Comparison with emission regulations.

3. Source description
   (a) Description of process, including operation of emission control equipment.
   (b) Process flow sheet or diagram (if applicable).
   (c) Type and quantity of raw and finished materials processed during the tests.
   (d) Maximum and normal rated capacity of the process.
   (e) Description of process instrumentation monitored during the test.

4. Sampling and analytical procedures
   (a) Description of sampling train(s) and field procedures.
   (b) Description of recovery and analytical procedures.
   (c) Dimensioned sketch showing all sampling ports in relation to breaching and to upstream and downstream disturbances or obstructions of gas flow.
   (d) Sketch of cross-sectional view of stack indicating traverse point locations and exact stack dimensions.

5. Test results and discussion
   (a) Detailed tabulation of results including process operating conditions and flue gas conditions.
   (b) Discussion of significance of results relative to operating parameters and emission regulations.
   (c) Discussion of any variations from normal sampling procedures or operating conditions which could have affected the results.
   (d) Documentation of any process or control equipment upset condition which occurred during the testing.
   (e) Calibration sheets for the dry gas meter, orifice meter, Pitot tube, and any other equipment or analytical procedures, which require calibration.
   (f) Sample calculations of all equations used to calculate the results.
   (g) Copies of all field data sheets.
   (h) Copies of all laboratory data, including quality assurance/quality control (e.g., blanks, spikes, and standards).

14.10 Legal requirements

The Atmospheric Pollution Act is about to be promulgated and the permissible emission concentrations will not be clear until this document is available. However, the environmental level of pollution must not exceed 1/50 of its OEL

For ground level concentrations or workplace levels the OELs referred to in the chapters on gas measurements and particulates should be consulted.

14.11 Stack emission levels

These are only Guidelines for the pollutant levels in stacks emitted for different processes. For example the concentrations for HCl, SO_3 and NH_3 should not exceed 35mg/m^3 and a general guideline for particulate matter is 120mg/m^3 .

14.12 Bibliography

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15. Noise

Author: Mike Franz, CSIR.

15.1 Purpose of measurements

The fundamental purpose of noise measurements is to identify and assess the extent of noise-related risks, including risk of noise-induced hearing loss (NIHL) and safety risks caused by interference with communication. Measurements are also necessary for the development of engineering controls for noisy machinery. For this purpose, frequency analysis is used to establish whether the noise is at high or low frequencies, to help identify those machinery components that contribute the most noise and select appropriate control measures. After controls have been implemented, follow-up measurements are used to evaluate their effectiveness and assess remaining risks. Where engineering controls are not feasible or all possibilities have been exhausted, frequency analysis can help in selecting the most suitable hearing protection devices (HPD) for exposed employees. Finally, employee exposure levels are measured, usually by means of personal noise dosimetry, to monitor remaining risks.

15.1.1 Compliance with regulatory requirements

In addition to the purposes outlined above, noise measurements are necessary to satisfy various legal and regulatory requirements. The Mine Health and Safety Act (MHSA) requires the employer to identify hazards [MHSA 11.(1)(a)], assess risks [11.(1)(b)], implement measures to eliminate, control or minimise them [11.(2) and (3)], and monitor those risks that still remain [11.(4)(a) and 12]. Exposure levels greater than 85 dBA pose a significant risk of NIHL and oblige the employer to implement a hearing conservation programme (DME 2003[1], 8 and 8.3.1). This should include the implementation and evaluation of control measures along with risk monitoring, indicating a need for accurate and representative noise measurements. Section 6.6 outlines Department of Mineral and Energy reporting requirements for occupational noise.

15.2 Equipment

15.2.1 Instrument types and level of accuracy

The two principal types of noise-measuring instruments are the sound level meter (SLM, Figure 15.1) for workplace and machinery noise, and the noise dosimeter (Figure 15.2) for personal exposure sampling. SANS 10083/SABS 083: 2004 requires that instruments used to measure occupational noise be of Class 2 accuracy or better, as defined by SANS/ IEC 61672-1: 2002 for SLMs and by IEC 61252: 2002 for noise dosimeters. Table 15.1 compares the four classes of sound-measuring instruments in terms of typical accuracy.

Author still to provide photo

Figure 15.1 Sound level meters with removable frequency filters

Author still to provide photo

Figure 15.2 Personal noise dosimeters

Table 15.1 Typical accuracy for classes of sound-measuring instruments

Class	Application	Typical Accuracy (dB)
0	Laboratory reference grade, for electro-acoustic calibration of sound-measuring instruments	±0,4
1	Precision grade, for engineering measurements or resolving disputes	±0,7
2	General purpose grade, for noise surveys and personal exposure monitoring	±1,0
3	Field survey grade, for spot checks and to identify areas requiring an assessment of risks	±1,5

While instrument accuracy is important for quantifying emission and exposure levels, the intrinsic variability of workplace noise indicates that representativeness is better served by increasing the number of samples. Exclusive use of Class 1 instruments limits the number of measurements that can be made, since Class 1 SLMs typically cost 50 per cent more than otherwise comparable Class 2 instruments. Accordingly, a given budget for sound-measuring equipment will only provide two-thirds as many Class 1 SLMs as Class 2 instruments or, conversely, the same budget used for Class 2 SLMs will allow 1-½ times as many samples to be taken. Workplace noise varies according to operational and performance factors, to such an extent that experts generally regard measurements corresponding within 2 dBA as comparable and indicative of confirmation. The valid assessment of NIHL risks is better served by increasing the number of measurements by 50 per cent than by improving the accuracy of individual measurements by three-tenths of a decibel.

A further argument in favour of Class 2 instruments is that replacing a microphone, which is the most vulnerable component of an SLM, typically costs one-fourth as much as replacing a Class 1 microphone. A damaged microphone renders the instrument unserviceable, and it is more likely to remain so for a longer period if the replacement cost is four times as great. Another consideration, albeit less significant, is that electro-acoustic calibration is more costly for Class 1 instruments. It should be noted that virtually all currently available personal noise dosimeters are of Class 2 accuracy.

Frequency analysis, whether for engineering purposes or to facilitate the selection of appropriate HPDs, requires a sound level meter equipped with an octave- or 1/3-octave-band frequency filter. Engineering measurements should preferably be made with a Class 1 SLM, microphone and frequency filter.

Frequency analysis can be performed with a real-time sound analyser (RTA, Figure 15.3). This type of instrument is approximately twice as costly as a comparable SLM and frequency filter, but an RTA can simultaneously measure, analyse and log sound levels across the entire spectrum of noise in a matter of seconds. This capability eliminates the need for separate

measurements at each frequency, thereby increasing the number of measurements that can be made in a given period of time. For this reason, a real-time sound analyser can simplify comprehensive assessments of noise sources that are being considered for engineering controls, as well as the evaluation of measures that have already been implemented.

Author still to provide photo

Figure 15.3 Real-time sound analyser

Irrespective of the type or class of sound-measuring equipment used, a sound calibrator (Figure 15.4) of the same class or better (as specified by SANS/IEC 60942: 2003) should be used to calibrate instruments before and after each series of measurements.

Author still to provide photo

Figure 15.4 Sound calibrators

15.2.2 Principle of operation

Figure 15.5 illustrates the components and processes generic to most sound-measuring instruments, with optional items and functions identified by an asterisk (*). When sound deflects the microphone's pressure-sensitive diaphragm an electrical signal is sent to the preamplifier, which boosts the signal to a usable level before sending it to the frequency weighting filters*, if the instrument is so equipped. The most basic instruments provide only A-scale weighting, but those that offer selectable weighting allow the user to choose A-, C- or Z-weighting (un-weighted or Linear). This setting is made by means of a switch or keypad in the case of SLMs, and in the set-up mode for noise dosimeters. (Appendix 1 provides a tabulation of weighting factors for A- and C-weighting.)

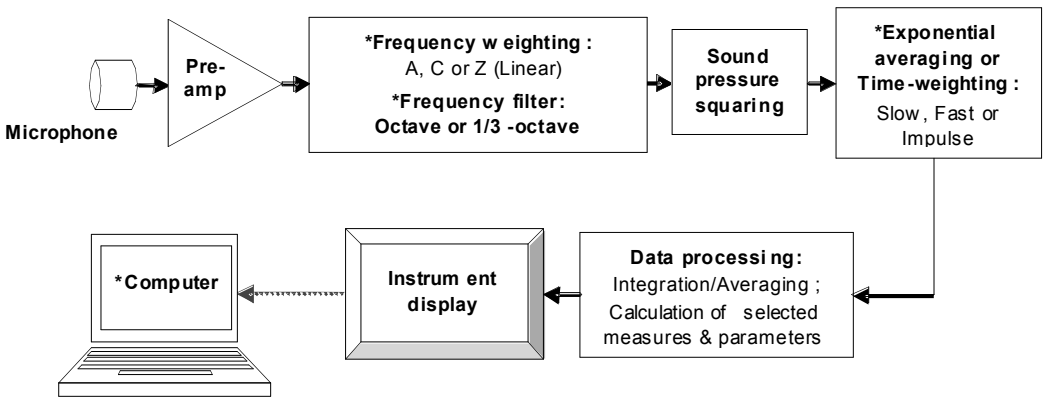

Figure 15.5 Components and processes of sound-measuring instruments

The filtered or unfiltered signal from the preamplifier, which corresponds with the pressure of the sound, is squared to produce a waveform proportional to the sound's instantaneous power.

The upper-right block in the figure represents exponential averaging, more commonly referred to as time-weighting. Instruments with selectable time-weighting allow the user to set the speed of response to varying levels of sound. Slow time-weighting applies a time constant (response time) of 1 second, to determine the average level of slowly changing sound. Fast time-weighting applies a time constant of 0,125 s to capture rapid fluctuations in sound level and determine its upper and lower limits. More sophisticated SLMs also offer Impulse time-weighting, which applies a time constant of 0,0035 s. This setting is used to measure suddenly occurring sounds of very short duration, such as those generated by the explosion of blasts and gunshots or the impact of hammering and stamping operations.

The lower right block in Figure 15.5 represents the data-processing stage, where measurement results are integrated to calculate the RMS (root mean square) or average sound pressure level, the maximum, minimum and peak levels, as well as various other measures selected by the user (depending on the instrument).

Measurement results are displayed on the instrument itself or, if it features a data output facility (cable or infrared), the results can be transferred to computer for further analysis, permanent storage and generating reports.

15.2.3 Electro-acoustic calibration

In addition to the pre- and post-measurement calibration checks detailed in Section 2.5, SANS 10083/SABS 083: 2004 requires that sound-measuring instruments be electro-acoustically calibrated by a laboratory meeting the requirements of SANS 10259/ SABS 0259: 1990 and traceable to the National Acoustics Standard (DTI[2]). The prescribed calibration intervals are one year for sound calibrators and two years for all other instruments.

15.2.4 Preparation of instruments

The following measurement criteria should be applied for all noise measurements, using the instrument's setup mode:

- Criterion level or Exposure limit: 85 dBA
- Threshold level or Low threshold limit: 80 dBA
- Energy exchange or Doubling rate: 3 dBA
- Time criterion: 8 h

These settings are normally made by the supplier prior to delivery but should be confirmed.

Data-logging SLMs, noise dosimeters and RTAs are capable of generating a complete time-history of all noise events detected by the instrument. Data is typically logged at one-minute intervals, but some instruments allow logging intervals of one second to several minutes. To prevent over-writing of the oldest data in the event that the instrument's memory capacity is reached, the instrument should be cleared of old data, but only after confirming that they have already been saved. To limit the risk of exceeding the memory's capacity, only the required parameters should be selected for logging, and logging intervals should be no shorter than necessary to provide the required resolution.

In the case of conventional noise dosimeters, the microphone and cable should be free of damage and securely connected to the instrument, and the clip should be sufficiently tight to

retain the device in the chosen position, either on the belt or in the chest pocket. A sliding clip (as used for employee clock cards) should be permanently attached along the length of the microphone cable to control slack and prevent fouling, particularly if the instrument will be worn in the chest pocket. One type of noise dosimeter has an integrated design that greatly reduces the size of the instrument and dispenses with the microphone cable. The latter feature eliminates the need for cable-related precautions, but integrity of the mounting clip or harness should be confirmed.

Before using any sound-measuring instrument, particularly noise dosimeters, battery status should be confirmed as adequate for the anticipated measurement or sampling time. This should be done before the pre-measurement calibration check but only after confirming the calibrator's battery status.

Current SLMs and dosimeters have a calibration mode and the facility to store the calibration result in memory along with the sampling results. General calibration procedures for SLMs and noise dosimeters are as follows:

1) Remove the windscreen and insert the microphone into the calibrator.

2) Switch the calibrator on and allow the instrument's display to stabilise.

3) Adjust the display to correspond with the specified output of the calibrator, using either a small screwdriver to turn the calibration trim pot or, for some instruments, the keypad or accompanying software (the latter requires a cable or an infrared device to link the instrument to a computer). Ensure that the meter display is stable and corresponds with the calibrator's specified output before accepting/saving the result and replacing the microphone windscreen.

4) Switch the calibrator off, unless it has an auto-off facility.

15.3 Measurement parameters and procedures

15.3.1 Workplace and machinery noise

The fundamental parameter used to quantify workplace and machinery noise is equivalent continuous A-weighted sound pressure level (LAeq, T). If normalised to an 8 h shift, as stipulated in the DME Guideline, the parameter becomes LAeq, 8h. Its value (in dBA) equates to the level of an unchanging sound continuing for 8 h that would have the same effect on people's ears as the varying noise occurring in the workplace. For continuous unvarying noise the values for LAeq, T and LpA (instantaneous A-weighted sound pressure level) would be identical. LAeq, 8h is measured directly with an integrating sound level meter. Another measurement parameter, equivalent continuous rating level for noise (LReq, T), is specified by SANS 10083/ SABS 083: 2004. It is based on LAeq, T but incorporates a correction for impulse noise. Both parameters are measured with a sound level meter, which should be mounted on a tripod where possible so the observer can step from the instrument to avoid influencing the sound field.

15.3.1.1 General procedures

The following general procedures should be used to measure LAeq, T and LReq, T:

- The area to be measured should be reasonably uniform in terms of noise level, i.e. all values for the various workplace operating conditions should be within 10 dBA. If this is not the case, the area should be divided into separate zones.
- The sound level meter's calibration should be confirmed immediately before and after each series of measurements. If the two calibration checks do not correspond to within 1,0 dB, the results should be discarded and the measurements repeated.
- If more than a single microphone position is needed to adequately cover the area, at least three representative positions should be used (more for larger areas and for more variable noise). As far as reasonably practicable, microphone positions should be at least 1,2 m from walls or other large reflective surfaces, and meet the following situation-specific requirements:
    - Standing persons: 1,5 m above the floor, ground or platform
    - Seated persons: 0,9 m above the chair seat
    - Fixed workstations at the position of the worker's most-exposed ear
    - Individual noise sources: 1 m from the source and 1,5 m above the floor
    - Where operations and activities result in sporadic noise emission, i.e. periods of high levels interspersed with quieter periods, composite measurements should be used to representatively divide the measurement time interval at each microphone position into sub-intervals. The measurement time for each sub-interval should be proportional to the relative duration of noisy and quieter periods.
    - For each microphone position and, in the case of composite measurements, for each measurement time sub-interval, measurements should extend over a representative time period. For steady noise, a measurement period of one minute is adequate but, where noise is variable or cyclical, the measurement period should be sufficiently long to capture variations in level and encompass three or more work task cycles.

The following instrument settings should be used when measuring LAeq, T and LReq, T:

- A-weighting: On
- Time weighting: as detailed below for LAeq, T and LReq, T
- Sound incidence (if selectable): Frontal if the microphone faces a noise source, or Random if the noise is non- or multi-directional
- Frequency Filter (if so equipped): Out or Off
- Operating mode: Integrate or Leq

Measurement procedures that specifically apply to LAeq, T and LReq, T are detailed in Sections 3.1.2 and 3.1.3, respectively.

15.3.1.2 Equivalent continuous A-weighted sound pressure level

In addition to the instrument settings detailed above, measurements of LAeq, T should apply time weighting as follows:

Slow for steady noise, provided the level dos not vary by more than 5 dBA

Fast for more variable or rapidly changing noise

Impulse for impulsive noise if the SLM has impulse-integrating capability

If the SLM does not provide for impulse integration, increase the measured value by 5 dBA for moderately impulsive noise (e.g. pneumatic rockdrill), or by 12 dBA for highly impulsive noise (e.g. air-driven charging-up of blast holes, hammering and metal-stamping)

1) From an appropriate microphone position and after a representative measurement period, read LAeq, T directly from the SLM.

2) If more than one microphone position is used, repeat Step 1 for each, pausing the SLM between positions and read LAeq, T for the entire area directly from the instrument after measuring at the last position.

3) For composite measurements, i.e. where the total measurement time for a given microphone position consists of discrete sub-intervals, pause the SLM between sub-intervals and read LAeq, T for that position directly from the instrument at the end of the last sub-interval, and

3a) calculate the average LAeq, T for all microphone positions in accordance with Equation 1 to determine LAeq, T for the entire area

(1)
$$L_{Aeq,T} = 10\log\left[\frac{1}{T_m}\int_{t_1}^{t_2}\frac{p_A^2(t)}{p_o^2}\,dt\right]$$

where:

LAeq T is the equivalent continuous A-weighted sound pressure level in decibels, determined over a specified measurement time interval Tm starting at t1 and ending at t2,

po is the reference sound pressure level (20 Pa), and

pA(t) is instantaneous A-weighted sound pressure of the sound in Pascals.

Note: The use of Equation 1 can be dispensed with in the following manner:

Pause the SLM at the end of the last measurement time sub-interval for each microphone position. At the end of the final sub-interval for the last position, read the average LAeq, T for the entire area directly from the instrument.

15.3.1.3 Equivalent continuous rating level for noise

LReq, T is determined in accordance with one of three methods (SANS 10083/ SABS 083: 2004), which are described below in descending order of preference. All three methods require use of the measurement criteria, general procedures and instrument settings detailed in Sections 2.4, 3.1.1 and 3.1.2, respectively. If more than a single microphone position is required to adequately cover the area, at least three positions should be used.

15.3.1.3.1 Using impulse time-weighting and integration

This method requires an impulse-integrating SLM, i.e. one that can integrate while applying impulse time-weighting. Proceed as follows:

1) Select impulse time-weighting

2) From an appropriate microphone position and after a representative measurement period, read LReq, T directly from the SLM.

3) If more than one microphone position is used, repeat Step 1 for each, pausing the SLM between positions and read LReq, T for the entire area directly from the instrument after measuring at the last position.

4) For composite measurements, i.e. where the total measurement time for a given microphone position consists of discrete sub-intervals, pause the SLM between sub-intervals and read LReq, T for that position directly from the instrument at the end of the last sub-interval, and

4a) calculate the average LReq, T for all microphone positions in accordance with Equation 2 to determine LReq, T for the entire area:

(2)
$$L_{\mathrm{Re}q,\,\mathrm{T}} = 10\log\frac{1}{n}\sum_{i=1}^{n}10^{L_{\mathrm{Re}q,Ti}/10}$$

where:

LReq, Ti is equivalent continuous rating level at the ith microphone position, and

n is the number of microphone positions (minimum of three where n 1).

Note: The use of Equation 2 can be dispensed with in the following manner:

Pause the SLM at the end of the last measurement time sub-interval for each microphone position. At the end of the final sub-interval for the last position, read the average LReq, T for the entire area directly from the instrument.

15.3.1.3.2 Using integration and derived impulse correction

This method requires an SLM with an integrating function, as well as Slow and Impulse time-weighting, but does not require integration and time-weighting to be applied simultaneously. Proceed as follows:

1) Measure LAeq, T using an appropriate microphone position and representative measurement time.

2) Switch the Operating mode from Integrate/Leq to SPL (sound pressure level), select Impulse time-weighting and, using the same microphone position and measurement time as in Step 1, note the maximum SPL.

3) While still in SPL mode switch to Slow time-weighting and, using the same microphone position and measurement time as in Steps 1 and 2, note the maximum SPL.

4) Calculate impulse correction (CI) as the difference between the values obtained in Steps 2 and 3.

5) Add Ci to the value obtained for LAeq, T in Step 1 to determine LReq, T.

6) Where more than one microphone position is used, repeat Steps 1 to 5 for each, pausing the SLM between microphone positions, and read LReq, T for the entire area directly from the instrument after measuring LReq, T at the last position.

7) For composite measurements, i.e. where the total measurement time for a given microphone position consists of discrete sub-intervals, pause the SLM between sub-intervals and read LReq, T for that position directly from the instrument at the end of the last sub-interval, and

7a) calculate the average LReq, T for all microphone positions in accordance with Equation 2 to determine LReq, T for the entire area.

See Note on dispensing with the use of Equation 2 at the end of Section 3.1.3.1.

15.3.1.3.3 Using integration and estimated impulse correction

This method can be used with a basic integrating SLM that does not have selectable time-weighting. Proceed as follows:

1) Measure LAeq, T using an appropriate microphone position and representative measurement time.

2) If the noise is judged to be impulsive, add the appropriate correction factor to the LAeq, T value obtained in Step 1 to determine LReq, T . Impulse correction is as follows:

Not impulsive: 0 dBA

Moderately impulsive, e.g. pneumatic rockdrill: +5 dBA

Highly impulsive, e.g. sharp hammer blows: +12 dBA

3) If more than one microphone position is used, repeat Steps 1 and 2 for each, then calculate the average of all positions on a mean-square pressure basis in accordance with Equation 2 to determine LReq, T for the entire area.

3a) Alternatively, if no composite measurements are made (as described in Step 4) and the impulsive nature of the sound is the same at all microphone positions, pause the SLM between positions and read LAeq, T for the entire area directly from the instrument after measuring LAeq, T at the last position, and

3b) Apply the appropriate impulse correction factor (Step 2) to determine LReq, T for the entire area.

4) For composite measurements, i.e. where the total measurement time for a given microphone position consists of discrete sub-intervals, use Equation 4 to determine LReq, T for that position.

4a) Alternatively, pause the instrument between sub-intervals, read LAeq, T for that position directly from the instrument at the end of the last sub-interval, apply the appropriate impulse correction (Step 2) to determine LReq, T for that position, and

4b) calculate the average LReq, T for all microphone positions in accordance with Equation 2 to determine LReq, T for the entire area.

See Note on dispensing with the use of Equation 2 at the end of Section 3.1.3.1.

15.3.1.4 Frequency analysis

It is sometimes necessary to quantify the level of noise generated at individual frequencies by means of frequency analysis. This measurement technique uses a sound level meter and frequency filter or frequency analyser to measure sound pressure level in each octave or 1/3-octave band (depending on the resolution required), while excluding sound in all other bands. Each frequency band is selected in turn, and SPL is noted by the observer or stored in the instrument's memory if it has a logging function. The same procedure is used as for LAeq, T (Section 3.1.2), except that the filter is switched in or on and frequency-weighting (A, C or Linear/Un-weighted/Z) is selected, according to the purpose of the measurements. Engineering measurements normally use C- or Z-weighting, but if the measurements are to assist in the selection of HPDs, A-weighting should be applied[1].

[1]C-weighted measurements are required for use of the NRR (noise reduction rating) method of HPD evaluation, but NRR grossly overestimates the level of protection provided. More accurate estimates of HPD protectiveness are obtained using the Octave-band/OB/NIOSH Long Method[3] which requires A-weighted values for SPL.

15.3.2 Employee noise exposure

15.3.2.1 Measurement with a sound level meter

Use of a sound level meter to determine noise exposure is only practicable for employees with fixed work stations in areas of relatively steady noise. In such cases determining exposure level is a simple matter of measuring LAeq, T over a representative time period, from a microphone position near the employee's most-exposed ear. To ensure representativeness, the measurement time should be of sufficient duration to encompass any variations in noise level that occur and, where applicable, at least three operational cycles.

15.3.2.2 Personal noise dosimetry

Where work activities and noise levels vary or employees do not have fixed work stations, personal noise exposure sampling is a more practicable and representative way of assessing NIHL risks (ISO 1999: 1990, ISO 9612: 1997), as well as satisfying DME reporting requirements. Although an integrating SLM can be used to combine the results of several measurement intervals, the need to closely follow employees as they perform their duties limits the number of samples that can be taken with an SLM. Furthermore, the difficulty of maintaining a microphone position near the most-exposed ear and the impracticability of full-shift sampling constrain the representativeness of SLM-based exposure measurements.

The conventional approach to segmenting the workforce for noise exposure monitoring is based on sampling area, activity area, homogeneous exposure group (HEG), and occupation. Operation/activity and workplace type can also be used for the same purpose. Ideally, each employee should be sampled at least once every two years, but this is only possible if the workforce is small. In the case of larger workforces, all noisy activities and occupations should be representatively monitored on an ongoing basis, taking more samples where greater numbers of people are exposed and where noise levels are more variable.

Before dosimeters are issued, they should be prepared and calibrated according to procedures detailed in Section 2.4. Instruments that have a timed start/stop facility should be set to Auto-run to streamline the issuing process, and keypads should be locked to prevent employee interference with sampling.

Procedures for briefing employees before they are sampled, issuing and recovering dosimeters and extracting results are detailed in the three sub-sections that follow.

15.3.2.2.1 Briefing participants

Employees to be issued with noise dosimeters should:

1) be identified in advance according to the employer's sampling strategy;
2) be given an explanation of the monitoring programme's purpose;
3) be encouraged to raise any questions or concerns they may have;
4) understand that sampling results will not be evaluated on an individual employee basis, but will serve to identify occupations and workplaces where significant exposure occurs, and
5) be confirmed as willing to participate: those who are reluctant should be excused, to reduce the risk of invalid samples and damaged instruments.

Participating employees should be asked to refrain from:

1) removing the dosimeter, either during or after the shift (some practitioners have found it useful to notify supervisors of selected employees in advance by means of a form asking the supervisor to check that the dosimeter is worn during the shift and record the times at which checks were made);
2) unnecessarily subjecting the instrument to harsh conditions or abuse;
3) intentionally exposing the microphone to unusual noise or otherwise interfering with measurements, and
4) tampering with the instrument or its microphone.

Employees should understand that dosimeters only record the level and duration of noise, not the sound itself, and that samples showing abnormal noise levels will be repeated to ensure overall accuracy.

Participants should:

1) be given a choice of where the dosimeter will be worn, to prevent undue interference with the performance of their duties;
2) be advised to report to a designated location at the end of the shift, where an official will remove the instrument and examine it and enquire whether work activities and noise levels were normal or otherwise;
3) understand that there is no linkage between their sampling result and any compensation-related decisions, and
4) be made aware that replacement of a dosimeter or microphone is costly, and that instances of lost or damaged instruments will be investigated.

15.3.3.2.2 Issuing dosimeters

For each dosimeter issued, record the instrument's identification or serial number, as well as the name, occupation and workplace of the employee to whom it is issued. If the instrument has not been set to Auto-run, switch it on, activate the data-logging or "Run" function, and record the start time. Before closing the instrument, confirm that it is running.

Fit the dosimeter in accordance with the individual's preference and work task requirements. Employees should not fit dosimeters themselves. If relevant to the individual's occupation, the microphone should be positioned as close as possible to the more-exposed ear, most often at a point midway between the neck and outer edge of the shoulder. It should face the likely origin of noise, i.e. forward, sideways rearward or, in exceptional cases, upward. Where relevant, the microphone cable should be routed under the arm to minimise cable slack and prevent fouling, using an extra cable clip (Section 2.4) to secure any slack.

Instruct the employee to leave the dosimeter exactly as it has been fitted until the responsible official removes it at the end of the shift, and to refrain from donning additional garments that would obstruct the microphone. Confirm that the instrument and microphone cable (where relevant) will not interfere with the employee's work tasks, and that he or she understands the arrangements for recovering the dosimeter (i.e. time and place).

15.3.2.2.3 Recovering dosimeters and extracting results

Remove the dosimeter and, while the employee is still present, examine the instrument for damage while accessing the controls and display. If the dosimeter was not set to stop at a predetermined time, manually pause it to halt further logging and record the stop time. Display the relevant parameters (variously indicated as Leq, Lavg, TWA8h or % Dose) and inform the employee of the result. Do not clear the instrument's memory at this time.

Ask the employee if work activities and noise levels differed from the norm and, if so, the cause and extent. If possible, similar input should later be sought from the employee's supervisor. Such information should be recorded along with other details of the sample.

After dosimeters have been recovered, display and record the values for all relevant parameters, manually or by means of a computer linked to the instruments by a cable or infrared connection. If results are downloaded to computer, do not clear the instrument's memory until it has been confirmed that the results have been captured. The pertinent measurement parameters are:

1) Average sound pressure level (Lavg) or Equivalent continuous sound pressure level (Leq) over the sampling period;
2) Time-weighted average sound pressure level normalised to 8 h (TWA8h), which will be equal to LAeq if the sampling period is exactly 8 hours but greater if it is longer;
3) Maximum sound pressure level (Lmax) detected during the sampling period;
4) Peak or highest instantaneous sound pressure level (Lpk) detected during the sampling period, irrespective of whether the dosimeter was set to Fast or Slow time-response (this parameter is of questionable value, as it incorporates artefacts caused by the microphone being brushed or bumped: Peak level will nearly always more than 140 dBA, but of extremely short duration), and
5) Run time, i.e. the period over which the sample was taken.

15.4 Evaluation of results

15.4.1 Classification of noise emission and exposure levels

Table 15.2 [adapted from Royster, Berger and Doswell-Royster[4] and the Occupational Hygiene Regulations: 9.1(f)(iii)] compares two methods of classifying noise emission and exposure levels. The OH Regulations stipulate the use of Categories A, B and C for classifying exposure, while the ECF (emission/exposure classification factor) method assigns a factor of 0 to 5, in accordance with the relative risk of NIHL to exposed persons [based on ISO 1999: 1990 and ISO 1999: 1975 (E)].

Table 15.2 Classification and appropriate action for various levels of emission/exposure

*LAeq, T / LReq, T/ TWA8h (dBA)	Emission/Exposure classification according to:	
	Occupational Hygiene Regulations	Emission/Exposure classification factor (ECF), Level of significance and Required action
<82	-	0 Insignificant risk of NIHL No action required
82-85	C	1 Potential risk of NIHL Monitor emission and exposure levels for upward trends
86-90	B	2 Moderate risk of NIHL Intervene, Re-assess and Monitor
91-95	B	3 Significant risk Priority intervention Re-assess and Monitor
96-105	B	4 Unacceptable risk Immediate intervention Re-assess and Monitor
≥106	A	5 Extreme risk Urgent intervention Re-assess and Monitor

*Values rounded to nearest decibel

ECF is used to calculate risk rating for noise (RRN) for a given type of machinery, operation, activity or workplace as follows:

RRN = ECF x Number of employees affected (3)

RRN can serve as a simple basis for quantitatively prioritising sources of NIHL risk for possible control measures.

15.5 Precautions and limitations

15.5.1 Care and maintenance of instruments

The introduction of integrated circuits, computer chips and improved storage batteries has simplified the design and construction of sound-measuring instruments, making them more portable, reliable and robust. Microphones have also been improved in the latter two respects, but they are still the most delicate and expensive component of a sound-measuring instrument. All instruments must be handled with care, particularly microphones, which should only be used with the windscreen in place for protection against bumps and the ingress of water or dust. The protective grid that covers the diaphragm of SLM microphones should not be removed except by qualified service personnel. Similarly maintenance and repairs should be entrusted only to the supplier or instrument manufacturer. In this regard, all but the simplest repairs make it necessary for the instrument to be electro-acoustically re-calibrated before returning it to service.

Instruments, particularly dosimeters, should be wiped clean after each use, to prevent accumulations of dust and other residue from causing damage or malfunction. Windscreens should be periodically washed in fresh water to remove dust, and allowed to dry before re-use.

If an instrument will not be used for an extended period, say more than four weeks, the batteries should be removed to eliminate the possibility of leakage and instrument damage. Most current SLMs and dosimeters have a small internal battery to retain instrument settings and data in the memory should the operating batteries be removed or become exhausted. The internal battery will normally last for five years or more, but should only be replaced by the manufacturer or authorised agent.

15.6 Reports

Reports on noise measurements for risk assessment and OH monitoring should contain information useful to role-players and stakeholders, as discussed in the sub-sections that follow. Where possible, recommendations should be offered to reduce emission, exposure and risk, preferably through engineering or administrative controls. In most instances this will require specialist input to identify and evaluate possible control measures, but the hygienist can play an important role in highlighting areas of significant risk to initiate appropriate action.

Input should be also sought from officials who make use of reports on noise measurements, to ensure useful content, appropriate key indicators and accessible format. This is the responsibility of senior personnel in the Occupational Hygiene Department, but hygienists and observers should be aware of the required content and format.

15.6.1 Engineering

Engineering personnel will be mainly concerned with the level of noise emitted by various types of equipment and the number of employees affected, as this will affect the prioritisation of machinery and workplaces for engineering-based control measures. Accordingly, reports for the Engineering Department should rank machinery and workplaces in terms of RRN and include the information used to derive it, and provide details of the physical and operating conditions at the time specific equipment was assessed. If frequency analysis is performed, these results should also be reported, to assist in devising control measures.

Where engineering controls have been implemented, the results of follow-up measurements should be reported and compared with expected results or targets that were set.

15.6.2 Production

Production officials should be informed of the level of noise emitted by various types of equipment and employees' exposure levels. To assess the extent to which noise emission may interfere with communication (which can have negative impact on safety and productivity), the results of frequency analysis in critical areas should also be reported.

Information on possible control measures to limit significant risks is also of concern, including likely impact on safety and productivity. Assessments of these aspects should be based on input from Engineering, Risk/Safety and Production personnel, as well as from equipment manufacturers.

15.6.3 Occupational Health

The Mine Health and Safety Act requires that, as far as practicable, the results of occupational hygiene monitoring be linked with employees' medical surveillance records [MHSA 12.(3)]. Accordingly, reports for the Occupational Health Department should include noise exposure by occupation and workplace type/activity area, to facilitate the required linkage.

In addition, occupations and workplaces with excessive exposure and emission levels should be highlighted, to allow closer surveillance and monitoring of affected employees.

15.6.4 Management

Management must be informed of the impact that prevailing noise levels will have on people's hearing, as this will determine what resources should be deployed to implement control measures. Accordingly, RRN should be reported by occupation, workplace type/ activity area and machinery type, along with information used to derive it, viz.:

- $L_{Aeq, T}$ and/or $L_{Req, T}$ values;
- exposure classification factor (ECF, as per Table 4.1), and
- number of employees affected.

This will quantify risk of NIHL in relative terms but more absolute predictions of compensable impairment can be determined, based on level and duration of exposure as given in Table A-3 (Appendix 2).

Management must receive information to evaluate progress in limiting NIHL risks, indicating a need for comparisons of current findings with previous results and targets, to establish trends and identify areas where significant risks persist.

15.6.5 Employee representative organisations

Union officials should be informed of the levels of risk and number of their members exposed, and of control measures that have been implemented or planned. RRN and the information used to derive it should be reported by sampling area, activity area, HEG and occupation, highlighting areas of significant risk and control measures being considered.

It is also important to inform Union officials regarding evaluations of control measures that have been implemented and possible further steps where such a need is indicated.

15.6.6 Regulatory authorities

The DME requires annual reports on the results of personal noise monitoring that identifies occupations in which employees are exposed to dangerous noise, the number of employees exposed, and the logarithmic average sound pressure level. The Department must also monitor the mining industry's progress towards compliance with Mine Health and Safety Council milestones for occupational noise, which will require reports that include at least the following information:

- an inventory of all noisy equipment in use and typical emission level for each activity area and workplace;
- total noise emission (LAeq) during full-scale operations for each activity area and workplace, and
- a list of workplaces ion each activity area where total noise emission exceeds 110 dBA.

15.7 References

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3. DOL 2003. Noise-induced hearing loss Regulations of the Occupational Health and Safety Act (Act No. 85 of 1993), Regulation No. R. 307, Government Gazette 7 March 2003. Pretoria: Department of Labour.

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10. SABS 1990. SANS 10259/SABS 0259, General requirements for the competence of calibration and testing laboratories. Pretoria: South African Bureau of Standards.

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12. SABS 2003. SANS 60942: 2003, Electroacoustics- Sound calibrators- Ed. 2. Pretoria: South African Bureau of Standards.

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Chapter 15 Appendix 1

Frequency weighting

Frequency weighting is often applied when measuring sound, depending on the purpose. A-weighting, which devalues sound at frequencies the ear is less sensitive to and less likely to be damaged by, is used to assess risks to human hearing. C-weighting is useful for measuring sound with blast-type waveforms. It can also be used with a SLM that is not equipped with a frequency filter, to determine whether sound contains significant low-frequency components. An A-weighted sound level that is lower than the corresponding C-weighted value indicates that the sound occurs mainly at frequencies below 1 000 Hz. Conversely, similar results for A- and C-weighted measurements indicate the absence or insignificance of sound at lower frequencies.

Table 15A1-1 gives the weighting factors applied to Linear/Un-weighted/Z-weighted values when A- and C-weighting are applied.

Table 15A1-1 Weighting factors for A- and C-weighted measurements

Frequency (Hz)	Weighting factor, relative to Linear/ Un-weighted/Z-weighting (dB)		
	A-weighting	C-weighting	Z-weighting
31,5	-39,4	-3,0	0
63	-26,2	-0,8	0
125	-16,1	-0,2	0
250	-8,6	0	0
500	-3,2	0	0
1 000	0	0	0
2 000	+1,2	-0,2	0
4 000	+1,0	-0,8	0
8 000	-1,1	-3,0	0
16 000	-6,6	-8,5	0

Chapter 15 Appendix 2

Risk of compensable impairment

Table 15A2-1 gives the risk of compensable hearing impairment for various levels and periods of exposure to occupational noise. The tabulated risks are based on the difference in prevalence of impairment between an occupationally exposed population and a population that is demographically similar but without exposure to occupational noise. The actual prevalence of impairment will typically be six per cent higher than the tabulated risks, as it can be expected that this proportion of individuals will become impaired even without occupational exposure.

It will be noted that the risk of impairment decreases after 30 to 40 years of exposure, depending on the level. This is due to loss of hearing sensitivity with advancing age in the non-exposed group, leading to smaller differences in the prevalence of impairment between the two populations.

Overall, the tabulated values indicate significant NIHL risks for exposures from 90 dBA upwards, particularly at 100 dBA and above, indicating the need for effective control measures to reduce emission and, hence, exposure and risk.

Table 15A2-1 Risk of compensable impairment for various levels and periods of exposure

Period of exposure (y)	Risk (per cent) of compensable hearing impairment for the given period of exposure at an equivalent level (dB) of:							
	80	**85**	**90**	**95**	**100**	**105**	**110**	**115**
0	0	0	0	0	0	0	0	0
5	0	1,5	5	9	14,5	20,5	28,5	38,5
10	0	3,5	11	19	31,5	44,5	57,5	73,5
15	0	5,5	15	26	39,5	55,5	73,5	85,5
20	0	6,5	17	30	44,5	60,5	80,5	89,5
25	0	7,5	17	31	45,5	62,5	80,5	86,5
30	0	8,5	19	33	46,5	64,5	79,5	83,5
35	0	9,5	21	34	46,5	63,5	74,5	77,5
40	0	10,5	22	31	43,5	56,5	64,5	66,5
45	0	7,5	16	25	35,5	43,5	47,5	49,5

Adapted from ISO 1999:1975 (E)

16. Human Vibration Measurement

Author: PS Heyns, University of Pretoria.

16.1 Purpose

The human body is a very complex system. To simplify the study of the effects of vibration on this system the human vibration problem is usually treated as two distinctly different problems. Whole body vibration occurs when the body is supported on a surface that is vibrating. The body may be sitting, standing or lying on the vibrating surface. This occurs frequently where operators are working in operator seats on vibrating machines. Hand-transmitted vibration occurs when the hand is in contact with a vibrating surface such as in the case of hand held machinery.

Vibration transmitted to the body cause a wide variety of symptoms and disorders in humans. Symptoms associated with whole-body vibration range from discomfort, interference with activities and motion sickness, while high levels of vibration may also lead to back problems, disorders of the digestive and reproductive systems, visual and nervous system problems. Symptoms associated with hand-transmitted vibration include bone and joint disorders, neurological and muscular disorders and also vascular disorders that include vibration-induced white finger. This is a painful condition due to impeded blood circulation to the fingers and causes whitening of fingers.

Human vibration measurements are usually performed to ensure that the levels of vibration to which human operators of vibrating machinery are exposed, are within limits that are believed will safeguard operators from the detrimental consequences of using these equipment.

16.2 Legislation

As in many parts of the world, South African legislation does not specify vibration limits. However, Directive 2002/44/EC of the European Parliament of 25 June 2002, lays down ‘limit values’ and ‘action values’ for 8-hour exposures in EU member states. The action and limit values are set at 0,5 and 1,15 m/s2 for whole-body vibration and 2,5 and 5,0 m/s2 for hand-transmitted vibration. The directive lays down minimum requirements and EU member states may adopt more stringent provisions for the protection of workers. It is to be expected that this EU initiative will gradually start to influence the situation in South Africa.

16.3 Methodology

16.3.1 Principles of operation

Human vibration measurements are usually done in accordance with international standards that have been developed to create consistent and repeatable measurement procedures. In South Africa the ISO 2631 (whole-body vibration) and ISO 5349 (hand-transmitted vibration) standards are commonly used for this purpose.

Basic evaluation of whole-body vibration always include measurements of the weighted root-mean-square (r.m.s.) acceleration, expressed in meters per second squared (m/s^2).

The weighted r.m.s. acceleration is calculated using the time weighted acceleration history $a_w(t)$ as a function of time and integrating over a period T which corresponds to the duration of the measurement. Measurements are usually taken in three orthogonal directions x, y and z (Figure 16.1). The precise weighting depends on the application under consideration, and different weighting curves apply in the various directions, for seated, standing or recumbent positions, and reflect the empirical observation that the human body is more sensitive to some excitation frequencies than to others. The so-called W_k weighting curve which applies for seated motion in the z-direction is depicted in Figure 16.2 by way of example. From this curve it is clear that a seated person is most sensitive to vibration in the 3 to 18 Hz frequency range.

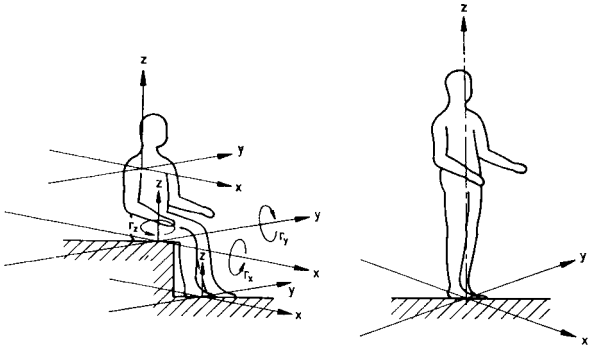

Figure 16.1 Measurement directions for whole-body vibration measurement

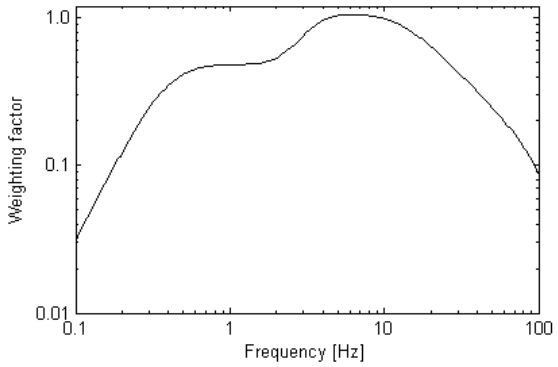

Figure 16.2 W_k frequency weighting for seated person

When the crest factor (which is a measure of the peaks present in a vibration signal and is defined as the ratio of the largest instantaneous peak in the frequency weighted signal to its r.m.s. value) is less than 9, the weighted r.m.s. acceleration approach is usually sufficient. If not, additional calculations are required. These include running r.m.s. values and the Vibration Dose Value.

Basic evaluation of hand-transmitted vibration also entails acceleration measurements in three orthogonal directions (Figure 16.3), assuming that vibration in each of the three directions are equally detrimental.

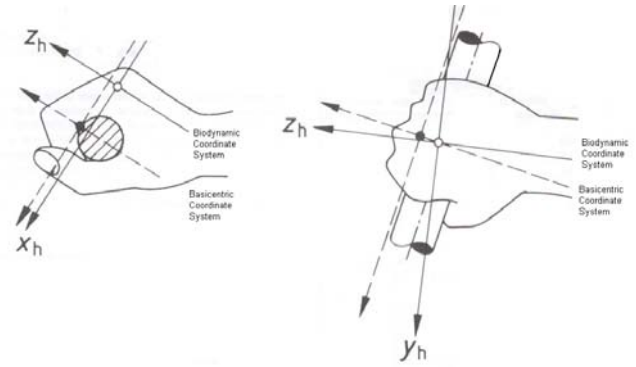

Figure 16.3 Measurement directions for hand-transmitted vibration

The measured vibrations in all three directions are weighted using the W_h weighting depicted in Figure 16.4 to render a_{hwx}, a_{hwy} and a_{hwz}, which reflect the importance of frequencies in the 6 to 22 Hz frequency range in the case of hand-transmitted vibration.

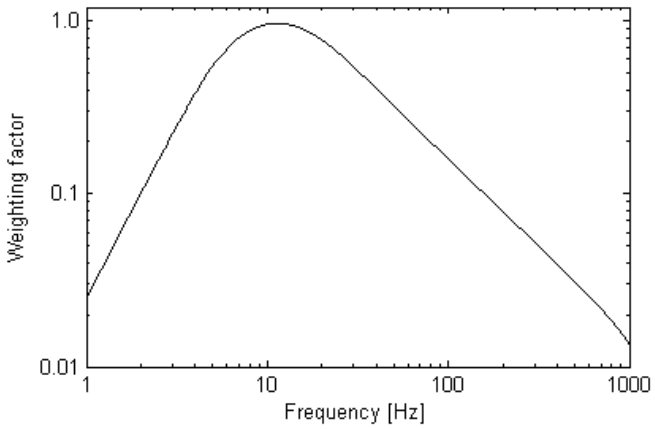

Figure 16.4 W_h frequency weighting for hand-transmitted vibration

The weighted r.m.s. values in the three orthogonal directions are then combined into the root-sum-of squares a_{hv} of the three component values.

From this the daily vibration exposure $A(8)$ is derived assuming an 8 hour energy equivalent value. The standard also provides a method to combine exposures to different levels of vibration into a single daily exposure.

16.3.2 Outline of procedure

Selection of measuring position for both whole body and segmental vibration

Author still to provide factors influencing measurements

Limitations

Author still to provide

16.3.3 Apparatus required

Human vibration measurements are increasingly being done by dedicated human vibration meters. Human vibration meters presently on the market include Brüel & Kjær, Larson Davis, Svantek and 01dB-Stell instruments.

16.3.4 Description of apparatus

Author still to provide

Figure 16.5 A typical human vibration meter

These meters are typically based on a digital signal processor that contains the frequency weightings for whole-body and hand-transmitted, and provides for tri-axial transducers to measure x- y- and z-acceleration.

16.3.5 Care and maintenance

Human vibration meters and the associated transducers are sensitive instruments and should be cared for and maintained strictly in accordance with the supplier's recommendations.

16.3.6 Calibration

Transducers should be calibrated regularly, typically every year.

16.3.7 Measurement procedure

Vibration transducers should be attached to the vibrating bodies under consideration. In the case of whole-body vibration measurements for seated persons a seat pad is usually used while special hand-held adaptors are usually used to grip the transducer attachment to the handles of hand-held equipment.

The duration of vibration measurements should be long enough to ensure that the signal is representative of the process under consideration.

16.3.8 Calculations

The weighted r.m.s acceleration a_w for whole-body vibration assessment is calculated as

$$a_w = \sqrt{\frac{1}{T}\int_0^T a_w^2(t)dt}$$

where $a_w(t)$ represents the weighted acceleration time history in m/s^2 and T is the duration of the measurement in seconds. If the crest factor exceeds 9, more detailed analysis should be performed in accordance with ISO2631.

Using a similar approach for hand-transmitted vibration, the frequency weighted r.m.s. values along the three orthogonal axes may be calculated as a_{hwx} , a_{hwy} and a_{hwz} . These values are then combined into the vibration total value, defined as the root-sum-of-squares of the three components:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2}$$

This value is then used to determine the daily vibration exposure in terms of the 8 hour energy equivalent frequency weighted vibration total value

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}}$$

where T is the total daily duration of the vibration a_{hv} and T_0 is the reference duration of 8 hours.

These calculations are nowadays usually done inside the human vibration meter.

16.4 Reporting and recording

16.4.1 Acquisition of data

Author still to provide

16.4.2 Analysis and evaluation of results

Author still to provide interpretation

16.4.3 Preparation of reports

When evaluation of whole-body vibration is conducted, the following should be recorded: The person exposed to vibration, the configuration of the vehicle or vibrating equipment, the operations under consideration, the location, orientation and identification of the transducers, the r.m.s. values of the frequency weighted accelerations, the weighting functions used, the time period of measurement, the crest factor, as well as any other factors that might influence the measurements.

When evaluation of hand-transmitted vibration is conducted, the following should be recorded: The person exposed to vibration, the tool configuration, the operations under consideration, the location, orientation and identification of the transducers, the r.m.s values of the frequency weighted accelerations in each of the orthogonal directions, the total vibration for each operation, the daily duration for each operation and the daily exposure.

16.5 Bibliography

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2. Griffin, M.J. Handbook of human vibration. Academic Press, 1990.

3. ISO 2631 Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration.

4. ISO 5349 (2001) Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration.

17. Thermal Stress

Author: Johan Kielblock, Consultant.

17.1 Nature of the hazard and its consequences

Of all environmental factors that have a bearing on one's entire life, temperature is arguably the most apparent: it influences our life-style, clothing and fashion, conversations and even our moods. It is hardly surprising, therefore, that 'temperature' or, more appropriately, the thermal environment, also has a major impact on industries.

Thermal stress is unique on several counts. Firstly, it is more complex in view of the number of determinants. This is best illustrated by reference to the body's heat balance equation, namely

$$H \pm K \pm C \pm R - E = 0$$

where **K** represents heat exchange by conduction, **C** by convention, **R** by radiation (non-ionising) and **E** by evaporation of sweat. The term **H** denotes the difference between total energy liberation by the body (**M**) and mechanical work rate (**W**). The term **M – W** may therefore replace **H**. The SIMRAC Handbook of occupational health practice in the South African mining industry[1] provides further details. However, the point to appreciate is that the assessment of risk must be based on environmental factors as well as the physical status of the individual, notably work rate.

Secondly, thermal stress is two-dimensional, i.e. environmental conditions become too 'hot' (heat stress) or too cold (cold stress). Few other hazard exhibits deviations on either side of the 'comfort' (thermoneutral) or safe zone.

Thirdly, irrespective of the nature of the stress imposed (heat or cold), the consequences are acute, i.e. within minutes or a few hours.

The perspectives presented above are intended to underline the complexity of the risk assessment process, as well as the need to establish risk management mechanisms that are both sensitive and responsive. The integration of good occupational hygiene and medical surveillance (Sections 12 and 13 of the MHSA) is fundamental to risk assessment and risk management (Section 11 of the MHSA). An overview of the consequences of thermal stress is given in Table 17.1 and it should be apparent that simplistic assessments of risk based would be entirely inappropriate.

Table 17.1: Consequences of thermal stress

Type	Consequence/Outcome	Risk factors
Heat	Premature fatigue/poor productivity Cognitive dysfunction/compromised safety Heat disorders[1] • heat cramps • heat exhaustion • heat stroke Direct organ/tissue damage[2]	• Excessive environmental heat loads • High DB, WB and GT • Low air movement • Strenuous work • Poor work capacity/endurance fitness • Inherent heat intolerance • Poor health • Poor management/supervision • Age (?)/Gender (?)
Cold	Shivering: poor productivity and compromised safety Frostbite[3] Hypothermia[3]	• High wind chill potential: • low DB and high air movement • Poor management/supervision • lack of insulative PPE

Abbreviations: see below.

17.2. Legislation

17.2.1 Action levels

According to Regulation 9.2(2) heat stress becomes a health hazard when the dry-bulb (DB) exceeds 32,0 °C, the wet-bulb (WB) 25,0 °C, or the mean radiant (MRT) or globe temperature (GT) 32,0 °C. Cold stress becomes a health hazard when the equivalent chill temperature (ECT) falls below 10,0 °C.

There are two scenarios to consider. In the first the assumption is that no previous risk assessment has taken place. Such scenario applies to any new operation or process and the possibility that any given risk exists can only be inferred from an understanding or knowledge of that operation, the specific process or from established precedent. In this respect the assessment of risk relies heavily on the judgement (‘anticipation’) and professionalism of the occupational hygienist.

In the event that the outcome of the above risk assessment fails to reveal health hazards as defined in Regulation 9.2(2), the occupational hygienist’s duty of care is to establish a monitoring system to ensure that the health risk remains within acceptable limits. This process is not dictated by legal formalities but solely by professional ethics and expertise.

An ‘acceptable’ thermal environment may therefore be defined as the zone between, on the one hand, temperatures that do not exceed 32,0 °C DB, 32,0 °C GT or 25,0 °C WB, and, on the other, do not fall below an ECT of 10,0 °C. (‘Comfort’ is an entirely different concept and also, to a certain extent, subjective.)

The second scenario applies to thermal environments that can be defined as 'hazardous' to health. In terms of Regulation 9.2(2) the employer is then instructed to 'establish and maintain a system of occupational hygiene measurements'. However, in terms of Section 5 (Part A2) of the DME Guideline on thermal stress[4], this means that in effect a mandatory code of practice (COP) must be compiled in compliance with that guideline. Table 17.2 provides a summary of the respective thermal zones.

Once again two scenarios emerge. In the first thermal stress levels are indeed deemed 'hazardous to health' but not 'significant'. (The DME Guideline, and Figure 17.1 below, describes this as 'potential risk'.) This means that the respective temperatures do not exceed certain critical limits. For heat stress these limits are DBs and GTs of equal to or below 32,5 °C and WBs equal to or below 27,5 °C. For cold stress the limit is an ECT of not below 5,0 °C. These limits correspond to those applicable to Category D (hot environments) and Category C (cold environments), as listed in the SAMOHP (South African Mines Occupational Hygiene Programme) Codebook[5].

The formalities applicable to this scenario are:

(a) a compilation of a mandatory COP in compliance with the relevant DME guidelines on heat stress but restricted to the assessment of risk and categorisation of the thermal environment,

(b) compliance with Regulation 9.2 (3), i.e. a report to the employer, and

(c) compliance with Regulation 9.2 (7), i.e. a report to the Regional Principal Inspector, the underlying methodology being provided in the SAMOHP Codebook, Section 2.2.

The remaining scenario also applies to 'hazardous' environments but here the health risk is regarded as 'significant'. The formalities to be observed are identical to those listed above although the COP extends to incorporation of formal risk management programmes, i.e. Heat Stress Management (HSM) or Cold Stress Management (CSM). A summary of the respective scenarios outlined above, as well as the associated formalities, are given in Figure 17.1.

17.2.2 Risk assessment and management

The risk assessment – risk management process depends on good communication. In this respect thermal stress is not unique but what sets it apart from other health and safety hazards, as already emphasised, is the acute nature of heat and cold overexposures. The fundamental requirement, therefore, is a communication network that is both sensitive to indicators of risk and capable of rapid response, i.e. 'instantaneous' risk management.

The nature and extent of such a communication network may be deduced from Sections 11, 12 and 13 of the MHSA. A summary is given below.

1. The starting point is the 'identification' and 'assessment' of health and safety risks (Sections 11(1) and 12 (2)).

2. The above findings ('records') must be submitted to the employer and to the Health and Safety Committee to establish a risk management programme (Section 11 (2) and (3)), as well as to the Occupational Medical Practitioner for the purpose of medical surveillance (Section 12 (3)).

3. The risk management programme must be subjected to 'periodic' review, the most significant inputs being those based on occupational hygiene practice and medical surveillance (Section 11(4) and 13 (2) (b)).

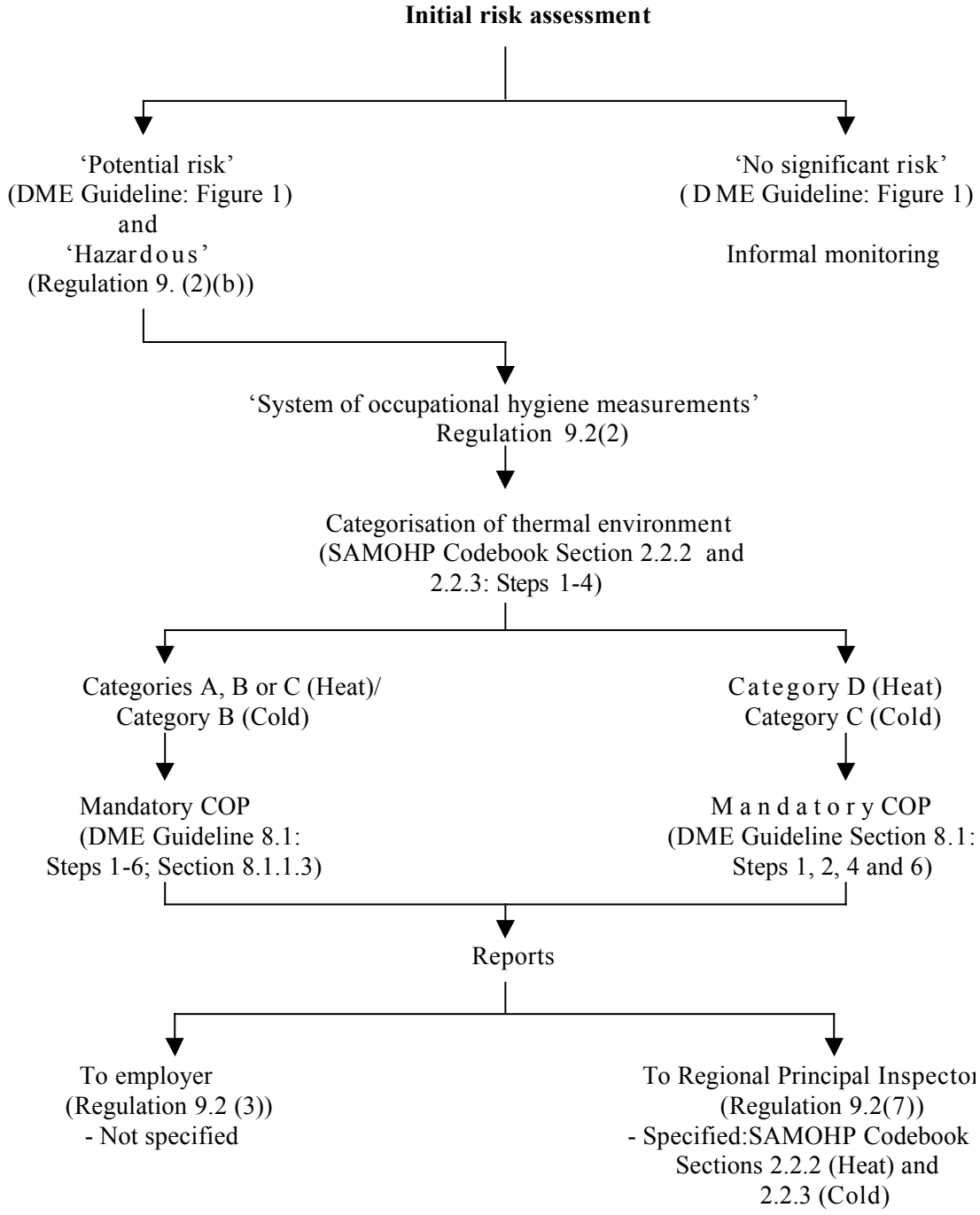

Figure 17.1:Legislation: scenarios and actions

Table 17.2 Categorisation of the thermal environment

Thermal zone	Environment (°C)	Health risk level	Category/action
Heat	DB > 32,5 GT > 32,5 WB > 27,5	Significant[a] to unacceptable	A, B or C[b] Formal HSM[c] EHSI[d] optional
	DB > 32,0 GT > 32,0 WB > 25,0	Potential[a]	D[b] Formal COP
Thermoneutral	DB ≤ 32,0 GT ≤ 32,0 WB ≤ 25,0 ECT[e] ≤ 10,0	No risk	Professional discretion
Cold	ECT < 10,0 ECT < 5,0 ECT ≤ 30,0	Potential[a] Significant[a] Severe[a] to unacceptable	C[b] Formal COP B[b] Formal CSM[c] A[b] Stop work; evacuate

[a]DME Guideline on Thermal Stress, Figure 17.1
[b]SAMOHP Codebook categorisation system (Section 2.2)
[c]Heat Stress/Cold Stress Management (See DME Guideline on Thermal Stress)
[d]Emergency Heat Stress Index (See DME Guideline on Thermal Stress: Annex 10)
[e]Effective chill temperature

Note: There are slight discrepancies between the action levels and actions specified in Regulation 9.2 (2)(b) and those associated with Category D ('Heat') and C ('Cold') in the SAMOHP Codebook. A 'system of occupational hygiene measurements' can only be established and maintained within the context of a COP (DME Guideline on Thermal Stress: Part A, Section 5).

17.3 Methodology

17.3.1 Objectives

The primary risk associated with thermal stress is of environmental origin. The health risk that stems from poor well-being, inadequate work capacity or heat intolerance, although significant, is a subject that falls outside the scope of this reference.

In present context the assessment of the environment must satisfy two objectives, namely

- to ensure that a safe thermal environment prevails on a day-to-day basis, and
- to provide meaningful input to the process of general risk management and review.

The objectives outlined above do not duplicate one another but are dictated, firstly, by the acute development of heat disorders, as well as the high mortality rates associated with heat stroke, and, secondly, the need to establish sound engineering practices and strategies in the longer term.

17.3.2 Basic parameters and instrumentation

The basic environmental or climatic parameters can be deduced from the heat balance equation, namely

- air temperature (t_a) or dry-bulb (DB) temperature,
- humidity of the air expressed in terms of partial vapour pressure (P_a in kPa) or relative humidity (%) or wet-bulb (WB) temperature,
- radiant temperature (t_r) or globe temperature (GT), and
- air velocity (V_a in m/s).

17.3.2.1 Instrumentation in general

The instruments required to assess and evaluate the thermal environment are described in the Instruments Section at the end of this Chapter. Further reference is also provided in Chapters 18 (Rock temperatures) and 22 (Air velocity). The current trend is towards sophisticated all-in-one electronic versions incorporating data logging and downloading capabilities. An example of such instruments is shown in Figure 17.3. The ultimate choice between dedicated and integrated instrumentation will depend on a number of factors, most notably the purpose of the measurement or survey. For example, routine monitoring for the purpose of averting employee exposure to critical escalations in the environmental heat load would only have to focus on wet-bulb temperature in deep-level stoping conditions, or primarily on radiant temperature in foundries. By contrast, air velocity is by far the most sensitive parameter under subzero conditions, as would be encountered during opencast operations in winter.

On the other hand, for the purpose of engineering control strategies, it follows that a more comprehensive database would be required. Such surveys are facilitated by the use of more sophisticated instruments. A fundamental requirement, irrespective of choice of instrumentation, is compliance with recognised standards.

In the event that measurements have to be undertaken within the context of a mandatory COP, the reader is referred to Sections 8.1.15 and 8.1.2.4 of the relevant DME Guideline. These sections are prescriptive but provide no further guidance. To discharge these responsibilities on the basis of ‘best practice’, two options are presented, namely:

- specifying compliance with internationally recognised standards when purchasing equipment, i.e. placing the onus on the manufacturer/supplier, and/or
- incorporating the respective ‘International Organization for Standardization’ (ISO) standards as part of the measurement methodology; in this respect, Table 17.3 provides an overview of the relevant ISO standards.(Further references also appear in Section 3.2.2.)

Irrespective of the option exercised, the use of certified thermometers is strongly recommended for verification purposes.

3.2.2 Parameters of thermal stress

Air temperature

Air temperature is the most common expression of the thermal environment and, more often than not, the least valid. It determines the direction of convective heat exchange between the body and the surrounding air. The cross-over point, for all practical purposes, is an assumed skin temperature of 35 °C. Heat exchange is influenced by air movement and, obviously, clothing.

Table 17.3 ISO Standards for thermal stress management

ISO Standard	Title
7726	Thermal environments - Instruments and methods for measuring physical quantities
2746	Hot environments – Estimation of the heat stress on working man, based on the WBGT index (Wet bulb globe temperature)
7933	Hot environments – Analytical determination and interpretation of thermal stress using calculation of required sweat rate
DIS 9886	Ergonomics – Evaluation of thermal strain by physiological measurements
8996	Ergonomics – Determination of metabolic heat production
9886	Evaluation of thermal strain by physiological measurements
TR 11079	Evaluation of cold environments – Determination of required clothing insulation
DIS 11933	Ergonomics of the thermal environment. Principles and application of international standards

The International Organization for Standardization (ISO), in terms of ISO 7726 (1985), specifies that sensors must have an accuracy of ± 0,2 °C in the range of 10 to 30 °C and ± 0,5 °C outside that range. Moreover, sensors must be protected from radiation without impeding air flow.

The type of sensor is immaterial. Mercury thermometers are cheap but accuracy needs to be verified using certified thermometers. Disadvantages are poor response and the inability to download information. Electronic versions overcome these disadvantages but are expensive and require calibration and maintenance.

Humidity

Humidity may be expressed in terms of:

- dewpoint temperature, i.e. the temperature at which dew begins to form if the air is cooled slowly,

- relative humidity, i.e. the ratio (expressed as a percentage) of the prevailing partial pressure of water vapour to the saturated water vapour pressure at a given temperature, or

- wet-bulb temperature (t_{wb} or WB), i.e. the lowest temperature that can be attained by a wet-sleeved thermometer protected against radiation and ventilated at more than 2 m/s (a whirling hygrometer); the term natural wet-bulb (t_{nwb} or NWB) refers to a wet-sleeved thermometer aspirated by prevailing air movement.

The ISO specifications applicable to 'dry-bulb' thermometers are the same for wet-bulb thermometers although the range extends from 0 to 36 °C. The wick material must be highly absorbent (cotton) material and kept clean. The use of distilled water is recommended, primarily to protect the integrity of the wick.

By precedent and practice the most widely used parameters of humidity in the South African mining industry is WB temperature, as measured by a whirling hygrometer (Figure 17.2). This does not rule out any other instrument or measuring technique but rather that good correlations be established between traditional and novel procedures before adopting the latter.

Radiant Heat

Radiant heat exchange between bodies does not require an intervening medium and is, therefore, independent of air movement. A distinction is made between mean radiant temperature (t_r or MRT), which provides an overall value, and plane radiant temperature (t_{pr}), which considers 'direction' and, therefore, becomes relevant in plants with large sources of radiant heat having a specific orientation to the body. Examples are electric fires, furnaces, a variety of procedures (arc welding) and even the sun.

For most applications, radiant temperature is measured by means of a 'globe thermometer', hence the term 'globe temperature' (GT). A standard globe thermometer consists of a copper globe, 15 cm in diameter and painted matt black so that the coefficient of emission is close to 1,0. The long response time (20 – 30 minutes) can be overcome by using smaller globes. However, adjustments to the basic equation are required to compensate for smaller globes. ISO 7726 specifies an accuracy of ± 2° C in the range between 10 to 40° C (GT) and ± 5° C outside that range.

Air Velocity

Air velocity (or more correctly air speed) can be considered to be the 'mean' air velocity intensity over an exposure time of interest and integrated over all directions, e.g. the square root of the sum of squares of air velocity in each direction. Variation in air velocity is important and ISO 7730 suggests that both mean air velocity and its standard deviation (SD) be calculated. This provides a so-called 'turbulence intensity', i.e. the ratio of the SD to the mean air velocity.

Air movement at temperatures below or above skin temperature lead to convective heat loss or gain, respectively. Air velocities in excess of 5 m/s do not substantially increase convective heat loss. Air movement increases evaporation of sweat and therefore also facilitates heat loss via this avenue.

The range of measurements recommended in terms of ISO 7726 extends from 0,05 to 2 m/s with an accuracy of 5%. Measurements should be expressed as a one- or three- minute average.

Instrumentation falls into two categories. Vane anemometers are very directional and have to be orientated strictly in the direction of air flow. If this is vague or unknown, measurements have to be taken in three directions at right angles to one another. Secondly, the general range of 0,3 (or even 0,5) m/s to 10 m/s (or more) does not adequately cover the 'comfort zone' where maximum velocities should not exceed 0,5 or even 0,25 m/s. (This limitation is unlikely to be relevant to deep-level mines in South Africa.)

Hot wire anemometers complement vane anemometers in the sense that their dynamic range extends to the 0 – 1,0 m/s zone. They are also directional (see above) and instantaneous. Correct positioning, therefore, is critical. See Chapter 22 for air velocity measuring instrumentation.

17.3.3 Data acquisition and analysis

From Figure 1 it will be evident that data acquisition and subsequent analysis should satisfy two requirements, namely

(a) an annual report to the Regional Principal Inspector (Regulation 9.2(7); SAMOHP Codebook Sections 2.2.2 and 2.2.3), and

(b) a report to the employer (Regulation 9.2(3)); this report is not subjected to a prescribed format or time frames.

The respective objectives differ: whereas the former is designed to establish a statistical base for the purpose of overall monitoring, the latter provides input to the risk management process. However, despite divergent objectives, duplication of effort can to a large extent be avoided through proper planning. The most convenient point of departure in this respect is the so-called 'Activity Area' (see SAMOHP Codebook Sections 2.2.2/3: Step 2) because it represents the smallest logical operational unit.

17.3.3.1 Steps

The following steps are proposed.

1. The requirement to introduce a system of occupational hygiene measurements (Figure 17.1) suggests that a 'preliminary' baseline risk assessment be conducted, primarily for the purpose of categorisation of the thermal environment typical of each activity area. 'Preliminary' in this context means that the outcome may not necessarily constitute the annual report to the Regional Principal Inspector. Surveys should include DB, WB, GT and air movement.

2. The formal report to the Regional Principal Inspector differs from the preliminary baseline survey only in that it reflects 'worst case' scenarios, i.e. the summer months (Jan – March) in respect of heat stress and the winter months (June – August) in respect of cold stress. Statistically it should be more robust than the preliminary baseline.

3. Initial input to risk management, especially from a strategic point of view, will stem from baseline surveys and, subsequently, from ongoing monitoring (see below).

4. In view of the acute nature of heat/cold stress, the next step would be to establish an ongoing monitoring programme. The purpose is to cater for a variety of events, planned and unplanned, that may lead to heat or cold overexposure, for example:
    - to cater for essential operational changes,
    - to monitor the efficacy of engineering interventions following control system failure, and
    - to review the thermal stress category, if indicated, as an input to the baseline risk assessment.

17.3.3.2 Procedure

Step 1:

The assumption is that no previous data are available to enable categorisation of a given activity area, although a distinct risk ('potential risk') may be inferred from random checks. (Where such a database already exists, the purpose of this step would be to verify, or otherwise, the category assigned to the activity area under investigation.) Measurements should be recorded and tabulated using the proforma presented in Table 4.

- Ensure that recordings are representative of the entire activity area (i.e. all localities where employees may be required to discharge their duties) and that all occupations are covered. (This approach will determine the number of readings required. The database does not have to be particularly robust at the outset but must under no circumstances underestimate the thermal environment.)
- Base any categorisation on the most critical parameter of the prevailing level of thermal stress (e.g. WB in deep-level stopes) and on the most severe exposures. ('Means' are inappropriate for this purpose.)
- Identify and list the most important determinants (sources) of the prevailing stress level as a preliminary input to risk management.

Step 2 and 3:

This represents a consolidation of data in order to establish a more robust database, as will be evident from the proforma presented in Table 17.4. The data captured at this level serves to (a) generate the Annual report to the Regional Principal Inspector (Step 2) and (b) provides input to risk management (Step 3).

- Ensure that the database is representative of the respective seasons in question (Section 3.3.1; Step 2).
- Data acquisition should take into account that the thermal environment may change from hour to hour during a shift (daily trends) and from day to day (weekly trends). Data analysis should therefore reflect 'worst case' scenarios to ensure that risk management is appropriate to the actual risk. (This is relevant especially where category shifts occur.)
- Use elementary statistics to enhance the quality of the database, e.g. standard error of the mean (SEM) as an indicator of the reliability of the sample mean, and standard deviation (SD), which is indicative of the mean deviation from the mean.

(If measurements reflect actual occupational exposure, a normal distribution of the 'mean 2SDs' represents about 95% (95,45%) of exposed personnel. A more meaningful categorisation of the activity area could therefore be based on the 'mean +2SDs' values for hot environments and 'mean – 2SDs' for cold environments. The absolute range may reflect outliers but should not be dismissed as irrelevant; if dangerous, they should be demarcated as 'no-go' areas.)

- List the essential features of the risk management process in place at the time of the survey so that their efficacy may be subjected to review.

Step 4:

Baseline surveys, if comprehensive and reliable, do not have to be conducted more than once a year. However, as a back-up, it is essential to establish an ongoing monitoring programme.

- Identify for each discrete activity area the most relevant and sensitive parameter(s) of the prevailing thermal stress level. Use only these for monitoring purposes.
- Establish whether or not trends (hour to hour; day to day, etc.) are present and adjust the frequency of monitoring to ensure that category shifts will be able to be detected. (For a stable environment, for example, weekly intervals may be more than adequate.)
- If category shifts occur, irrespective of cause, the activity area in question must be subjected to a full baseline survey and the outcome entered in the baseline records. (The frequency of measurements to confirm the status of the affected activity area may have to be adjusted to ensure a reliable outcome.)
- Respond immediately to any indication of escalating thermal stress, even if only based on subjective perceptions or hear-say evidence.

Table 17.4 Proforma for data acquisition

Step 1: Preliminary baseline survey[1]

Occupations (SAMOHP)	n	Environmental parameters (mean and range)				Category[2] (provisional)	Source(s)
		DB (°C)	WB (°C)	GT (°C)	Velocity (m/s)		

Step 2 and 3: Formal report and input to risk management[a]

Occupations (SAMOHP)	n	Environmental parameters (mean and range)				Category[b] (provisional)	Source(s)
		DB (°C)	WB (°C)	GT (°C)	Velocity (m/s)		

Essential features of risk management (summarise):

Step 4: Ongoing monitoring[1]

Source(s) of thermal stress	Parameters	Measurements (n)	Mean ± SD; range	Category	Category shift (e.g. B to C/Nil)

Recommended routine monitoring programme:
Revisions (provide references):

[a]The proforma tables apply to discrete activity areas; the nature of the stress, 'Heat stress' or 'Cold stress', should be specified.

[b]Base the provisional category on the most severe levels of thermal stress recorded or, where applicable, the 'mean + or - 2SDs' criterion.

Note: It is essential to retain original raw data at least until after completion of the following annual cycle.

17.3.4 Indices

17.3.4.1 Heat

Heat stress indices attempt to integrate a range of factors contributing to heat stress into a single numerical value designed to reflect overall heat strain. This is a complex requirement and, not surprisingly, these indices differ considerably from one another in interpreting a given environment. Moreover, from a risk management point of view, the index obscures the relative importance of those factors on which the index is based.

While useful in many respects and therefore tempting to use, their application requires specialist knowledge and experience. As such, a review of heat stress indices falls outside the scope of this manual. The SIMRAC 'Handbook of occupational health practice in the South African mining industry[1] may nevertheless be considered as a ready reference to heat stress indices. The use of indices is not prescribed and, therefore, remains an option.

17.3.4.2 Cold

By contrast, the only practical index addressing cold stress is the wind chill index (WCI), which expresses the combined effect of air temperature and air movement (speed; velocity) in terms of and equivalent cooling (chill) temperature (ECT). The relevant reference is ISO TR 11079 (Table 17.3). Cold stress must be reported as 'ECT' according to Regulation 9.2(7).

17.4. Reports

The process of risk assessment serves to generate a baseline with respect to the thermal environment, determinants of any ensuing stress and occupational exposure levels. Because of the consequences of overexposure to heat or to cold, risk assessment must be sensitive to adverse trends, even if only of a transient nature. The database would therefore consist of (a) baseline information and (b) the outcome of an ongoing monitoring process.

The database must be able to satisfy two legal requirements, namely Regulations 9.2(3) and 9.2(7). The latter entails a report to the Regional Principal Inspector. The formalities are prescribed whereas with the former no such formalities are specified. However, the nature of these reports may be inferred from Sections 11, 12 and 13 of the MHSA, i.e. providing input to risk management and to medical surveillance (see Section 2.2).

For the purpose of thermal stress risk management two types of reports are apparent. The first is an extension of the report to the Regional Principal Inspector and the basis of this report may be deduced from the proformas presented in Table 4. However, the fundamental objective is that it should facilitate strategic planning with regard to achieving a healthy balance between engineering and personal protection through, for example, the formal introduction of Heat Stress Management.

Thermal stress injury and disorders are true medical emergencies and it follows that reports must be able to be generated (and responded to!) where such events, irrespective of origin, are imminent or may already have occurred. The precise mechanisms cannot be prescribed but there should not be any doubt that this is an integral element of the risk assessment – risk management process. Incidents should be monitored and early-warning/emergency reports

must be extended to 'incident reports', bearing in mind that heat exhaustion and heat stroke are reportable disorders.

The fourth report provides input for the general purpose of medical surveillance which, in fact, is simply an extension of risk assessment, i.e. a health risk assessment. The information required by the Occupational Medical Practitioner comprises, apart from personal particulars, etc., occupation, place of work and thermal stress category. There is therefore a need to establish communication links between Occupational Hygiene, Human Resources and Occupational Medicine for the purpose of exchanging reports that support the risk assessment – risk management process.

In the final analysis it should be borne in mind that risk assessment itself should be subjected to review and modified to remain sensitive and relevant. One of the most useful inputs in this respect is the incidence of heat disorders, particularly with regard to heat cramps: although not serious (or even reportable), epidemic escalations often signify poor environmental control and the need for rapid intervention. (Sporadic occurrences are mostly related to individual responses and have implications with regard to fitness.) Heat exhaustion and heat stroke are extremely multifactorial in origin and it is essential, inter alia, to target environmental control. Frostbite and related incidents are not well documented (if at all) and to rely on such disorders as an input to risk assessment practices would be inappropriate at this stage.

17.5 References

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Instrumentation

The Whirling Hygrometer

Purpose

The whirling hygrometer is used to determine the wet- and dry-bulb temperatures of air.

Theory and Principle of Operation

The hygrometer consists of two thermometers, a dry-bulb thermometer which measures the ambient air temperature, and a wet-bulb thermometer, the bulb of which is kept wet by means of a thin film of water, which measures the wet-bulb temperature.

When unsaturated air passes over a wet-bulb thermometer, water evaporates from the surface of the wet-bulb. The latent heat needed to evaporate the water comes partly from the bulb of the thermometer, which causes the bulb to be cooled. The bulb and its wet sleeve, therefore, become colder than the air and heat flows from the air to the sleeve. Equilibrium is reached when the amount of heat transferred to the sleeve by convection is equal to the amount of latent heat needed to sustain the evaporation.

In saturated air the wet- and dry-bulb temperatures are the same. In unsaturated air the wet-bulb temperature is always lower than the dry-bulb temperature; the drier the air the greater the difference between the two temperatures.

Radiation of heat between the surroundings and the wet-bulb thermometer can play an important part in the reading obtained. In most circumstances the temperature of the surroundings in a mine is roughly the same as the dry-bulb temperature of the air, and, in the absence of shielding, an air velocity over the wet-bulb thermometer of about 3 m/s is needed to compensate for the effect of the radiation. However if accurate readings of air temperatures are to be obtained near a hot body such as a furnace, or in direct sunshine, the thermometer should be shielded.

Description

The whirling hygrometer consists of the following components:

- two identical mercury-in-glass thermometers,
- a light wooden or plastic frame fitted with a handle so that the frame can be whirled,
- a water reservoir with a screw cap, and
- a cotton sleeve to cover one thermometer bulb.

A commonly used whirling hygrometer is illustrated in Figure 17.2.

The thermometers are mounted in the frame in a manner exposing the bulbs and stems to the air and kept firmly in position by cork or rubber pads.

For routine work the thermometers used cover the ranges 0 °C to 50 °C or 10 °C to 45 °C, with 0,5 °C graduations. For more accurate work, thermometers with a smaller range and graduations of 0,1°C are used. In all cases, the graduations on the stems should cross the mercury threads completely.

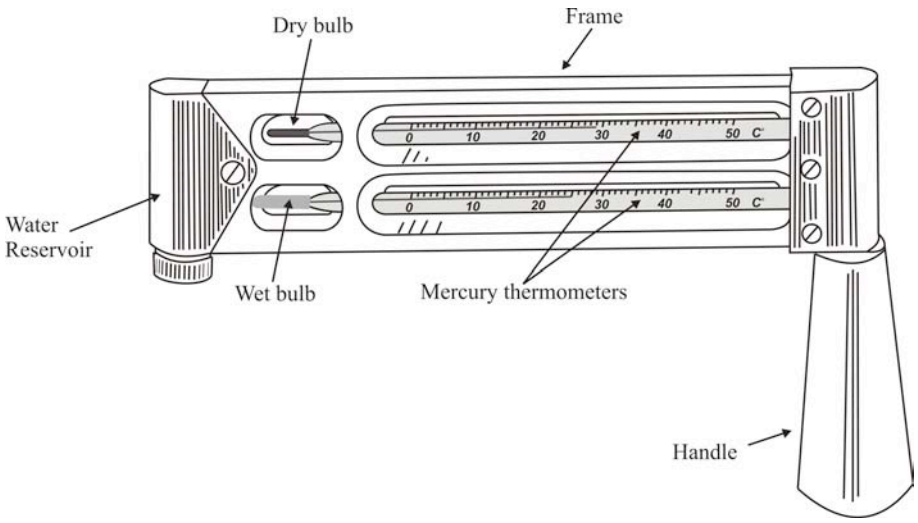

Figure 17.2 Whirling Hygrometer (Ordinary Type)

Precautions Before Use

(f) Thermometers intended for routine work should be checked to ensure that the mercury column is unbroken and that the glass is not cracked.

(g) Readings should be compared with those of a standard thermometer at several different temperatures. Thermometers which give readings which differ by more than 0,2 °C from those of the standard should be discarded. Thermometers to be used in very accurate work should be calibrated by a recognised authority, such as the SABS.

(h) The two thermometers should be set in the frame of the hygrometer in such a way that the two mercury columns can be read without having to move the instrument.

(i) The sleeve must fit snugly around the wet-bulb and must project at least 3 mm beyond the end of the bulb. It should be secured with cotton thread so that centrifugal action caused by whirling the instrument will not cause the sleeve to slide down.

(j) The thermometers and the sleeve must be clean at all times.

(k) The reservoir should be filled with distilled water but tap water may be used. As tap water will gradually contaminate the sleeve with impurities deposited as the result of the continual evaporation of thewater during use, it will be essential to wash or replace the sleeve at regular intervals.

(l) The frame and handle should be mechanically sound.

(m) The spindle should be oiled.

(n) New sleeves should be boiled before use.

Precautions During Use

(a) Observations must not be made near any local source of heat which might affect the readings, such as lamps and machinery. Furthermore, the observer must not place his hands near the bulbs when temperatures are being read.

(b) When the air is humid, condensation is likely to occur on the stems of both thermometers and on the dry-bulb if these are cooler than the air. It will be necessary to continually remove the condensed moisture until the temperature of the thermometer is the same as that of the air.

(c) In dry conditions the sleeve is likely to dry out rapidly. The water in the reservoir must therefore be replenished frequently. In a very dry atmosphere it is necessary to keep a wet cloth around the outside of the water reservoir in order to maintain the temperature of the water supply at about the wet-bulb temperature. This is because the whir- ling of the instrument causes the water to be drawn away from the sleeve by centrifugal action. When whirling is stopped, water from the reservoir (normally at about dry-bulb temperature) rushes back into the sleeve by capillary action and leads to an inaccurate wet-bulb reading.

Measuring Procedure

Expose the instrument so that it will acquire the temperature of the ambient air. This may take some considerable time when the instrument is introduced into a hot airstream from a cold airstream, e.g., in an acclimatization centre during winter when taking the first underground measurement of a day.

Face the airstream and hold the instrument at arm's length in front of the body.

Whirl the hygrometer at a rate of approximately three revolutions per second to give an air velocity past the bulbs of about 3 m/s. Whirling is not necessary when the air velocity is materially greater than 3 m/s.

After whirling the hygrometer for 30 seconds, read the two temperatures as rapidly as possible. The wet-bulb temperature must be read first as it tends to rise when whirling ceases.

Take several readings until consistent temperatures are obtained.

Note: Temperatures should be estimated to the nearest 0,1 °C, although the thermometers are usually graduated in half degrees. The practice of reading temperatures only to the nearest half of a degree leads to inaccuracies and is thus not recommended. The wet-bulb temperature should be listed first because it is read first and is the more important reading.

The Single Wet-bulb Whirling Thermometer

In underground workings where there is a likelihood of the wet-bulb temperature reaching or exceeding 32 °C it has been recommended that frequent measurements of the wet-bulb temperature of the air be made by responsible personnel.

A compact wet-bulb whirling thermometer may be used for this purpose.

Bibliography

1. Shaw, A. The whirling hygrometer. Demonstration and discussion of routine ventilation measurements. J. Mine Vent. Soc. S. Afr., Vol. 11, 1958, p. 77-78.

Multi-Sensing Insrument for the Thermal Environment

Figure 17.3 Multi Sensing Instrument

18. Rock Temperatures

Author: Mike Jones, University of the Witwatersrand.

19. Illumination

Author: Deon Marais, Consultant.

19.1 Introduction

Illumination is required at all places where personnel are required to travel or work. The levels of illumination required are dependent on the type of work being conducted as well as the presence of any special circumstances, such as safety hazards.

The lux meter is used for measuring illumination levels at these places in order to determine whether they conform to acceptable standards for safety and productivity.

19.2 Nature of the Hazard and Consequences

Illumination is required to allow the human eye to discern objects, form, colour and brightness. Without sufficient illumination, a number of potential hazards exist. These typically include:

- Safety hazards associated with low level illumination, which, for example, constitute the risk of bumping into or tripping over obstacles, an inability to discern approaching objects and the risk of falling into cavities;
- Safety hazards associated with over-illuminated situations involving strong contrasts between the background and the illumination source, generally known as glare. There are three fundamental types of glare, namely:
    - Relative glare, caused by contrasts in brightness, which may either cause discomfort to the eye or a disability to discern objects;
    - Absolute glare, too bright for the eye to adapt to, and
    - Adaptive glare, which is temporary and to which the eyes can adapt.
- Physiological hazards, such as:
    - development of a physical condition known as nystagmus which is a condition resulting from poorly illuminated workplaces associated with a bent-over posture during working activities for extended periods. This condition is usually associated with rapid, involuntary movement of the eyeball.
    - Damage to the retina of the eye resulting from overexposure to light, e.g. when looking into the sun

Another safety hazard associated with artificial lighting is known as stroboscopic effect, which occurs when the flicker speed of luminaires match the moving speed of rotating objects, thus leading to an impression that the rotating objects are stationery. In designing lighting systems this effect should be considered where people work, work with or travel in close proximity of such rotating equipment and either the illumination source or, if impossible, the speed of the equipment should be changed.

19.3 Legislation and Standards

The assessment of illumination levels, although not specifically stipulated are covered in the Mine Health and Safety Act, 1996 as amended by the Mine Health and Safety Amendment Act, 1997, in two sections, these being:

- Section 11, which requires that employers are to identify hazards, conduct risk assessments and take reasonable practicable steps to reduce risks identified. Due to the safety and health risks associated with poor illumination, the need for light level assessments therefore is clearly identified, and
- Section 12, which requires that the employer must have occupational hygiene measurements taken to determine appropriate actions and that records must be kept of such assessments as are conducted.

The Regulations associated with the above Act do not specify illumination levels for specific work places or activities. The definition of "reasonably practicable", however, also specifies that cognizance must be taken of the knowledge reasonably available concerning the risk or hazard.

When considering such information, other acts, regulations and standards as may apply elsewhere are also applicable, for example, the Occupational Health and Safety Act and Regulations, where detailed information is given regarding specified lighting levels for a number of applications.

In addition, the Mine Ventilation Practitioner's Data Book, 2nd edition, published by the Mine Ventilation Society of South Africa also contains similar information.

The reader may also refer to the South African National Standards User Code for interior Lighting, SANS 0114, Part1 for additional information on recommended illumination levels for certain activities.

When conducting and interpreting illumination surveys, this information should be consulted so that appropriate deductions can be made as relevant.

19.4 Principle of operation

A lux meter basically consists of a photovoltaic cell connected to a sensitive ammeter, which transmits a signal, either to a display, which is graduated directly in lux, the unit of illumination or to a display, which gives a direct numerical value, also in lux.

A photovoltaic cell contains a light-sensitive element of some material such as selenium, which has the characteristic property of converting the energy of light, which impinges on it into electrical energy. The electrical current produced is directly proportional to the intensity of the light and therefore it is possible, by using a suitable conversion factor, to graduate the ammeter directly in units of lux.

When the cell is not held normal to the light source (i.e. directly facing the light source), particularly when there is more than one light source, some of the light is reflected away from

the surface of the cell and some light is obscured by the frame of the cell. To overcome this problem, a cover of opaque curved glass is employed to diffuse and transmit all the incident light from every angle onto the cell.

Because the sensitivity of a selenium cell to light of different wavelengths (colours) is not the same as the sensitivity of the human eye to these same wavelengths, a compensating glass filter is also incorporated to correct for this discrepancy.
Description of apparatus

There are two instruments commonly in use in the mining industry. These are the analogue (scale and needle) type and the digital, or direct reading output type. These are discussed individually below.

Analogue Type Lux Meter

This is a conveniently small instrument, the indicator measuring 113 X 106 X 48 mm and weighing 0,37 kg while the light sensing cell, which is connected to it by a length of electric cable, measures 29 X 66 X 125 mm and has a mass of 0,24 kg. (Figure 1).

By means of a slide switch the measuring range can be set to either 0-3 000 lux, 0-1 000 lux or 0-300 lux. In each of the ranges an accuracy of 5% of the full-scale value is claimed, which means that readings at the lower end of each scale are not very accurate.

The sensing head has a selenium cell, which is covered by a compensating filter and a globe for obliquity correction and light diffusion.

An instruction manual is supplied with each instrument.

Figure 1 Analogue Type Lux Meter (Yokogawa Type 3281 Lux Meter)

Digital Type Lux Meter

As with the analogue type instrument, this instrument consists of a measuring head containing the photovoltaic cell linked to the body of the instrument by means of a cable (see Fig. 2)

Figure 2: Digital Luxmeter (Goldilux Model --- Lux Meter)

19.5 Outline of procedure

The basic procedures for each of these are discussed below:

Analogue Type Lux Meter

(a) Decide on the position at which the reading is to be taken.
(b) Check the zero setting by covering the sensing head with a hand or a cloth to exclude all light.
(c) Set the meter to the highest scale, 0-3 000 lux.
(d) Place or hold the sensing head on the working surface in a position representative of the effective illumination, while holding the meter in the other hand and ensuring that no avoidable shadows are cast on the sensing head.
(e) Observe the approximate value of the reading. If it is less than 1 000 lux set the meter to the second scale and if it is less than 300 lux, to the lowest scale.
(f) Avoid parallax by lining up the indicator with its image in the mirror behind it.
(g) Make a note of the reading together with details about the place, the work being performed and the position, type, size and condition (cleanliness, etc.) of light sources.
(h) Before restoring the instrument to its carrying case, switch the meter back to the 3 000 lux scale.

Digital Type Lux Meter

(a) Decide on the position at which the reading is to be taken.

(b) Switch on the instrument and check the zero setting by covering the sensing head with a hand or a cloth to exclude all light.

(c) Place or hold the sensing head on the working surface in a position representative of the effective illumination, while holding the meter in the other hand and ensuring that no avoidable shadows are cast on the sensing head.

(d) Observe the approximate value of the reading. This instrument is equipped with a "hold" button, which allows the user to obtain an instantaneous result where illumination levels are fluctuating. By depressing this button, a fixed result can thus be obtained at any given time. The decision as to when the button is depressed depends on the observer. It is therefore possible to obtain approximate maximum, minimum and average levels of illumination.

(e) Make a note of the reading together with details about the place, the work being performed and the position, type, size and condition (cleanliness, etc.) of light sources.

(f) Before restoring the instrument to its carrying case, switch the meter off.

19.6 Selection of measuring points

Careful observation of the work being performed and common sense are essential when deciding upon the actual measuring points. In travelling ways the light meter should be placed on the floor, at a winch or a hoist the measurements may be made at the controls, while at a workbench the measurement will be made where the actual activity takes place.

19.7 Care and maintenance

General care and maintenance of the instruments consist of wiping the photovoltaic cell with a soft cloth. Where dirt or grime has accumulated, the cloth may be dampened with water containing a mild detergent. Care should be taken that the surface of the cell is not scratched or damaged during the process.

19.8 Precautions

Do not expose the photocell to excessive illumination such as direct sunlight because this may cause reduction of its sensitivity and other troubles. The selenium photocell is sensitive to humidity. Although the instruments are generally of a humidity-proof type, it is wise to store them in such a place as will be least influenced by humidity or by mechanical vibration.

Because of potential damage to the surface of the cell, the instrument should always be repackaged in its carrying case directly after use and between measurement sites.

19.9 Calibration

It is useful to calibrate one instrument against another before use (on the premise that more than one instrument is available for the purpose).

These instruments should, furthermore be calibrated annually by an accredited authority.

The Illumination Survey and Report

Before conducting an illumination survey, the following preparations should be made:

- Ensure that the light meter is in good working condition, clean and calibrated
- Evaluate the area to be measured (i.e. determine what activities would apply, e.g. is it an office environment, workshop, underground stope, etc.).
- Check what typical levels of illumination should apply to the area/s to be assessed.
- If possible, obtain a copy of the plan for the area to be assessed (e.g. workshop or office layout, shaft station layout, etc.).

When conducting the assessment, the following should be borne in mind:

- Take the readings where the activity occurs, e.g. on the desk top, at the work piece being shaped, on the walkway where persons are required to work, etc. A rule of thumb is that the reading should be taken on the surface where the observer should be visually focussing during the task or activity.

- When positioning the sensor head, bear in mind the position of the light source relative to the position of the worker's eye. For example, if the light source is behind or above the worker, the sensor head should be facing towards the source. If the light is poorly positioned, e.g. where it causes glare, the sensor should still be facing towards the operator as the level observed on the working surface is that which would be seen by the operator.

Note the type, position and condition of the light source. For example, is it an incandescent or fluorescent type source, how clean is the light and the light fitting, especially where there is a reflector involved, how far away from the working surface id the light source, etc?

Also take note of the light contrast between the work piece and the background. For example, if both the working surface and the background are at similar intensities and colour, it might be difficult for the operator to clearly discern between the two. On the other hand, if the contrast is too great, for example where the background is too bright whilst the work piece is dull, it may also be difficult to discern the detail required to effectively or safely conduct the task.

Check for stroboscopic effects where moving machinery is involved. The observer should also be particularly careful where he/she is not familiar with the working environment that no contact is made with such surfaces.

Note any situations where glare may affect the visual field.

When recording the results, use the workplace plan as far as possible to log precisely where every reading was obtained. Log all results, deficiencies observed and comments in the log book and/or on the plan being used.

Where obvious safety risks are encountered, these should be communicated to the supervisor of the workplace as soon as possible. Where relevant, recommendations on corrective action should be given to remedy the situation as soon as possible.

The final report should contain all relevant information, including:

- The date of the survey
- The name of the observer
- Purpose of the survey (e.g. to determine normal working conditions, to assess emergency lighting levels, etc.)
- Description of the measuring equipment used, including calibration information
- The time of the survey (especially whether it is a day time or night time survey for surface operations)
- The levels measured, preferably linked to the workplace plan in a meaningful way which allows for ease of interpretation
- Sketches and descriptions (including photographs) where relevant
- Comments on luminaire condition, position and effectiveness
- Comments on observed glare, contrast effects, etc.
- Safety equipment that is in use (or should be in use) such as visual aids, goggles, welding glasses, screens over moving components, etc.
- Comments on compliance with recommended illumination levels and use of safety geat
- Recommendations for corrective actions
- Signatures as relevant

In addition to the foregoing, other information that may be relevant, depending on circumstances, may include:

- Status of the visual acuity assessment programme (e.g. have workers been tested and are they tested on a regular basis?)
- Provision of visual aids such as glasses
- Use of such aids
- Condition of the visual aids (e.g. are the glasses or goggles clean, functional and correct for the task?)

The report should be forwarded to relevant supervisors for corrective actions and working instructions to remedy any non-compliances.

In addition, the information should be linked to the occupational health records, where relevant, to ensure compliance to Section 12 of the Mine Health and Safety Act.

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20. Ultraviolet Radiation

Author: Casper J. Badenhorst, Anglo Platinum.

20.1 Purpose

To quantify the ultraviolet radiation power density magnitudes (μWatt/cm^2) emitted from natural (example the sun) and artificial sources to which employees may be exposed.

20.2 Introduction

UV radiation is electromagnetic radiation similar to visible light. Electromagnetic radiation is transmitted in the form of waves. The waves can be described by their wavelength or frequency and their amplitude (the strength or intensity of the wave). Wavelength is the length of one complete wave cycle. For radiation in the UV region of the spectrum, wavelengths are measured in nanometers (nm), where 1 nm = one millionth of a millimeter.

Different wavelengths of electromagnetic radiation cause different types of effects on people. For example, gamma rays are used in cancer therapy to kill cancerous cells and infrared light can be used to keep you warm.

UV radiation has shorter wavelengths (higher frequencies) compared to visible light but have longer wavelengths (lower frequencies) compared to X-rays. UV radiation is divided into three wavelength ranges:

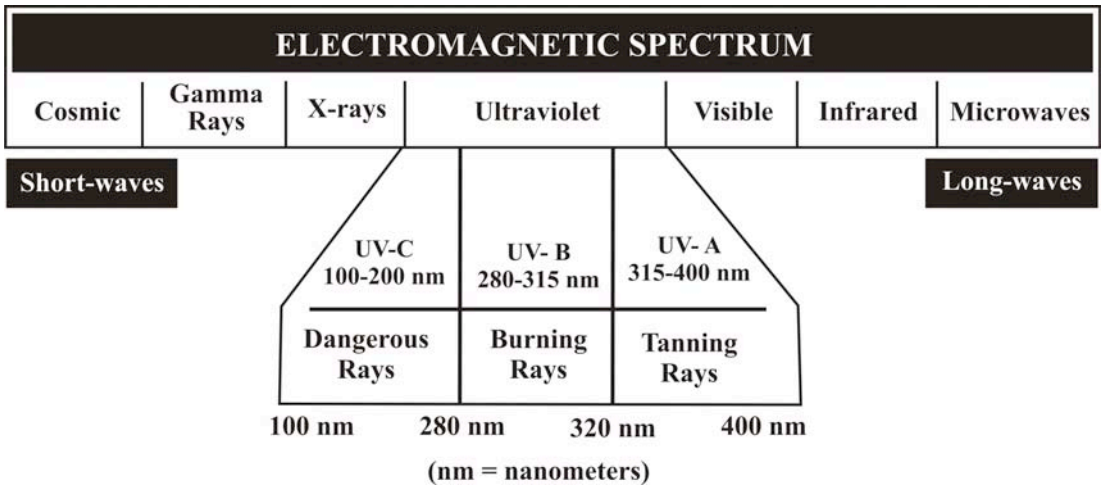

Figure 20.1 - Electromagnetic spectrum

Sunlight is the greatest source of UV radiation. Man-made ultraviolet sources include several types of UV lamps, arc welding, and mercury vapour lamps.

UV radiation is widely used in industrial processes and in medical and dental practices for a variety of purposes, such as killing bacteria, creating fluorescent effects, curing inks and resins, phototherapy and sun tanning. Different UV wavelengths and intensities are used for different purposes. Some UV exposure is essential for good health. It stimulates vitamin D production in the body. In medical practice, UV lamps are used for treating psoriasis (a

condition causing itchy, scaly red patches on the skin) and for treating jaundice in new born babies.

Excessive exposure can damage the skin and the eyes. The severity of the effect depends on the wavelength, intensity, and duration of exposure.

20.3 Occupational Exposure Limit

There are no South Africa regulatory occupational exposure limits for UV radiation. Many jurisdictions follow the limits recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). These limits are given below:

For the UV-A or near ultraviolet spectral region (315 to 400 nm), exposure to the eye should not exceed 1 milliwatt per square centimeter (1.0 mW/cm^2) for periods greater than 1000 seconds (approximately 16 minutes). For exposure times less than 1000 seconds, the dose (total energy) should not exceed 1.0 J/cm^2. Additional exposure limits apply to the amount of UV light exposure to the skin and the eyes. The amount of UV exposure a person can receive on their skin or eyes during an 8-hour period varies with the wavelength of the UV radiation. For specifics, one can consult the Ultraviolet Radiation section of the current edition of the ACGIH publication Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices®.

For the actinic ultraviolet spectral region (200-315 nm; about half of the UV-C and most of the UV-B range), the exposure of unprotected skin or eye should not exceed the values given in Table 20.1 within an 8-hour period. For detailed TLVs refer to the current TLV booklet published by ACGIH.

Table 20.1: Exposure limits for different wavelengths of UV radiation

Wavelength (nm)	TLV (mJ/cm2)*	Wavelength (nm)	TLV (mJ/cm2)*
200	100	270	3.0
210	40	280	3.4
220	25	290	4.7
230	16	300	10.0
240	10	305	50.0
250	7.0	310	200
254	6.0	315	1000
260	4.6		

* TLV is smaller for wavelengths which are more harmful.

20.4 Principle

In general, ultraviolet meters consists of a number of different models of UV-A, UV-B and UV-C meters (with build-in detectors and displays) and a serious of external probes (with build-in detectors, but without displays.

The external probes can either be used in combination with UV-A, UV-B and UV-C meters or together with a non-specific UV meter (without built-in detector, but with display). The non-specific UV meter can only be used in conjunction with an external probe and not by itself.

The instrument measures the power per unit area of the UV radiation falling on the detector.

The meters and probes have been specifically designed and calibrated for use with narrow-band UV sources (most UV lamps). In such UV sources most of the UV radiation is emitted in a narrow wavelength region around a dominant spectral line.

If the UV-A and UV-B meters have to be used for the measurement of wide-band UV sources (which emit UV radiation over a wide range wavelength, like for instance sunlight), this should only be done after having the meters re-calibrated for that specific type of wide-band source. UV-C meters should not be used for measurement on wide-band sources like sunlight at all, quite apart from the fact that there is no UV-C component in sunlight.

A wide range of meters and probes, covering the various UV regions as well as different measuring ranges and application areas are available.

20.5 Methodology

1. Remove the instrument from its case and plug in the external probe (if used) and mount or place the instrument in the position in which the measurements are to be made. The detector must face the source.

Figure 20.2 The Oriel GoldiluxTM UV meter fitted with an UV-A Smart probe

2. Switch on the instrument and check its zero with the detector cap firmly on the detector (of either the meter or the probe, depending on which is being used for the measurement). A zero adjustment may be performed at any time without affecting the calibration status of the instrument.

3. Remove the protective cap from the detector being used.

4. Record reading. If the probe range selector switch is at a setting other that x1, the reading must be multiplied by the selected range factor.

20.6 Instrument maintenance and precautions

- Avoid touching the detector as natural oils and acids from the skin may form a layer, on the detector which absorbs UV, our could etch and damage the surface of the detector.
- When not in use, always put the protective cap on the detector and keep the instrument in a safe place.
- If necessary, clean the detector with a soft clean cloth or tissue moistened with alcohol. Dry and polish lightly with a dry tissue.

20.7 Reports

It is vitally important that the findings of UV measurements are recorded. Reports serve many purposes e.g. communication, triggering an emergency and (very important) an input to risk management. Whatever format the reports, it must be easily accessible to employees, their representatives and to inspectors. Although the recording and reporting of occupational hygiene measurements is important, the generation of a paper system is not. The documentation system should not detract from the major purpose of the measurements; that is, to improve the management of risks and thereby ensure the health and safety of employees.

Appropriate systems should be put in place to ensure that the results and findings of occupational hygiene surveys are reported to management and the Occupational Medical Practitioner. Adequate information should be kept to enable reporting on the management of occupational health risks and the reporting on occupational hygiene surveys must enable management to take appropriate and preventive action.

20.8 References

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21. Ionising Radiation

Author: Andre van der Linde, Anglo American plc.

21.1 Introduction: Sources of Natural Radiation and Potential Health Consequences

Radioactive substances that occur naturally originated from either of three "parent" substances namely 232-Thorium, 238-Uranium and 235-Uranium. The sequence of the "parent" atom decaying into a lower atoms (new elements) over many thousands of years has resulted in a situation where a mixture of radioactive substances exists in the terrestrial environment, for example, an ore body. One of these decay series, 238-Uranium that gives rise to the 222-Radon found at mines, is depicted in Appendix A. Note that the 232-Thoron series of radioactive nuclides, giving rise to 220-Radon, is sometimes also found in mines, together with the 238-Uranium series.

Radon is the only gaseous element in these series. If radon and its precursors are present in the ore, it will continue to be produced and continue to emanate into the excavations, and mix with the ventilating air or any other carrier, such as fissure water. Lesser amounts of ventilating air will result in higher radon gas concentrations in these excavations and development and worked out areas.

Radon, per se, does not pose a significant risk because

a) it is an alpha emitter (little penetrating power) and has to be inhaled before it can pose a risk, and

b) being a gas, it is continuously inhaled and exhaled during the shift; personnel are, therefore, effectively exposed to one lung volume (about five litres) during a full shift.

Due to the relatively short half-life of radon a significant amount of the radon in the ventilating air will decay into its short lived progeny. This progeny consists of metallic atoms and are highly ionized. They readily attach to any surface, especially airborne particles (dust), and are then inhaled by exposed employees.

Respirable particles remain in the lungs when inhaled. Therefore, at a typical respiration rate of 1,2 m^3/hour, persons will be exposed to the equivalent of eight to ten m^3 of radon progeny during an eight-hour shift.

Other Forms of Natural Radiation

Other decay series occur naturally and some radionuclides have long half-lives. Beta and gamma radiation, i.e. external radiation, is also emitted by some of the members of these decay series.

If radon is demonstrated to be present in ore, then persons might also be exposed to the other types of radiation and the health risk is expressed in terms of the total radiation dose as the sum of:

Alpha radiation from the Short-lived Radon Progeny

Alpha radiation from the Short-lived Thoron Progeny

Radiation from the Long-lived alpha emitters

External (beta and gamma) radiation

21.1.1 Health risks associated with natural radiation

The biological effect of all ionising radiation is associated with the ionising properties of the radioactive particles or electromagnetic waves emitted that could cause mutation, cancer and cell death. The differences in health risk of the various types of radiation lie in the penetrating power, the linear energy transfer and the energy of the particular particle/wave. For example, alpha particles have almost no penetrating power and have to be inhaled or ingested to pose a health risk. Once inside the body, it is capable of transferring all of its energy to surrounding tissues and organs. External gamma radiation, on the other hand, has strong penetrating power (stopped by about one metre of concrete) and personnel would be exposed to that radiation by merely being in the vicinity of the source. This type of radiation has a low linear energy transfer and only a small amount of its ionising energy is transferred while traveling through the body.

The dose-response relationship of all ionising radiation is linear (stochastic or predictable) and, therefore, the cumulative dose from radiation is the parameter considered. For example, the detriment associated with ionising radiation at operations is determined by the radiation dose incurred by individuals and the number of persons potentially exposed.

21.2 Legislation

South Africa

Natural nuclear radiation in South Africa is regulated by the Department of Minerals and Energy. The National Nuclear Regulator administers this function in terms of the National Nuclear Regulations Act of 1999.

The ICRP provides recommendations and guidance on all aspects of protection against ionizing radiation

The IAEA is the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field. Provides news and recourses.

21.3 Methodology

21.3.1 Units of expression of dose

It should be evident from the introduction that the risk associated with radon is very much time dependent. If radon could be removed soon after it enters the workings, there will also be lesser amounts of its progeny. If the same amount of radon is allowed to remain due to

poor ventilation, more of the short-lived daughters will be formed and the health risk of inhaling those will be greater. This time dependent relationship is depicted in Figure 11.1.

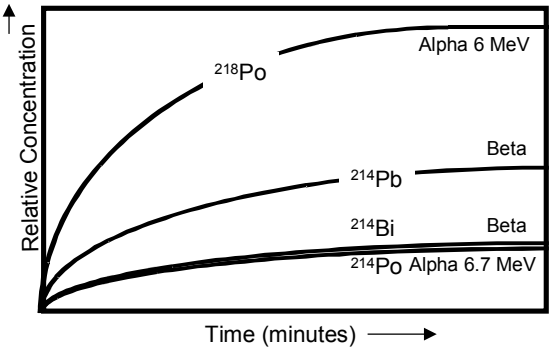


Figure 11.1 Time dependence of radon progeny.

The standard unit of radiation measurement is the Bequerel[1] (Bq). From the above it should be clear that this type of measurement is not only an indirect measurement of radon gas, but also an indirect measurement of the alpha energy concentration. In this regard it should be noted that 218-Polonium and 214- Polonium emit alpha particles at different energy levels (electron Volt).

The alpha energy associated with the short-lived radon progeny is expressed in Working Level (WL). This is the basic unit for expressing health risk associated with radon progeny.

$$WL = \frac{F \; x \; [Radon \; in \; Bq/m^3]}{3700}$$

where F = the ratio of radon progeny to radon gas. The potential alpha energy concentration of 3700 Bq/m^3 of radon = 0,34 WL.

F will be larger in poorly ventilated areas where the radon has had an opportunity to decay into its progeny. In mines the F factor may vary between about 0,2 to 0,5 in ventilated areas and up to 0,8 to 1 in poorly or unventilated areas, i.e. sealed off old areas or the basement of houses.

Because radon is commonly measured, limit values (action levels or exposure limits) have also been set based on the radon activity concentration (expressed in Bq.m^{-3} or B.m^3.hr). However, conservative F factors are usually used to set these limits, as shown in the examples given below, the exposure limit being 0,34 WL.

$$\frac{0.4 \text{ x } [3\,100 \text{ Bq/m}^3]}{3700} = 0.34 \text{ WL}$$

versus

$$\frac{0.8 \text{ x } [1550 \text{ Bq/m}^3]}{3700} = 0.34 \text{ WL}$$

[1] Bq is equal to one disintegration or nuclear transformation per second.

In the first instance the limit based on the radon concentration will be set at 3 100 Bq.m^{-3} and in the second instance the limit will be set at 1 500 Bq.m^{-3}. Unless "F" is known, it is more appropriate to measure the actual radon progeny activity in areas where the risk of exposure is significant. Those techniques are, however, more complex and expensive, and trained persons are required to conduct and to interpret the findings.

When assessing the health risk of personnel in any specific environment, the potential dose from all applicable types of radiation must be assessed and the following factors become relevant, namely:

- accounting for all types of ionising radiation applicable,
- accounting for the exposure pathway (inhalation, ingestion, external), and
- accounting for the dose-response (toxicity of specific type of radiation).

The total dose is expressed in a common unit called a milliSievert (mSv) and the potential annual radiation dose is determined by the summation of all the different types of radiation exposures as follows (similar to the calculation of the Air Quality Index):

$$\text{Total Dose} = \left[\frac{WL_{RnProgeny}}{\text{limit}} + \frac{WL_{TnProgeny}}{\text{limit}} + \frac{\text{Long-lived Alpha}}{\text{limit}} + \frac{\text{Gamma}}{\text{limit}} \right] \text{x } 20 \text{ mSv}$$

Note that radon does not feature in this equation

The following factors apply when potential annual dose is assessed:

0,34 WL Rn progeny for 2000 hours	=	20 mSv.a^{-1}.
1 WL Th progeny for 2000 hours	=	20 mSv.a^{-1}.
3100 Bq.m^{-3} Rn gas for 2000 hours (F= 0.4)	=	20 mSv.a^{-1}.
0,96 Bq.m^{-3} Long-lived alpha (ore) for 2000 hours	=	20 mSv.a^{-1}.
10 Sv.h^{-1} Gamma radiation for 2000 hours	=	20 mSv.a^{-1}.

Therefore:

$$\text{Potential Total Dose} = \left[\frac{WL_{RnProgeny}}{0.34} + \frac{WL_{TnProgeny}}{1} + \frac{\text{Long-lived Alpha}}{0.96} + \frac{\text{Gamma}}{10} \right] \text{x } 20 \text{ mSv}$$

$$\text{Annual Dose} = \textit{Potential Dose x } \frac{\textit{Annual Hours Worked}}{2000} \quad \text{mSv.a}^{-1}$$

21.3.2 Reporting data

The recording and reporting of data are detailed in Appendix B.

21.3.3 Exposure Scenarios

Radiation exposure scenarios in the surface and underground environments are significantly different. In the underground environment the major potential dose results from radon emitted from the ore which decays into its progeny and which are inhaled by personnel. In some instances long-lived alpha emitters and external radiation may also contribute to the dose.

In surface environments, because of its low emission rates and dilution into the air, radon and its progeny are normally not regarded as significant. Here the major contributors to dose are the long-lived alpha emitters and sometimes also external gamma/beta radiation.

The limit on exposure of the public is about two orders of magnitude lower (more strict) than those for occupationally exposed persons. The emanation or 'export' of all types of radiation from the mine should, therefore, be monitored. This includes radon and dust, contaminated scrap material and other effluents such as water ways.

21.3.3.1 Assessment of potential dose underground

The focus on underground radiation risk assessment is on an evaluation of the levels of radon progeny that personnel may be exposed to. In principle an understanding must be developed of the rate of radon emanation and to what extent it is diluted and carried away by the ventilating air. Assessments are, therefore, conducted of radon gas and radon progeny. The former is usually conducted by use of the "Track Etch" technique and the latter is conducted by using techniques that collect airborne particles (to which the radon progeny is attached) and an analysis of the short-lived alpha activity associated with these particles.

In addition to the radon progeny, external radiation and long-loved alpha radiation may also contribute to the total radiation dose.

a) Activity concentration of radon gas

The Radon Gas Monitor (RGM) is a passive monitor that operates on the alpha particle etched-track principle. It contains an alpha radiation sensitive film which is influenced by the alpha radioactive decay of radon gas that diffuses into the cup during the deployment period. Following deployment, the RGMs are submitted to the supplier where the film is chemically etched to expose the spots where alpha radiation penetrated. The number of etched spots on the film is a function of the radiation activity concentration of radon gas. The results are, therefore, expressed as Bequerels per cubic metre ($Bq.m^{-3}$) and not in the volume/volume units generally used for gas concentrations.

Factors influencing measurements

Background Radon Levels: RGMs are dispatched to the user by means of a courier or the postal system in airtight material to prevent the ingress of radon gas whilst in transit and prior to deployment. Long storage and dispatch periods must be avoided. The RGMs received from the supplier should be deployed within seven days and the seal should not be broken more than 12 hours prior to deployment. The same principle applies with respect to RGMs retrieved after deployment. It further implies that, while stored RGMs may be locked away, it should be in well-ventilated areas such as an office and not in a poorly ventilated basement.

Additional RGMs must be ordered with each batch and should be treated like filter blanks in all respects, except that these blank RGMs are not deployed.

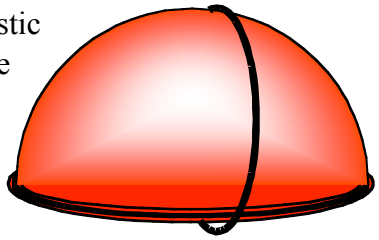
The above limitations call for appropriate administrative arrangements and quality control in respect of the supply and return of RGMs and their identification numbers.

Limitations: RGMs are relatively unaffected by temperature variations and moisture. However, care must be taken where they could be exposed to excessive moisture such as fandrifts. In those cases the RGMs should be sealed in plastic containers, i.e. sealed bank sachets.

Apparatus and facilities required

The availability of appropriate storage facilities applies particularly if RGMs are used for personal dosimetry. For example, RGMs are collected and returned before and after each shift by selected workers during typical deployment periods of two months. The facility for storage of deployed RGMs between shifts must, therefore, be carefully selected in terms of convenience and of an unwanted build up of background interference.

Description of apparatus



RGMs are provided in the form of a 45mm halve spherical plastic container which holds an alpha radiation sensitive film. While the lid at the bottom fits tightly, it is not air tight to allow gases (including radon gas) to diffuse into the plastic container. There is no requirement to open the RGMs and a cable tie is fitted to prevent tampering with the units. These cable ties are usually also used for fastening the RGMs to structures during deployment.

Experience has demonstrated that RGMs may be prone to theft due to their compact structure, light weight and conspicuous colour. While the loss of deployed RGMs is not associated with significant replacement cost, the loss in terms of resources employed for the deployment of the RGMs and consequent delays in the surveillance schedule may be significant.

Care and maintenance: RGMs must not be opened, other than by the supplier, and no maintenance is required.

Calibration: The calibration of RGMs is the responsibility of the supplier, who must be accredited by a national standards authority in respect of maintaining approved analytical procedures and an international calibration reference. Proof of this status should be on record for users of RGMs.

Measurement procedure

Deployment: RGMs are provided ready for use. The monitors are placed at working places or any other area of interest (including the public domain) or on persons for periods of time as dictated by the survey plan. At the end of deployment period the RGMs are retrieved and submitted to the supplier for analysis to determine the time-weighted radon gas concentration to which the RGMs were exposed (on the person or in the environment).

A survey sheet should be established for each batch of RGMs deployed (see Appendix B).

In principle sampling positions are selected to demonstrate the emanation of radon and the dilution and ventilation route of the radon, e.g. in the intake airways, in stopes and in return air.

It is preferable to deploy RGMs in groups of three at the same location for statistical and quality assurance purposes. Exposure times vary from two weeks to two months, depending on the expected levels of radon gas.

The RGM, being light-weight, compact and not sensitive to temperature, moisture or gamma radiation fields, presents almost no limitation in respect of where it could be placed.

Provided that excessive moisture and vibration are avoided, the only consideration regarding the placement RGMs are that the location is representative of the air (ventilating or other) being monitored and that it is protected from physical damage and potential loss.

The deployment periods for RGMs underground are typically two months.

Personal Monitoring: Suitable methods for the attachment of RGMs to the person should be established, depending on site-specific circumstances. Attachment of RGMs to the hard hat or the cap lamp are often preferred options.

The deployment period for RGMs used for personal monitoring is typically two months.

Calculations

No manipulation of the data is required. The responsibility for quality assurance on the analytical processes lies with the supplier (see "Calibration" above). The validity of the results then becomes dependent only on the deployment strategy in respect of representation of the locations to be monitored.

Evaluation of results

The lower level of detection (LLD) is about 22 $Bq.m^{-3}$ per month or 11 $Bq.m^{-3}$ per two months, etc. (Refer to Section 11.3.3.1 for further information on the evaluation of results and the reporting of data).

With reference to Section 11.3.3.1, other important parameters, such as the "age" of the radon air, which gives rise to variations in the radon to progeny ratio ("F" factor), the radon plate out rate (the rate at which radon attach to surfaces other than dust) may also be important parameters to consider in some instances. These parameters may be determined by use of the ML98B Alpha Radiation Spectrometer discussed below.

References.

1. Supplier's manual.

b) Activity concentration of radon progeny

The ML98B alpha radiation spectrometer provides a facility for the assessment of mainly the radiation activity concentrations of the short-lived alpha progeny of radon. It can also be used

for the assessment of other important parameters, for example, of the activity concentration of radon gas and of long-loved alpha radiation emitters.

The short-lived alpha progeny of radon usually adsorbs very fast onto airborne particles and the rate of breakdown of the progeny is time dependent as shown in Figure 11.1. The radiation emitted from these short-lived alpha emitters could be measured by collecting the airborne particles.

The principle of the operation is, therefore, to sample the dust onto a filter and to simultaneously measure the specific alpha radiation emitted from each individual radon daughter. This sequence of events has been programmed into the ML98B and it is called the "Batch Method" of short-lived alpha assessment. The unit of measurement is the "Working Level" (WL) as referenced in Section 11.3.1.

Outline of procedure

The ML 98 is portable and is taken to the site of measurements. Each measurement takes about nine minutes and several measurements could be taken during a shift.

Selection of measuring position/site:

The selection of measuring positions to be monitored is beyond the scope of this book. These measuring positions are to be determined by the responsible radiation protection officer in line with an approved overall radiation survey plan for the operation. In principle sampling positions are selected to demonstrate the emanation of radon, the dilution by ventilating air and the ventilation route of the radon, e.g. in the intake airways, in stopes and in return air.

Factors influencing measurements

The operation of the ML98 is automated and, apart from calibration and maintenance requirements, the only factors that could influence the results or assessment are the selection of the sampling position and the use of contaminated filters. The ML98 could be used in high humidity conditions, but not in areas where high levels of mist occur, i.e. fandrifts where condensing atmospheres prevail.

Apparatus and facilities required

Apart from the normal charging and storage facilities, no other facilities specific to the ML 98 are required.

The dimensions of the ML98 are 55 mm x 110 mm x 240 mm and it has a mass of about 1,2 kg. The spectrometer is coupled via a connecting cable and suction tube to a personal air sampler calibrated in respect of flow rate (1,9 l/min.) by the same procedures used for gravimetric sampling. An electronic modification allows control of the pump by the spectrometer.

A filter cassette (25 mm diameter, 0,8 micron pre size cellulose nitrate filter in modified cassettes) is inserted into the filter drawer of the spectrometer and the instrument started to perform measurements.

For the Batch Method the spectrometer records and calculates all pertinent data gathered during a one minute background measurement, four minute sampling time (during which air is drawn through the filter to collect dust particles) and four minute measuring time sequence. The concentrations of the individual radon daughters and radon are stored in memory, together with the "potential Alpha Energy Concentration' (PAEC), age of the air and the equilibrium factor ('F' Factor). These data could be retrieved by interface with a personal computer using the RAMOS programme. The Working Level (WL) is displayed at the end of each measurement.

Care and maintenance:

The only routine maintenance required is the recharging of the batteries. The supplier should conduct annual maintenance. Any damage or malfunction should be referred to the supplier. Do not attempt to clean the face of the detector inside the filter drawer compartment.

Calibration:

An accredited institute must perform the calibration of the alpha spectrometer and the instrument must be calibrated:

- after any repairs or modifications to the instrument,
- whenever the functioning of the unit is suspect, and
- annually and at intervals not exceeding 14 months.

Records should be kept of the calibration history, calibration certificates and calibration record sheets for inspection by the National Nuclear Regulator. See Appendix B.

Calculations

The Potential Alpha Energy Concentration (WL, PEAC) is calculated by the instrument and requires no further manipulation. The interpretation of other parameters provided by the ML98, such as individual radon daughter concentrations, the age of the radon air and the 'F' factor should be conducted by competent and trained persons.

The validity of the results, including traceability, accuracy, precision and repeatability is a function of the calibration and checks performed as indicated above.

Evaluation of results

The instrument readings are linear between 0,1 - 2 000 J/m^3 (0,005 - 100 WL) PAEC and the PAEC sensitivity is within 0,1 J/m^3 (0,005 WL) at a sampling rate of 1,9 l/min (See section 11.3.1 for an evaluation of results).

References.

Manufacturer's manual.

c) Measurement of long-lived alpha emitters

Personal and environmental measurements are conducted by use of essentially the same techniques. Only the method of collecting the dust samples differs (on the person, vs in the environment) in respect of the two types of assessment.

The ML98B radiation spectrometer is used for the assessment of long-lived alpha activity on airborne dust particles in conjunction with conventional respirable dust sampling apparatus. The principle of operation and facilities required, care and maintenance and calibration of these instruments are described in the relevant sections.

Respirable dust is collected in the conventional way onto a filter and the sample is aged for a period of seven days to allow the short-lived alpha emitters to decay. Thereafter the filter is transferred to the ML98 for measurement.

Selection of measuring position/site:

Personal dust samples, collected for the assessment of dust exposures, are generally also used to assess personal exposures to long-lived alpha radiation. In other instances air borne particulates in any environment of interest could be sampled.

Factors influencing measurements

Since the same dust samplers deployed for gravimetric sampling and the ML 98B are used for the assessment of long-lived alpha radiation, the same limitations, health effects and influencing factors described earlier apply.

In addition, it should be noted that too much dust on the filter (typically in excess of 5 $mg.m^{-3}$) would result in an underestimate of long-lived alpha emitters.

Measurement procedure

After allowing the short-lived radionuclides to decay for seven days the remaining long-lived alpha activity is measured by using the ML98B spectrometer in accordance with the manufacturer's procedures.

Radioactivity count rates of long-lived alpha emitters are usually relatively low and a thorough distinction between normal background counts and counts from the sample has to be made. Procedures for the assessment of background activity and the lower level of detection are given in Appendix B.

Validity of results, including traceability, accuracy, precision and repeatability of the results, is dependent on the assessment of the Lower Level of Detection (LLD) and the calibration, maintenance, etc. of the instrumentation used.

The following records should be maintained by the RPO for quality assurance

- Results of measurements and calculations
- All background checks and ongoing long term averages.

Evaluation of results

The radiation toxicity of different long-lived radionuclides varies and should be accounted for in certain instances (see Section 11.3.1).

References.

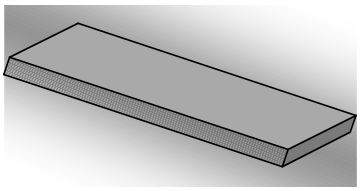
Radiation protection procedure for mines: ML98B Portable Radiation Spectrometer, CSIR Miningtek, January 1994.

c) Measurement of external radiation

Large amounts of natural radiation (such as in an ore body) may also be associated with significant amounts of external (penetrating) gamma radiation. The mere presence in the vicinity of these emitters will result in exposure to external radiation. These may also be assessed by use of passive or direct reading portable dose rate meters.

Thermo-Luminescent Detectors (TLD)

The TLD uses an electron trapping process. Exposure to beta/gamma radiation results in electrons being gathered in energy traps existing within the semiconductor material of the TLD chips and stored there for prolonged periods of time.



After the exposure period, the TLD chip is heated. This allows the trapped electrons to be released, producing a small but detectable amount of light. The light emission is proportional to the number of trapped electrons, which in turn is proportional to the integrated beta/gamma dose received by the chip during the exposure period. To “clear” the TLD for re-use, the TLD is annealed following temperature elevations in excess of 200°C.

TLDs are deployed similarly to Track Etch, except that the area or persons selected for assessment may vary. They could be deployed for assessment of external radiation in the work place, for personal dosimetry or for environmental monitoring. TLDs are ordered from the SABS, deployed for periods of time and resubmitted to the SABS for analysis.

Factors influencing measurements

- Storage: TLDs should be stored in a low background area, i.e. < 0,2 μSv per hour.
- Tampering: Attempt to open the plastic cover should not be permitted.
- Temperature: Area and environmental TLDs should not be allocated to positions where temperatures exceed 40°C.
- Shielding effect: Care should be taken not to place area and environmental TLDs inside objects, i.e. pipes, tanks, etc., which could shield the TLD from the radiation field under surveillance. Remember: For example, the battery of the caplamp provides a 17% shielding effect.
- Fading effect: The SABS assumes a fading effect of 9% per month due to signal loss. Correction for fading is done by the SABS during their analysis.
- Humidity: Water can have an affect on the TLD results, i.e. due to absorption of a portion of beta radiation.

- Exposure period: TLDs should not be exposed to less than one month (unless for a specific operation) or more than three months.
- Reportable dose: TLDs have a minimal reportable dose of 0,2 mSv. Values below this level are not recorded by the SABS.
- Low energy betas: Low energy beta fields are not recorded by the TLDs.

Description of apparatus

All maintenance and calibration requirements are fulfilled by the SABS. This, however, require that at least two "control" TLDs should be retained in a low background area on surface for an assessment of potential background radiation levels.

Measurement procedure.

The principles of deployment of TLDs are the same as those for Track Etch, including ordering and dispatch facilities, arrangements for storage and background assessment, etc. The locations and persons selected for assessment are, however, dictated by the survey plan established for the specific operations.

Evaluation of results

Section 11.3.1 outlines the general evaluation of results. The validity of results, including traceability, accuracy, precision and repeatability of the results, is the responsibility of the supplier of TLDs who must be accredited by national standards authorities in respect of maintaining approved analytical procedures and an international calibration reference.

References

1. South African Bureau of Standards

Scintillation Detectors

Portable dose rate meters are used as low level gamma survey monitors incorporating an internal Geiger-Muller detector. These instruments are low field gamma survey meters that measure absorbed dose in µSv/h and µGy/h.

These instruments are portable and spot measurements are conducted at the site. Measurements are applicable to any site where the presence of external radiation is suspected on surface and underground.

Factors influencing measurements

Magnetic fields influence the accuracy of results. (Even a small handheld magnet can influence the reading). These instruments are not very responsive to low energy X-rays, albeit that man-made radiation is excluded from the scope of this book. Exposure of these instruments to water, acid and high condensing atmospheres and contamination must be avoided (In very wet areas the monitor can be wrapped in a plastic bag).

Apparatus and facilities required

Apart from storage facilities, no other facilities are required for the routine operation of the instruments.

Care and maintenance: The only routine maintenance to be conducted on the monitor is the replacement of the batteries. Note that any other maintenance, i.e. replacement of monitor parts, etc., should be referred to the supplier.

Calibration: An accredited authority should calibrate the instrument at least annually and following any damage, repairs, etc. The calibration procedure includes the use of three gamma energies namely Cs-137, Am-241 and Co-60.

A check source should be used to determine the monitor's operability prior to each day's use. It is important that the same check source should used and that the check be conducted at the same location as the background check.

Measurement procedure

Measurements are conducted on contact and at one metre distance from the object to be monitored. Measurements at 1 metre distance (typically at waist height) should be conducted with the monitor held parallel to the ground and with the instrument held in front of the operator.

Calculations.

No manipulation of the readings is required since the readings are provided directly in dose rate units ($\mu Sv.h^{-1}$). The validity of results is dependent on the quality of the calibration record and checks as discussed.

Evaluation of results

Evaluation of results are covered in Section 11.3.1

References.

1. Relevant instrument manual for Portable Dose Rate meters.

11.3.3.2 Assessment of potential dose in surface workplaces

The focus on radiation risk assessment in surface workplaces is on an evaluation of potential dose from external radiation and long-lived alpha emitters that personnel may be exposed to. Radon and its progeny normally contributes insignificantly to the potential dose because of low emanation rates and high levels of dilution by ventilating air.

The same techniques described for the assessment of external radiation and long-lived alpha emitters underground are used to assess potential exposures.

Due to the beneficiation processes in surface plants, radionuclides may be concentrated in various ways, including unwanted scaling of equipment. The associated long-lived alpha and external radiation should be assessed by use of radiation contamination meters.

a) Measurement of radiation contamination

Direct reading, hand held instruments, with a large window dual phosphor scintillation detector (typically 49 to 100 cm^2 sensitive area), are used for the monitoring of alpha and beta contamination.

The probe comprises an aluminum housing with a light-tight aluminised polycarbonate window protected by a chrome plate grille. These instruments provide direct readings of counts per second or counts per minute for count rate measurements, or Sievert per hour or Roentgen per hour with the appropriate probes for dose rate measurements.

Plastic and steel sheets to cover the window for beta and gamma measurements, respectively, are provided with the instruments.

Factors influencing measurements

Monitoring in wet conditions should be avoided since alpha particles will be absorbed by the moisture and not detected. If excessively high count rates and/or unusual sounds occur, the window and window seals and the cable connections should be checked.

These detectors can generally not be used to measure beta activity in elevated gamma fields in excess of 0,2 mSv per hour. Caution should be used when interpreting these results.

These instruments usually feature electronic safeguards such as overload and fail safe indications and variable audible tones indicating the type of measurement (alpha or external) being conducted.

Apparatus and facilities required

No additional facilities, apart from storage are required.

Description of apparatus.

Care and maintenance: It should be recognised that the probe and window are suseptable to shocks such as bumping or dropping, and that the polycarbonate (mylar) film could be easily damaged. Since the probe should be brought in close proximity of the object to be monitored, care must be taken in respect of possible contamination. A useful test is to perform a “light” check by holding the probe towards a light source; if no increase in scale reading is evident, the mylar film is still intact.

Calibration: Instruments should be calibrated annually or after any repairs or modifications to the instrument and/or probe, or whenever the functioning of the unit is suspect. During calibration the activity response of the probe will be established and recorded on the calibration record.

The manufacturer's manual should provide further reference for general maintenance requirements and routine calibration checks by use of a reference source.

Measurement procedure

Direct reading: Background measurements for alpha, beta and gamma should be performed routinely, i.e. prior to each survey in a low background area. In addition, it is recommended that background measurements be conducted at the survey site in a low background area selected.

For alpha contamination measurements the plastic or steel shields should be removed, i.e. open face probe. The probe should be held as close as possible to the surface being measured without actually touching the surface. The distance to the surface should be kept constant during monitoring.

Smear sampling: Taking of smear samples on surface and underground requires some practice as the filters used for smears are extremely brittle. Utmost care must be taken when collecting a smear to prevent the filter paper being damaged.

It is recommended that 47 mm diameter fibreglass filters be used. The filter paper should be lightly scraped over about 100 cm^2 of the surface investigated.

The probe should be gently placed over the smear paper as close as possible to the surface of the paper (not exceeding 5mm) without touching the smear. The measurement should be conducted in a low background area. Long integration time settings on the instrument should be used during measurement of alpha emitters on the smear.

Calculations

Example of the calculation of alpha contamination.

Alpha measurement:	0,13 cps
Alpha % activity response:	17%
Detector area:	49 cm2
Net dps:	0,13 x 100/17 = 0,765 dps
	(Alpha cps x activity response %)
Net dps.cm-2:	0,765/49 = 0,012 $Bq.cm^{-2}$ alpha contamination

NB: No alpha background is subtracted from the measured alpha reading.

Example of the calculation of beta contamination.

Background count rate:	5,00 cps
Beta measurement:	10,0 cps
Net cps:	5,0 cps
Beta % activity response:	20%
Detector area:	49 cm^2
Net dps:	5 x 100/20 = 25,0 dps
	(Net cps x activity response)
Net $dps.cm^{-2}$:	25,0/49 = 0,51 $Bq.cm^{-2}$ beta contamination

Note: Where a 100 cm^2 probe is used, the appropriate value for the larger probe area should be implemented.

Smears do not pick up all the removable contamination on a surface. A pick-up factor of 10% is used, i.e. multiply the calculated result by 10 to obtain the estimated removable activity. This result then reflects the activity rate of the area smeared, i.e. $100cm^{-2}$.

References

1. Relevant manufacturer's instruction manuals.

11.3.3.3 Assessment of potential dose in the public domain

Radiation risk in the public domain involves all radiation that may be exported from the mining environment, e.g. radon from upcast shafts and slimes dams, long-lived alpha and external radiation from contaminated scrap material and water effluents. Radon is monitored in the public domain by use of the Track-Etch technique. Radon concentrations are usually too low to be assessed by use of the ML98 spectrometer.

Long-lived alpha and external radiation is monitored by use of the techniques described earlier.

a) Measurement of radiation contamination in water.

Radionuclides may enter water resources and it is sometimes required to assess the extent of contamination. This procedure applies to any type of water sampled underground, in surface processes and in the public environment. Groundwater monitoring strategies should be addressed in a separate procedure specific to the mine.

In principle, water is sampled in accordance with a water sampling strategy and submitted to accredited laboratories for assessment.

Factors influencing measurements

Special water sampling and filtration kits are used for this purpose. Extreme care should be taken to avoid contamination of the kit during repeated use.

Apparatus and facilities required

Water sampling and pressurised filtration kits are available commercially. These are used together with special filters for the filtration of solids from the water and with solutions for cleaning of the apparatus and the preservation and preparation of the samples for analysis.

Measurement procedure

The measurement procedure hinges on the correct sampling, filtration and preparation of water samples, in accordance with a water sampling strategy, and the analysis of the water and filtrate by an accredited institute.

Calculations

No calculation is required. Results are given in concentration terms, i.e. $Bq.l^{-1}$.

Evaluation of results

The evaluation of results involves consideration of individual radionuclides in water and should be conducted by the radiation protection officer.

References

11.4 Reports

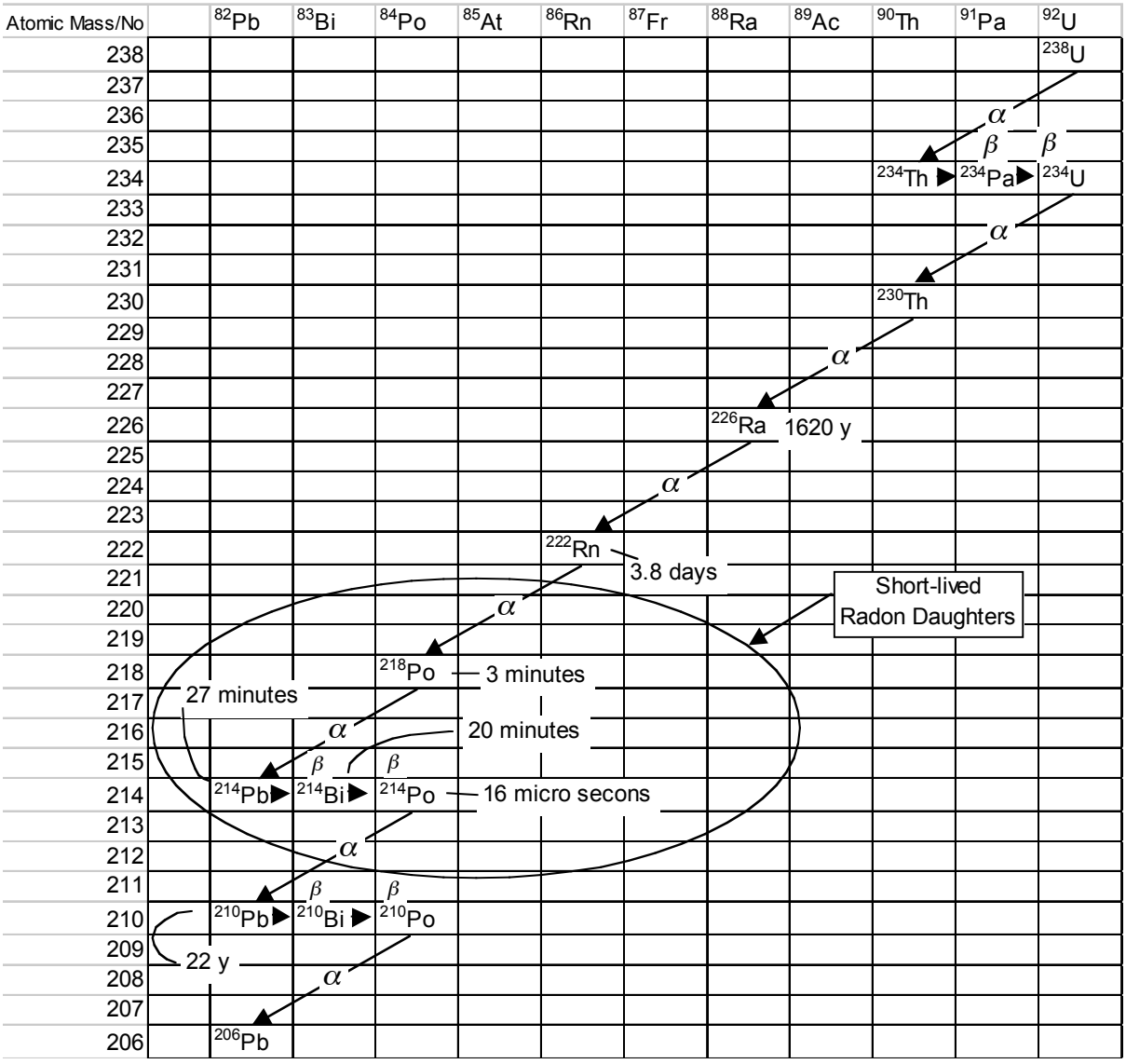
Formal reports are prepared and submitted through the company management system. It is the radiation protection officer's duty to define a radiation protection strategy in collaboration with company management, local safety and health committees and the regulatory authority. This strategy includes a radiation risk assessment and monitoring programme. It is also the duty of the radiation protection officer to evaluate, analyse and assess the radiation measurement data and to maintain a system for record keeping, including quality assurance on calibration of instrumentation, etc.

The radiation protection technician is responsible for conducting radiation measurements in accordance with the defined radiation protection monitoring programme and prescribed monitoring procedures. Competencies and experience is required in this regard to enable an evaluation of measurements on the spot in respect of the validity of the result and to record all relevant data and associated information (see Appendix B for examples of generic record sheets).

11.5 Bibliography

Author to provide

Appendix A: Simplified uranium-238 decay series



Appendix B: Recording and Reporting of Data.

RGM RADON GAS MONITOR SURVEY SHEET

Location	Date From Supplier	Date To Supplier	Date Deployed	Date Retrieved	Radon Conc. Bq.m-3	Stdev	Remarks

ML98 SURVEY DATA SHEET

DATE:.....OPERATOR:.....

INSTRUMENT ID:.....CHECK SOURCE ID:.....

LOCATION	SAMPLE No.	TIME	BACKGROUND	WL	REMARKS

ML98 CHECK SOURCE DATA SHEET

INSTRUMENT ID:.....

DATE	CHKSRC ID	READING	OPERATOR	REMARKS

ML98 CALIBRATION RECORD SHEET

1. Instrument make:.
2. Instrument type:
3. Instrument serial number:
4. Date of purchase:
5. Calibration facility:
6. Date of calibration:...../...../.....
7. Certificate number: .....……...
8. Date of expiry: ...../...../.....
9. Alpha efficiency (%):.....……...
10 Beta efficiency (%):.....……
11.General:

11.1. Contact person and telephone number at calibration facility:

11.2. Remarks (if any):.....

11.3. Limitations specified by calibration facility (if any):

LONG-LIVED ALPHA RECORD SHEET

The long-lived alpha record sheet is produced by down loading the stored data from the ML98 spectrometer. This record sheet should be completed by addition of sample details, i.e. person, shift, location, filter ID, etc.

All calibration records are those described for the ML98 spectrometer.

TLD SURVEY SHEET (AREA TLDs)

TLD NUMBER	1	2	3	4	5	6	7	……..
Location								
TLD ID number								
TLD BIN No.								
Date from SABS								
Date in location								
Date out location								
Date to SABS								
Comments/ remarks								
Whole body dose (mSv)								
Skin dose (mSv)								

TLD MOVEMENT RECORD

LOCATION	DATE	TIME ISSUED	TIME BACK	REMARKS

GAMMA DOSE RATE RECORD CHECK SHEET

DATE	BATTERY CHECK	BACKGROUND CHECK	CHECK SOURCE CHECK	OPERATOR INITIALS
e.g. 01-01-96	e.g. OK	e.g. 0,2	e.g. 1,5 (centre)	e.g. jjl

GAMMA DOSERATE SURVEY SHEET

NAME:.....DATE:.....

INSTRUMENT No.:.....

REF.	LOCATION	DOSERATE (in Sv/h)		REMARKS/ COMMENTS
		ON CONTACT	AT 1 METRE	

CONTAMINATION MONITOR CALIBRATION RECORD SHEET

INSTRUMENT (MAKE, TYPE. SERIAL No.):.....

PROBE (TYPE, SERIAL No.):.....

CALIBRATION FACILITY:.....

CALIBRATION DATA

Date	Cert No.	HV Setting kV	Alpha Efficiency Am-241	Beta Efficiency		
				Co-60	Cl-36	Sr-90/Y-90

CONTAMINATION MONITOR REFERENCE SOURCE RESPONSE CHECK SHEET

DATE:..... OPERATOR:.....

INSTRUMENT (Make, Type, Serial No.):.....

PROBE (Make, Type Serial No.):.....

HV SETTING:.....

Position	Alpha cps	Beta + Gamma cps
Central		
Left upper		
Right upper		
Right lower		
Left lower		

SOURCE (Type):.....

CONTAMINATION MONITOR ROUTINE CHECK SHEET

INSTRUMENT (Make, Type, Serial No.):.....

PROBE (Make, Type, Serial No.):.....

DATE	**BATTERY CHECK**	**HV CHECK**	**BACKGROUND CHECK**			**SOURCE RESPONSE CHECK cps**	**OPERATOR**
			α cps	**β + γ cps**	**γ cps**		
e.g. 10/12/96	e.g. OK	e.g. 875	e.g. 0,03	e.g. 4,56	e.g. 3,89	e.g. 675	

CONTAMINATION MONITOR MEASUREMENT SURVEY SHEET

DATE:.....OPERATOR:.....PREMISES:.....

INSTRUMENT (Make, Type, Serial No.):.....

PROBE (Make,Type, Serial No.):.....

No.	Location	Count rate in cps				Remarks
		α	β + γ	γ	β	

SMEAR SAMPLE SURVEY SHEET

DATE:.....OPERATOR:.....PREMISES:.....

INSTRUMENT (Make, Type, Serial No.):.....

PROBE (Make, Type, Serial No.):.....

No.	**Location**	**Sample Count cps**			**Background Count cps**			**Net β cps**	**∝ - activity Bq/cm²**	**β - activity Bq/cm²**
		α	**β + γ**	**γ**	**α**	**β + γ**	**γ**			

WATER SAMPLE RECORD SHEET

Operator:..... Date:.....Time:.....

Sample reference no.:.....

Location:.....

Source and type of water:.....

Type of sample: Grab ☐ Composite ☐ Split ☐ Other ☐

Volume of sample:.....

Pre-filter type:..... Membrane filter type:.....

Preservatives: Sulphuric acid ☐ Hydrochloric acid ☐

Name of analytical laboratory:.....

Date to analytical laboratory:.....

TOTAL DOSE REPORT SHEET

Month	Occupation	Workplace Location	External Exposure				Internal Exposure				Total
			Whole Body		Skin Dose		LL-Alphas		SL-Alphas		
			Dose	Method	Dose	Method	Dose	Method	Dose	Method	
JAN											
FEB											
MAR											
APR											
MAY											
JUN											
JUL											
AUG											
SEP											
OCT											
NOV											
DEC											
TOTAL											

METHOD:
NR - NOT RECORDED
DA - DOSE ASSIGNED
PD - PERSONAL DOSIMETRY

REMARKS:

Appendix C: Assessment of the Lower Level of detection of Long-Lived Alpha assessments

LOWER LIMIT OF DETECTION (USING THE MDCR)

The following approach has been approved and accredited by the National Nuclear Regulator and is considered to be optimal with regard to simplicity and the need for accuracy within the parameters of uncertainty of the total system for the assessment of the activity concentration of long-lived alpha emitting radionuclides. Note that other methods are available, but these are beyond the scope of this book.

When counting a sample for 100 minutes, the MDCR (Minimum Detectable Count Rate) at 95% confidence is calculated as follows:

$$\text{MDCR} = 2 \times m \sqrt{\frac{R_b}{t_s} + \frac{R_b}{t_c}}$$

$$= 2 \times 1.645 \sqrt{2 \times \frac{R_b}{t_s}}$$

Where,

Rb = Background count rate

tb = Background counting time

ts = Sample counting time

tc = 1, since both tb and ts are 100 minute units

m = Factor associated with the 95% level of confidence

For example:

$$\text{MDCR} = 2 \times 1.645 \sqrt{2 \times \frac{28}{1}}$$

$$= 3.29 \sqrt{56}$$

$$= 24.6 \quad (\text{say } 25 \text{ counts per } 100 \text{ minutes})$$

The Lower Level of Detection (LLD) of the sampling and counting system is then calculated as follows:

$$\text{LLD} = \frac{\text{MDCR}}{(\text{Detector eff.}) \times (\text{Collection eff.}) \times (\text{Volume}) \times (6000)} \ \text{Bq.m}^{-3}$$

Where:

Detector eff. = Decimal efficiency specified for the detector

Collection eff. = Decimal efficiency of filter medium to collect dust (taken as 1)

Volume = Volume of air sampled (m3)

6000 = 100 minutes x 60 seconds

For example:

$$\text{LLD} = \frac{\text{MDCR}}{(\text{Detector eff.}) \times (\text{Collection eff.}) \times (\text{Volume}) \times (6000)}$$

$$= \frac{25}{(0.25.) \times (1.) \times (1) \times (6000)}$$

$$= \frac{25}{1500}$$

$$= 0.0167 \quad \text{Bq.m}^{-3}$$

Therefore, counts less than the LLD should be recorded as < 0,0167 Bq/m^3.

ESTIMATION OF UNCERTAINTIES

Radioactive decay and counting abides poisson statistics. Small deviations occur if the counts are very low (<20), but these will be disregarded here. One standard deviation of a normal statistic represents a confidence level of 68% that the actual value lies between the average minus one standard deviation and the average plus one standard deviation. If the average value is A and the standard deviation is SA , then the actual value is between A - S_A and A + S_A and this is written as A ± S_A

The net count rate, R, and its standard deviation, S_A , is calculated from:

$$R \pm S_R = \frac{A}{t_A} - \frac{B}{t_B} \pm \sqrt{\frac{A}{t_A^2} + \frac{B}{t_B^2}}$$

where:
A = total count of the sample
t_A = counting time of the sample
B = total count of background
t_B = counting time of background

EXAMPLE

Part 1: Count for sample: = 36 counts
Counting time for sample = 10 minutes
Background count: = 16 counts
Counting time for background: = 50 minutes

What is the count rate ?

$$R \pm S_R = \frac{36}{10} - \frac{16}{50} \pm \sqrt{\frac{36}{100} + \frac{16}{2500}}$$

$$= 3280 \pm 0.605 \text{ counts per min ute}$$

Part 2: The count efficiency is 30% and 0,9 m^3 of air was sampled.

What is the airborne concentration ?

$$\text{ActivityConc.} = \frac{36 \pm 0.605}{60} \times \frac{100}{30} \times \frac{1}{0.9}$$

$$= 0.202 \pm 0.037 \quad Bq.m^{-3}$$

OTHER UNCERTAINTIES AND ERRORS:

1. The uncertainty in the calibration value is less than 1% of the calibration value.
2. Timing error is 0,03% and is considered negligible.
3. The sample flow rate error is 2% and considered negligible.
4. The error of the energy of the calibration source vs. the energy of the alphas being measured, is undetermined and cannot be quantified. This issue shall be addressed in future research.

Data Sheet

Date		
Location		
Sample No		
Count	25	
B/G Count	20	
Efficiency	25 %	
Sample Time	480 min	
Net Count	0.000833	Total sample count minus Back Ground Count divided by 6000 = cps.
Efficiency	0.25	Fractional Efficiency
Volume	0.912	Sample Time x 1.9 and divided by 1000 = m^3
$Bq.m^{-3}$	0.003655	Net Count divided by the product of the Fractional Efficiency and Volume
$MSv.a^{-1}$	0.258	Activity Concentration multiplied by the total working hours (2400 hrs), all divided by 1700 (ALI) and multiplied by 5 = mSv per annum
LLD	23.5	As per equation xx
Standard Deviation	0.005	As per equation xx