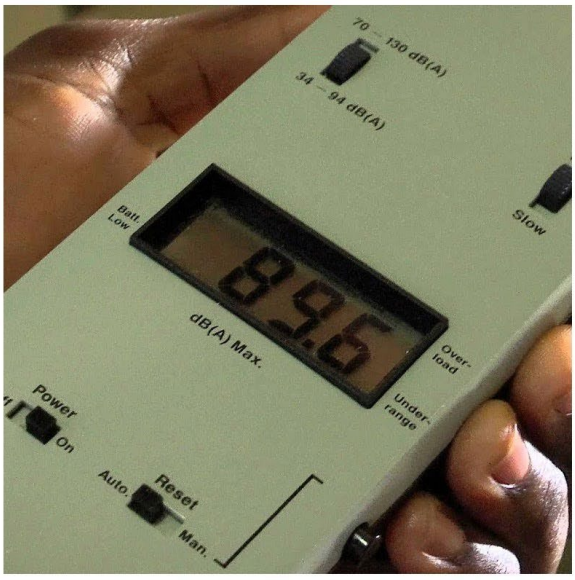


Manual in Occupational Health:

Exposure and Health Assessment Methods

AM Tungu, I P Nyarubeli, S Wakuma Abaya, M Bråtveit and BE Moen (Eds.)

Acknowledgement

We would like to express our sincere gratitude to the dedicated contributors who made this book possible. Their expertise, guidance, and commitment were invaluable throughout the development process. In that regard, we would like to thank the contributors from the following institutions:

Muhimbili University of Health and Allied Sciences and Ministry of Health, Tanzania

Dr Alexander M. Tungu, Department of Physiology, School of Biomedical Sciences, Campus College of Medicine

Dr Israel P. Nyarubeli, Department of Environmental and Occupational Health, School of Public Health and Social Sciences

Dr Hussein Mwanga, Department of Environmental and Occupational Health, School of Public Health and Social Sciences

Dr Dorothy Ngajilo, Ministry of Health, Tanzania

Professor Simon HD. Mamuya, Department of Environmental and Occupational Health, School of Public Health and Social Sciences

Addis Ababa University, Ethiopia

Dr Samson Wakuma Abaya, School of Public Health

Dr Meaza Gezu, School of Public Health

Dr Teferi Abegaz, School of Public Health

Professor Abera Kumie, School of Public Health

University of Bergen, Norway

Professor Bente Moen, Department of Global Public Health and Primary Care, Centre for International Health

Professor Magne Bråtveit, Department of Global Public Health and Primary Care

Associate Professor Prof Kaja Irgens-Hansen, Department of Global Public Health and Primary Care

Associate Professor Gro Tjalvin, Department of Global Public Health and Primary Care

Associate Professor Bjørg Eli Hollund, Department of Global Public Health and Primary Care

Associate Professor Ole Jacob Møllerløkken, Department of Global Public Health and Primary Care.

Dr Vilhelm Koefoed, Haukeland University Hospital, Section for Occupational Medicine.

Our appreciation to Ms. Gunhild Koldal (Centre for International Health, University of Bergen) for her contribution.

Additionally, we are grateful to the research team members in the SAFEWORKERS project and administrative staff for their crucial roles in the successful execution of this book project. Special appreciations to Edson Protas, William Nelson (Department of Environmental and Occupational Health, MUHAS) and Joseph Anisethi Temba (Department of Physiology, MUHAS) for enabling the completion of the book.

Editorial team

ISBN: 978-82-91232-88-1

Publisher: University of Bergen & Muhimbili University of Health and Allied Sciences and Ministry of Health

Front page photos: A.M. Tungu, G. Tjalvin, S. W. Abaya

Foreword

Occupational health challenges are of public health concern. These challenges continually evolve and affect safety and well-being of workers across all sectors worldwide. The rapid socio-economic developments coupled with technological advancements, evolving work environments, and emerging occupational hazards require robust methods to effectively assess risks and associated health effects. To achieve this, the “Manual in Occupational Health: Exposure and Health Assessment Methods” becomes an important resource, particularly in Low- and Middle-Income Countries (LMIC).

This book describes the fundamental concepts in several exposure assessment methods and health examinations at workplaces. We hope that this book will serve as an important tool for professionals working in occupational health (physicians, nurses, occupational hygienists, physiotherapists), students, researchers, and those dedicated to creating decent and safe work environments.

The importance of proper assessment of exposure and health at workplaces cannot be emphasized enough. This manual offers various assessment techniques for selected occupational hazards and their associated health effects and aims to provide the readers with practical aspects.

Notably, collaborative efforts and multidisciplinary involvement of the leading experts in the field have enabled the development of this manual. This ensures that their collective expertise gives scientifically viable and practicable aspects. We hope that this manual will enhance your knowledge and skills and consequently inspire proactive and effective occupational health practices.

As we embark through the rapid socio-economic developments, a myriad of occupational hazards and emerging modern work environments, we hope that this manual will be a building block towards safer, healthier, and more productive workplaces. It is with great honour for the authors and their contributions that we present to you "*Manual in Occupational Health - Exposure and Health Assessment Methods"*

We hope that this book will inspire and empower the readers, and consequently enhance efforts towards promoting safe workplaces.

Alexander M. Tungu, Israel P. Nyarubeli, Magne Bråtveit, Samson Wakuma Abaya and Bente E. Moen

Editors

Table of Contents

Introduction: General Principles on Exposure Assessment and Health Examinations

Bente E. Moen, Magne Bråtveit and Simon H.D. Mamuya

This book describes several types of exposure assessments and health examinations for use during studies of workplaces. Here at the start, we describe some fundamental issues in studies and examinations of the work environment.

A. Risk assessment

Risk assessment is the responsibility of the employer and is a part of the management system. Occupational health risk assessment is an examination of which hazards could cause injury or ill health to people in the work environment, and then assess the health risks involved by taking into account the existing control measures. The results of a risk assessment should help employers to choose which risk controls are most appropriate. Health screening among workers to prevent the development of work-related health injuries and diseases should be based on a sound risk assessment in the working environment.

Risk assessment methods rest upon the two terms HAZARD and RISK. A HAZARD is anything that has the potential to cause illnesses or injuries to workers. RISK is a function of the probability (likelihood) of a hazardous event to occur and the severity of the injury or damage caused by this event. One way to carry out a risk assessment is to follow the five steps in the template provided in a Training Package on Workplace Risk Assessment developed by ILO as indicated below:

Step 1: Identify the hazards.

There are several potential hazards in almost any workplace, and it might be helpful to group the hazards into different categories (Figure 1). Identification of relevant hazards could be done by a walkthrough survey at the workplace and by asking the workers.

Figure 1. Different hazards in workplaces. ©University of Bergen

Step 2: Identify who might be harmed and how.

Which group of workers might be exposed to the hazard in question?

Step 3: Evaluate the risk.

Relevant questions to ask for assessing the level of risk are:

- How likely is a situation that may cause an event to occur?
- What are the consequences of the event likely to be?

A risk matrix (Figure 2) illustrates the principles of risk evaluation that could be used to make decisions on how to prioritise control measures. In this matrix the likelihood of harm and the potential severity of that harm could be categorised as indicated in the figure below. The risk level (red, yellow and green areas) determines which risks should be tackled first, starting with the highest risks (red area).

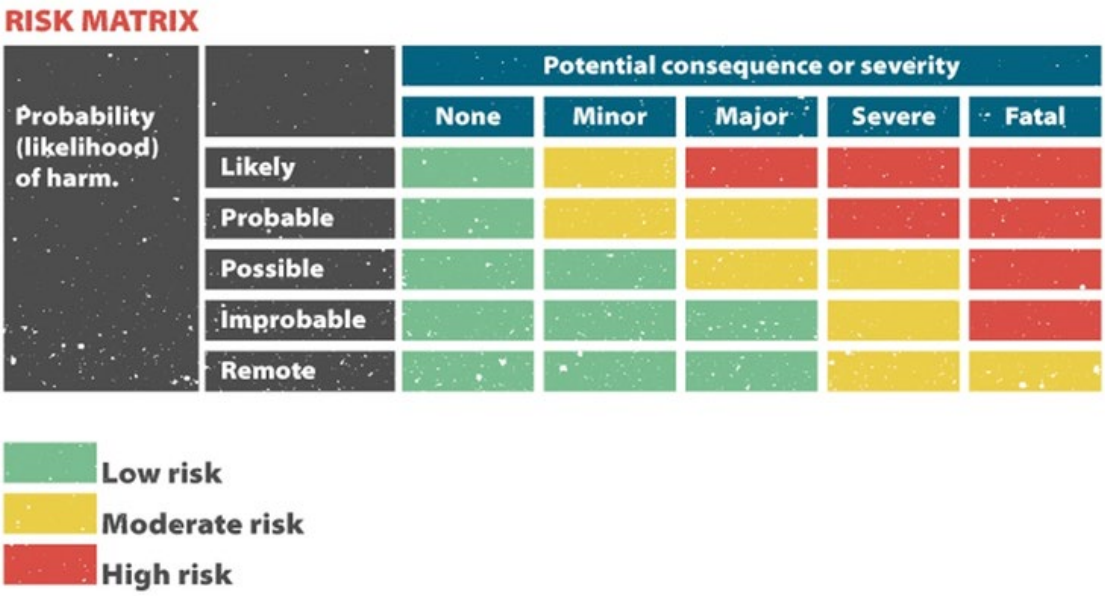


Figure 2. A risk matrix. ©University of Bergen

Step 3.A: Identify what you are already doing in terms of existing risk control measures

Control measures to reduce risk might be categorised in terms of administrative and engineering controls, and/or in terms of location of control, i.e., at the source/hazard, at the path and at the receiver/worker (Figure 3). Controls at the source might be to keep a toxic chemical in a closed container, controls at the path might be to increase the distance between the hazard and the worker or install an efficient ventilation to remove the toxic chemical from the workplace air while control be the receiver could be to wear personal protective equipment (PPE) such as a gas respirator mask. However, PPE is considered the least effective measure and is placed at the bottom of the hierarchy of control.

Figure 3. Three main locations of control measures. ©University of Bergen

Step 3.B: Identify what further risk control measures are necessary:

Look at what you're already doing, and the controls you already have in place. Ask yourself:

- Can I get rid of the hazard?

If not, how can I control the risks so that harm is unlikely?

If you need further controls, consider:

- Redesigning the job
- Replacing the materials, machinery or process
- Organising your work to reduce exposure to the materials, machinery or process
- Identifying and implementing practical measures needed to work safely
- Providing personal protective equipment and making sure workers wear it

Step 4: Record who is responsible for implementing which control measures and the timeframe.

Implement the safety and health risk control measures (deciding who is responsible for doing what, and by when).

Step 5: Monitor and review your risk assessment, and update when necessary.

Review of the risk assessment may be required at any time when there are any changes in machinery, tools, processes, or tasks OR be scheduled to be conducted after intervals.

Example of a risk assessment template for summarising the different steps:

Table 1. Example of risk assessment template

STEP 1	STEP 2	STEP 3		STEP 4		
What are the hazards?	Who may be harmed and how?	What is the existing control measure?	What further action is necessary?	Who is responsible for implementing control measures?	When is the action needed to be done?	Done

B. Exposure assessment

An occupational exposure assessment is the estimation of workers' exposure level to workplace hazards. The aim is to obtain a representative exposure level for groups of workers assumed to have similar exposure levels (Similar Exposure Groups=SEGs).

A typical exposure assessment first involves identifying which hazards are likely to be present and where they are in the workplace. This could be done during a walkthrough survey at the workplace. Other information about the processes and procedures should also be collected: The work organisation, the process(es), the workplace layout, the emission sources, the ventilation, and other means of control at source and the frequency/duration of exposure. Based on the collected information it should be decided whether measurements are necessary or not, and how to constitute a priori SEG. The intensity of the exposure to specific hazards is then measured among the SEGs, using appropriate technology. Conducting full-shift measurements in the breathing zone of the workers to determine the exposure level is the preferred method in exposure assessment. Often, samples must be taken for laboratory analysis but at other times portable instruments are used on the site.

There might be different reasons to perform exposure assessments. It is normally an important part of the risk assessment in which the estimated/measured exposure levels will provide valuable information in evaluating possible health risk associated with this exposure level. Exposure measurements are also needed when the employer wants to document compliance with occupational exposure limits (OELs) or when the aim is to evaluate control measures established to reduce exposure level at the workplace. Such exposure limits exist internationally, and many countries also have their own limit values. Furthermore, exposure measurements are of great importance for studying the association between exposure and health effect in epidemiological studies.

C. Health examinations

Some types of work have a particular health risk, due to specific exposure(s). To perform a proper risk evaluation, it might be necessary to perform health examinations of the workers, to be able to evaluate the effect of the unwanted exposures on their health. Sometimes, the legislation of a country tells that the employer has a duty to ensure that the employees have health examinations carried out. The purpose of such examinations is to survey and if

needed, to prevent the development of work-related health injuries and diseases. An example of work that requires a health examination is work with asbestos, where x-ray is performed among the exposed workers, as they might develop mesothelioma. Other examples are hearing examinations performed among workers exposed to high levels of noise that might cause hearing loss, and spirometry among miners exposed to dust that may cause lung diseases. The doctor who carries out the health examination must have expertise to perform the examination. If the examinations show that the workers have developed signs of disease, preventive measures must be taken both for the individual and the environment. Some examinations may show minor changes in the health situation before a serious disease has developed. To evaluate the results from health examinations is an important part of the risk evaluation process.

Screening is a type of health examination that normally is not considered as a workplace health examination. Screening is a term used for health examinations done on a larger population group, for instance screening of cervix cancer among women. The expression is often confused with ordinary health examinations.

D. Workplace visits

Visiting a workplace can be very useful if you want to learn about the workers and the work process. This can be important if you want to prepare for a study or if you want to contribute to the improvement of the work environment.

If you want to visit a workplace, you need to contact the management to get permission. It is needed to give the leadership the aim of your visit, the plan, who you wish to contact, where and when. It is necessary to establish a good relationship with people in the management, otherwise you will not succeed in your plans. On the other hand, you should also make sure that you meet workers, not only the management during a workplace visit.

If you are allowed to study the workplace in detail, you can use different tools for making a systematic workplace visit. There exists for instance different checklists and surveys for use during a walk-through in different types of companies. It is difficult to recommend one, as all companies differ, and there will be different risk factors in different workplaces. You will not study the same risk factors in an office environment as you do in a textile factory, for instance. You can see an example of a checklist for a workplace visit in a factory in Table 2. You can also make your own notes and describe the place with your own words.

If you make a report from the visit, you should inform the company about it and share your report with them. If you are allowed to do research work in the company, the information you obtain should be disseminated to the management and workers. This should be a part of the agreement between you and the company before you perform your study.

A strength of a workplace visit is that it is quick and inexpensive, and you may get information you cannot obtain otherwise. Weaknesses are that you might be guided in other directions than where problems are, and you might not be able to talk to more than a few people. The workers might tell you untrue stories, and they might not tell important issues. Due to these factors, you must interpret your perceptions during the visit with caution.

E. Legislation and limit values

Legislation

Most countries have national laws or regulations relating to occupational health and safety. The national laws state that the employers are responsible for ensuring a safe and healthy working environment. Employers must comply with the standards for occupational health and safety in their country and they have to perform risk assessments in their company to assess their potential needs for improvements.

The International Labour Organization (ILO) has adopted more than 40 standards dealing with occupational health and safety, as well as 40 Codes of Practice (https://www.ilo.org/). These standards are often the basis for the development of national legislation.

Occupational Exposure Limits

Regulatory authorities in many countries have established criteria for determining the level of occupational exposure to hazardous exposures in the workplace and specified Occupational Exposure Limits (OEL) for many chemical substances, such as inhalable dust, lead, mercury, crystalline silica, and asbestos, as well as for physical factors like noise and vibrations. There are differences between countries in the terminology used for limit values, what they mean, and in the actual value of the respective OELs. Not all countries have developed their own criteria and OELs and use limit values from other countries. Countries developing their own limit values often consider other factors than health effects when setting the OELs. The setting of OELs often involves consultation with the interested parties in the working life, normally the employers and the employee's organisations. Thus, in addition to the scientific knowledge about the hazardous effects there is also an opportunity to take technical and economic factors into consideration when setting OELs.

The OELs are usually expressed as the average exposure level over an eight-hour shift and, when necessary, as short-term peak exposure. Representative exposure measurements should be taken in the breathing zone of the workers. Air samples of contaminants will normally have to be analysed later by appropriate methods, unless direct-reading instruments are used. The estimated exposure levels can then be compared with the OEL and used as an important part of the risk assessment. However, one should be aware that there is no absolute dividing line between harmless and harmful exposure, and the OELs are merely a guide for the prevention of hazards. Thus, the application of the OEL in the risk assessment process relies on good professional judgement.

One example of a list of limit values widely referred to is the Threshold Limit Values (TLV) for Chemical Substances and Physical Agents developed by the American Conference of Governmental Industrial Hygienists (ACGIH). According to ACGIH, the TLVs refer to exposure levels at which it is believed that nearly all workers may be repeatedly exposed to, without adverse health effects.

F. References

American Conference of Governmental Industrial Hygienists (ACGIH)

https://www.acgih.org/about/

Gardiner K & Harrington M. Occupational Hygiene, Chapter 10. Principles of risk assessment. Wiley-Blackwell, 3rd edition June 2008. ISBN: 978-1-405-10621-4.

ILO Codes of practice and guidance documents
https://www.ilo.org/empent/areas/business-helpdesk/codes-of-practices/lang--en/index.htm

Chapter 12. Risk assessment. In: Gardiner K, Rees D, Adisesh A, Zalk D, Harrington M. Pocket consultant Occupational Health, Sixth Edition. Wiley Blackwell, 2021, pages 249-297.

Table 2. General workplace observation checklist for industry - an example

Information obtained by interview of management	
Date of inspection /observation	
Name of workplace	
Owner of the company	
Establishment year	
Activity/production	
Number of employees	
Departments	
Work hours	

Checklist for observation	**YES**	**NO**
Do the floors have uneven areas, loose finishes, holes, spills etc.?		
Are the floors slippery, e. g., due to cleaning, spilling of liquids?		
Are there thresholds or other changes of level on the floors?		
Are there loose cables on the floor?		
Are there any obstructions from loose objects left lying around?		
Are the floors dusty?		
Is the air dusty?		
Is there any ventilation?		
If items are transported inside -are all transport routes marked?		
Is there any lighting inside the building?		
Is the lighting at the workplace sufficient to perform tasks neede?		
Are there assembly lines present inside the building?		
Is the noise level so high that you must raise your voice to be heard?		
How many machines have dangerous moving parts?		
Are there any machine safeguards?		
Other comments		

Chapter 1. Aerosol Exposure Assessment

Magne Bråtveit and Samson Wakuma Abaya

1.1 General concepts and definitions

Aerosol is a suspension of tiny particles or droplets in the air, such as dust, fumes, smoke or mist. These particles may be inhaled and can sometimes cause adverse health effects for workers. From a health perspective, the two key factors which are important when assessing exposure from aerosols are the chemical composition of the material (toxic effect) and the particle size (where it deposits in the respiratory system). These properties of aerosols determine the sampling method to be used for exposure measurements. The air concentration of aerosols is normally expressed in mg/m^3, while the particle size, the Aerodynamic Diameter (AD), is expressed in µm. The size of the particles can vary from less than 0.01 to more than 100 µm.

- Dust: Solid particles originating from mechanical disintegration such as cutting, crushing, grinding and abrasion of solid materials. Examples of dust are quartz, wood dust and metallic dust. (AD: 1 - >100 µm)
- Fumes: Particles produced by condensation of vapourised metals (metal vapour) after hot work such as welding and cutting (AD < 1 µm)
- Smoke: Small solid particles from chemical or thermal processes. Examples are carbon/soot particles from incomplete combustion of oil/coal (AD: 0.01-1 µm)
- Mist: Fine liquid suspensions generated by condensation of vapour back to the liquid state, or breaking up a liquid into the dispersed state (AD: 0.01-10 µm)
- Spray: Liquid droplets from mechanical disruption of liquids (AD:10- >100 µm)
- Fibres: Fibres are either natural (e.g. asbestos) or synthetic materials (e.g. glass wool) of thread-like characteristics which are three or more times longer than their width.

1.1.1 Particle sizes in occupational exposure measurements

The particle size determines where the particles deposit in the respiratory system. Are they capable of penetrating to the alveoli or only to the upper respiratory tract? In 1995 the International Standards Organisation (ISO) defined sampling conventions for particulates (Figure 1.1). One must consider these particle size fractions when evaluating health hazards, and when selecting sampling equipment:

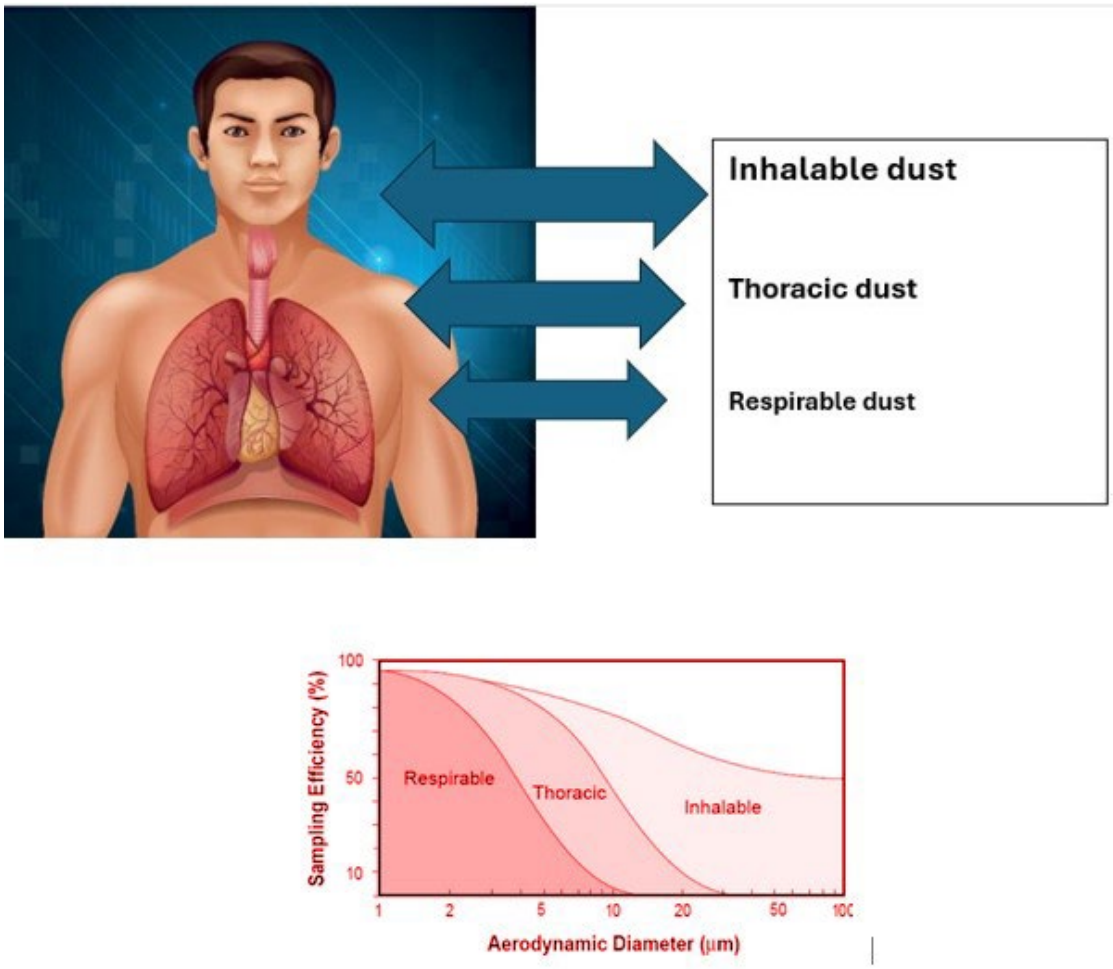


Figure 1.1. Dust particle size distributions for the three conventions; Inhalable, thoracic and respirable fractions. ©University of Bergen

- Inhalable fraction: The mass fraction of total airborne particles that is inhaled through the nose and mouth. The AD is less than or equal to 100 µm. This fraction is important for health effects in all locations of the respiratory system, for example, rhinitis, cancer of the nose and lung, and other respiratory disorders.
- Thoracic fraction: The mass fraction of total airborne particles that penetrates below the larynx. This fraction is important when it concerns health effects such as asthma, obstructive lung diseases (COPD), bronchitis and lung cancer. The thoracic fraction has the 50% cutoff at an AD of 10 µm.
- Respirable fraction: The mass fraction of total airborne particles that penetrate to the alveolar part of the lungs, including the bronchioles. The fraction is important in e.g. development of chronic diseases such as emphysema and dust lung diseases. The particle size corresponds to 50% cut-off at an AD of 4um.

1.2 Measurement of aerosols

When measuring the airborne concentration of a particular contaminant, it should be representative of the worker's exposure to that contaminant. Therefore,

the contaminant is measured in the breathing zone of the worker. Area/static measurements are not representative of worker's exposure.

When assessing workers' exposure to dust, fumes or fibres, two different approaches can be adopted. These are filtration samplers and direct reading instruments; both of which have advantages and disadvantages.

1.2.1 Personal aerosol exposure measurements

The most common approach in workplace exposure assessment is the use of filtration samplers. Figure 1.2 illustrates a sampling train where a sampling head is preloaded with a filter and attached in the breathing zone of the worker. The breathing zone is defined as a hemisphere of 300mm radius extending in front of the face and measured from the midpoint of a line joining the ear. The sampling head is connected to a pump that pulls air through the sampling head/filter at a predefined flow rate.
As the air passes through the filter, the aerosol is captured on the filter paper mounted inside the filter cassette. Gravimetric analysis is usually used to measure results (i.e. by measuring the weight gain of the filter). Further analysis can be carried out on the filter to identify the specific chemicals captured.

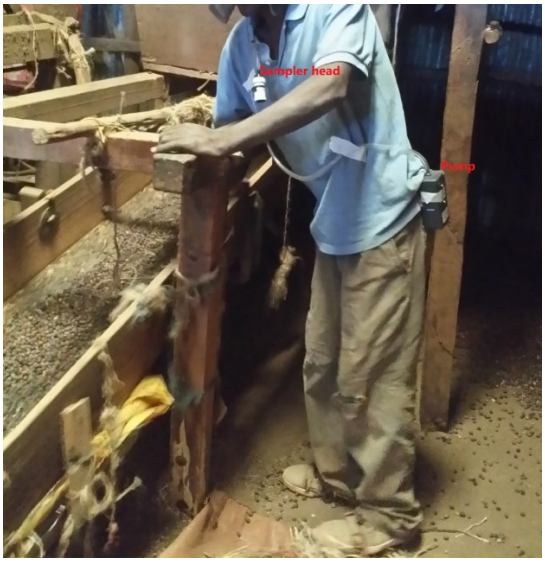


Figure 1.2. Sampling of dust with filtration samplers, showing the location of the sampling head in the respiratory zone of the worker, while the pump is attached to his trousers. ©Samson Wakuma Abaya

1.2.1.1 Sampling heads

Inhalable aerosol samplers:

There are several types of samplers for inhalable aerosol such as the IOM sampling head (IOM) (Figure 1.3) and the Conical inhalable sampler (GSP-sampler) (Figure 1.4).

The IOM inhalable sampler (Figure 1.3) requires a sampling pump operating at 2 L/min. The design of the IOM sampler inlet allows only the inhalable fraction to be drawn into the sampler. where it is captured on the filter paper inside the filter cassette. Dust that deposits on the internal wall of the cassette is included in the sample analysis since the whole filter cassette is weighed during gravimetric analysis. It is important that when a sample is taken the cassette and filter paper are pre and post weighed as a single unit.

The IOM sampler tends to oversample when large particles are present. Furthermore, the large inlet allows sampling of large

projectiles (e.g. blasting operations) and splashing. It should also be highlighted that this sampler is designed as a personal sampler only, not for area sampling.

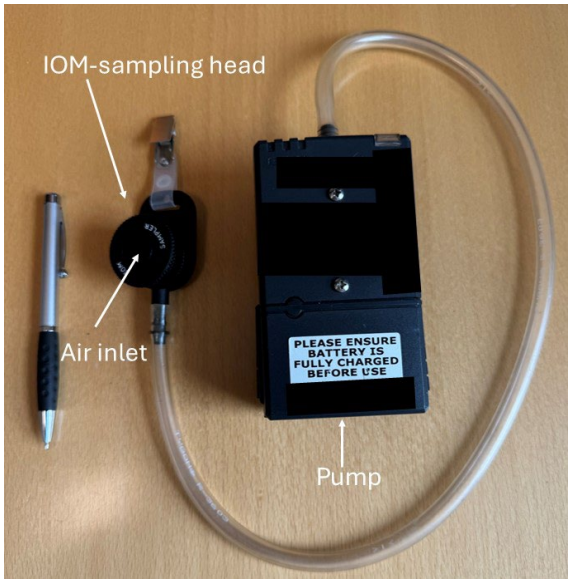


Figure 1.3. The IOM-sampler for inhalable aerosol/dust connected by a tube to a pump. A filter is mounted inside the sampler. ©University of Bergen

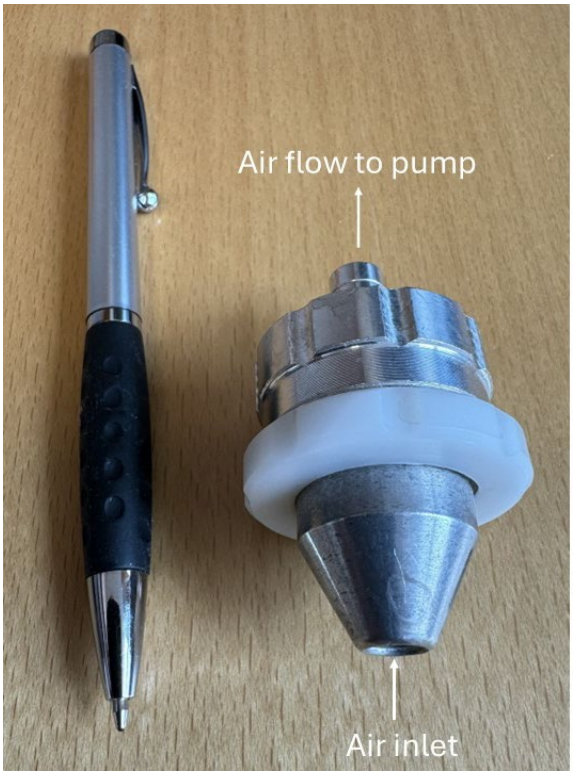


Figure 1.4. The conical inhalable aerosol/dust sampler with filter mounted inside the sampling head. ©University of Bergen

The conical inhalable sampler (GSP-sampler) (Figure 1.4) requires a sampling pump operating at 3.5 L/min. This relatively high flow rate may need other sampling pumps than those needed for the IOM-sampler. It has an advantage over the IOM-sampler that the inlet is smaller and points to the downward direction, thus reducing the risk of projectiles and splashes that may contaminate the filter.

Total aerosol sampler - three-piece air sampling filter plastic-cassette: These samplers are also called 37mm Millipore cassettes (Figure 1.5), and require a sampling pump operating at 2 L/min. It was common in the US to use these sampling heads to measure “total dust”. However, this sampler does not equate to the ISO definition. Thus, this sampler does not sample the inhalable fraction as they significantly underestimate the concentration of larger dust particles from 30-100 µm. Another concern for this sampler is sample losses that occur from particles that adhere to the interior cassette walls. Conductive (antistatic) 25 mm cassettes are normally used for fibres (asbestos) and organic dust.

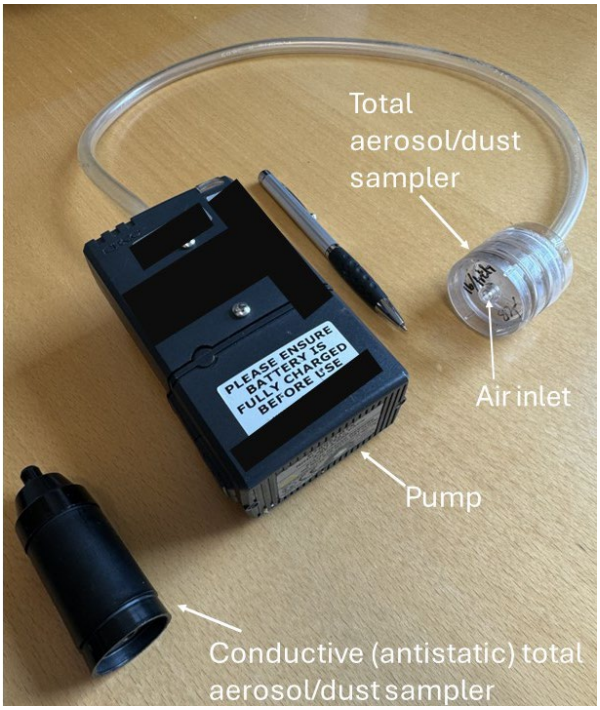


Figure 1.5. Total aerosol/dust samplers. A 37 mm three-piece filter cassette connected to a pump (right). A 25 mm three-piece conductive plastic cassette (left). ©University of Bergen

Figure 1.6. Cyclone for sampling of respirable aerosol/dust (left). A filter is mounted in the cassette (right) that is placed in the cyclone. ©University of Bergen

Respirable aerosol sampler

Respirable aerosol is sampled by Cyclone samplers (Figure 1.6) using a cyclonic action to separate out the fine respirable particles which is captured on a filter paper mounted inside a cassette at the top of the sampler. The air flow rate should be adjusted to 2.2 l/min. The grit pot on a cyclone must be in place during calibration and sample collection The larger dust particles drop into a 'grit pot' mounted at the bottom of the sampler. However, be aware that inversion of the cyclone during or after sampling causes larger particles to erroneously fall from the grit pot onto the filter material.

1.2.1.2 Filter types

The type of filter used in the sampling heads is selected based on which type of aerosol/dust to be determined. There are some general recommendations on which filter to select:

- Cellulose acetate-/mixed cellulose ester-filters for mineral/rock dust, quartz. (NB! The filters are hydrophilic)
- Polyvinylchloride (PVC)-filter for welding fumes
- Glass fibre filter for bioaerosols/endotoxins, mineral oil mist

1.2.1.3 Calibration of flow rate

When the filter is mounted in the sampling head, and connected to a pump, the air flow through the filter needs to be adjusted to the recommended flow rate. For this purpose, different types of flowmeters

could be used (Figure 1.7). The simplest type often used for fieldwork is commonly referred to as “rotameters” where the flow rate is indicated by a float inside a graduated glass tube. For some types of pumps, the flow adjustment is done with a screwdriver. The air flow has to be adjusted for all samples, before the sample is taken. After the sample has been taken the air flow needs to be checked and recorded in the sampling form.

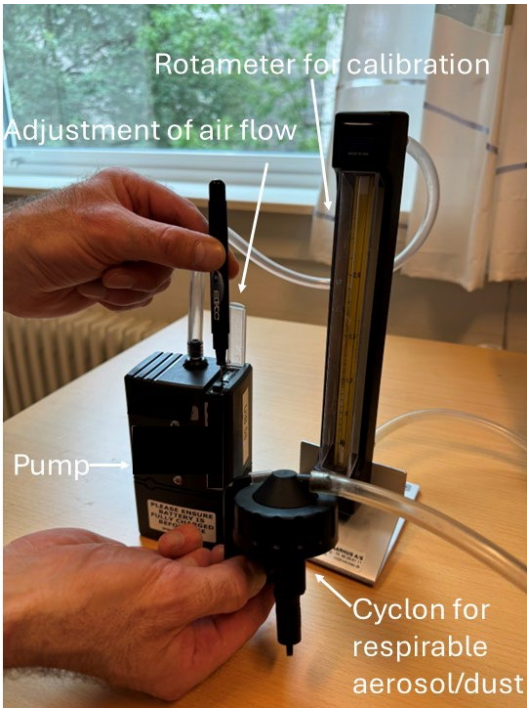


Figure 1.7. Calibration of a cyclone for sampling of respirable aerosol/dust. The cyclone is connected to a pump that pulls air through the sampling filter inside the cyclone. A rotameter is connected to the cyclone for calibration of air flow through the filter. A screwdriver is used to adjust the pump to the predefined flow rate. ©University of Bergen

1.2.1.4 Checklist for aerosol sampling

Before sampling:

- The pumps must be charged during the whole night before sampling.
- Prepare the sampling form.
- Ensure the pump is fully charged.
- Treat the collection media with care.

Sampling:

- Record the sample media, sample ID, person sampled, time, date and location in the sampling form.
- Calibrate in a clean area to avoid contamination of the collection media.
- Remove the caps from the filter holder and attach the tube end to the filter holder (to the opposite end of the inlet).
- Do not run the pumps without attaching a filter.
- Turn on the pump and let it run with the filter attached for 1-2 min.
- Ensure the flow rate is set at the correct level.
- Read the flowrate through the filter with the flowmeter pressed against the open end of the filter holder. Adjust if necessary.
- Ensure that all connections are leakproof and secure.
- Mount the sampler in the “breathing zone” of the worker.
- Ensure the flexible tube is not left to hang free.
- Personal sampling starts. Note the starting time.
- Control the flow rate after 4 hours. Stop the sampling if the flow rate has decreased by more than 10% from the start value.
- Control/note the flowrate at the end of the sampling period before stopping the pump.
- Stop the pump, note the time.

- Attach the caps on the filter holders and store them for sampling.
- Charge the pumps for the next day's samplings.

1.2.1.5 Information to be recorded in the air sampling worksheet/sampling form (Table 1.1):

- **At commencement of sampling**
    - Sampler identification number
    - Filter identification number
    - Pump identification number
    - Date & pump start time
    - Initial flow rate of pump
    - Worker's name or description of static location

- **During sampling**
    - Description of task(s) undertaken during sampling period
    - Risk control measures in place
    - Atmospheric conditions
    - Any other relevant data (e.g.- unplanned events)

- **At conclusion of sampling exercise**
    - Record the time
    - Re-measure flow rate prior to switching off pump

Table 1.1. Example of an air sampling worksheet where important information on each aerosol sample is recorded.

Air sampling worksheet

Date	Sample ID	Pump ID	Employee	Job tasks	Time 1 start	Time 2 stop	Sampling time	Flow start	Flow stop	Sampling volume (m^3)	Analysed amount (µg)	Air conc. ($mg/m^{3)}$	Air conc. (ppm)

Sample ID	Job description

Process Description _____

Engineering Controls_____

Work Practice Controls_____

Ventilation Measurements_____

Personal Protective Equipment Used_____

1.2.1.6 Laboratory analyses - gravimetry

Determination of mass on the filter is done with a microanalytical balance by weighing the filter before and after sampling (Figure 1.8). If the humidity is difficult to control the filters should be put overnight in a desiccator before weighing (both before and after sampling).

The average aerosol concentration in the working air over the measurement period can then be calculated by knowing the volume of air that has passed through the filter. The scale is placed in an air-conditioned weighing room (i.e. temperature and humidity are more or less constant). The weighing procedure also includes weighing blank filters (unexposed filters) for blank value correction and reference lots/reference filters as quality control. A gravimetric determination gives no information about what the aerosol contains of specific components. To characterise the aerosol, a chemical analysis of the aerosol collected on the filter must be carried out.

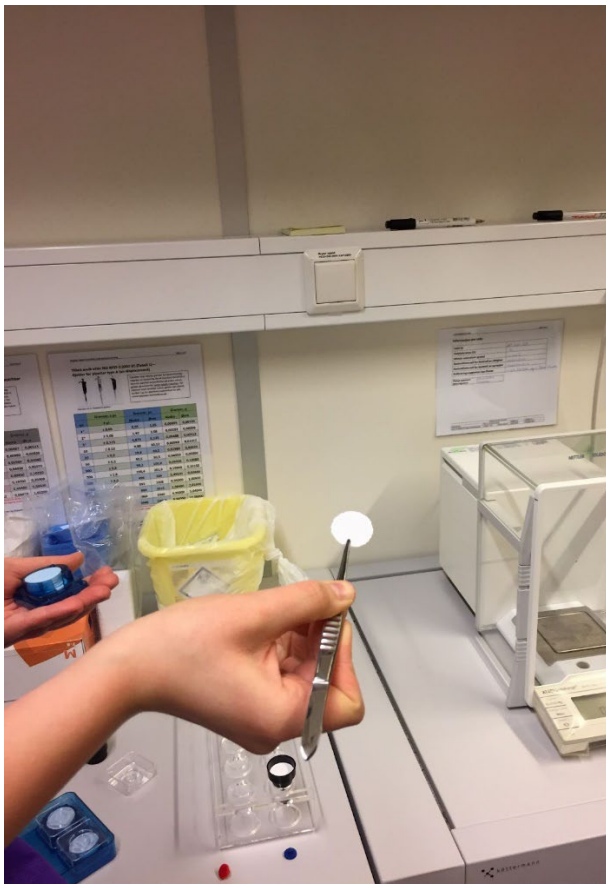


Figure 1.8. A filter to be placed in a scale for weighing dust amount. ©University of Bergen

Calculation of results

To calculate the workers exposure, we require:

- Total volume of air sampled
  - Volume (L) = Flow Rate (L/min) x sampling time (min)
  - Volume (m^3) = Volume (Litres)/1000

    (Note: 1 m^3 = 1,000 L)
- Mass of contaminant on filter:
  - Mass (mg)[a] = (post weight of filter (mg) - pre weight of filter (mg))-blank (mg)

Aerosol concentration (mg/m^3) = Mass of contaminant (mg)[a]/Sampling volume (m^3)

[a] Corrected for blank

1.3.1 Area/static measurement of aerosols

Area or static sampling should not be compared directly with exposure standards as they are not indicative of the worker's actual exposure and hence risk. Occupational Exposure Limits are linked to personal sampling and the use of static or area samples for health assessment is not generally accepted.
Area samples do not normally correlate well with actual personal exposures, but they still could have a useful role, and might be useful for the following purposes:

- To check the performance of control devices.
- In identifying and quantifying contaminant sources in the workplace.
- In identifying potentially unacceptable areas of exposure.
- Are sometimes the only realistic means of measurement when certain types of continuous monitoring are required.

1.3.1.1 Direct-reading instruments for particles

Several types of direct-indicating instruments can measure different particle sizes; Respirable fraction (PM4), thoracic fraction (PM10) and total fraction, as well as the fractions PM1 and PM2.5 which are used for air quality measurements. Some of these instruments can measure these size fractions simultaneously, while others can measure only one particle size at the time (Figure 1.9). It shows data in both real-time particle mass concentration and as time-weighted average (TWA). These monitors are hand-held, battery-operated, multi-channel, data-logging, light-scattering laser photometers.

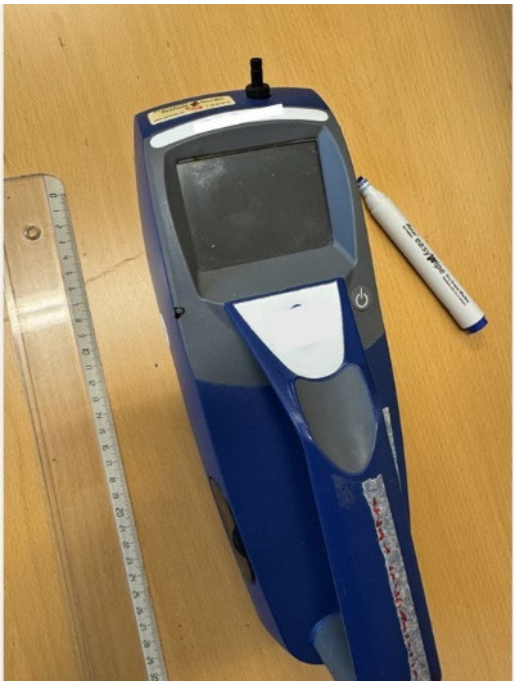


Figure 1.9. Hand-held, direct-indicating instrument for measurement of different particle sizes. ©University of Bergen

1.4.1 Bioaerosols

Bioaerosols are commonly defined as aerosolized particles with a biological origin. These particles originate from all types of organisms and can be dispersed into the air by a variety of abiotic and biotic mechanisms. In the occupational environment, examples of bioaerosols include fungal and bacterial spores/cells, fungal hyphae, pollen, viruses and amoebae, aggregates and fragments of these particles, larger organisms and growths, including cotton and wood dust, flour, skin scales, animal dander, textile and paper fibres. Endotoxin is a common constituent in bioaerosol in occupational settings. Endotoxins are lipopolysaccharides (LPSs) found in the outer membrane of most gram-negative bacteria and cyanobacteria. Endotoxins are released into the working environment when agricultural products contaminated

with gram-negative bacteria are processed or during cell lysis.

1.4.1.1 Exposure measurements of bioaerosols

Exposure assessment of bioaerosol in the workplace involves three important stages: air sampling, sample transport and storage, and sample analysis. Methods used for the collection of bioaerosols depend on the type of bioaerosol to be assessed, and comprise impingers, cyclones, impactors, filters, spore traps, electrostatic precipitation, thermal precipitators, condensation traps, and gravitational samplers.

Cotton, grain, wood, flour and other organic dust are measured by filter sampling and gravimetry of the collected dust as described in the first part of this chapter. Airborne fungi and bacteria can be quantified by cultivation and non-culture-based methods. Visible colonies are identified, counted and results are given as colony forming units (CFU).
For endotoxin there are several methods for the assessment of airborne occupational exposure. Table 1.2 summarizes some recommendations for air sampling, sample transport and sample analysis for endotoxin.

Table 1.2. Recommendations for air sampling, sample transport and sample analysis of endotoxin.

Activities	Recommended
Sampling method	Sampling on filter
Sampling equipment	Three-piece closed-face cassette (CFC) or Inhalable sampler
Filter type	Glass fibre
Flow rate	The recommended flow rate for endotoxin air sampling depends on a number of factors, including the type of sampling device being used, the size of the sampling area, and the desired sampling duration. For most endotoxin air sampling applications, a flow rate of 2-4 litres per minute (LPM) is recommended.
Duration of sampling	The duration of air sampling for endotoxin depends on a number of factors, including the expected concentration of endotoxin in the air, the desired accuracy of the results, and the limitations of the sampling device and analytical method being used. In general, a sampling duration of 1- 8 hours is recommended for most endotoxin air sampling applications. The sampling duration should be sufficient to collect a representative sample of the airborne endotoxin, while also being practical and achievable.
Sampling transport	The filters should be transported in a sampling cassette
Sampling transport temperature	The temperature should be in dry condition or frozen
Endotoxin samples extraction	Extraction by immersing the filters in 5 ml of pyrogen-free water (PFW) with 0.05% (v/v) Tween-20
Endotoxin sample storage	Samples should be stored at –20 ºC until analysis
Extract analysis	Using the kinetic chromogenic Limulus Amebocyte Lysate (LAL) test

1.5 References

Health and Safety Executive, UK. EH40/2005 Workplace exposure limits, Fourth Edition, 2020 https://www.hse.gov.uk/pubns/priced/eh40.pdf

Health and Safety Executive, UK. G409 Exposure measurement: Air sampling. 2022. https://www.hse.gov.uk/pubns/guidance/g409.pdf

NIOSH Manual of Analytical Methods (NMAM) 5th Edition (R. Andrews & P. F. O'Connor, Eds.), 2020. https://www.cdc.gov/niosh/nmam/pdf/NMAM_5thEd_EBook-508-final.pdf

Occupational Hygiene Training Association (OHTA). Measurement of hazardous substances. OHTA Student manual, 2023. https://ohtatraining.org/students/fmanuals/manuals/ohta501/

Chapter 2. Noise and vibration exposure assessment

Israel Paul Nyarubeli

2.1 Noise exposure

2.1.1 General concepts of noise exposure

Sound is the result of pressure variations, or oscillations, in an elastic medium (e.g., air, water, solids) generated by a vibrating surface, or turbulent fluid flow. It is characterised by frequency (the number of pressure variation cycles per second, in Hertz (Hz)); wavelength (the distance travelled by the pressure wave during one cycle) and the period (the time taken for one cycle of a wave to pass a fixed point). For simplicity and meaningful understanding of human perception of relative loudness of a sound; the sound pressure level is measured and expressed in decibel (dB), i.e., the logarithm of the ratio of two sound intensities or two sound pressures. The decibel uses a hearing threshold of 20μPa as a reference level.

Sound waves are detected in the human ear, starting with vibrations of the eardrum. The human ear has different sensitivities to different frequencies, i.e., less sensitive to extreme high and low frequencies. The human ear has a remarkable dynamic range of roughly 0-120 dB (10^6 sound pressure level), which allows for detection of sound from the faintest noise to painful stimulation. At a given sound pressure level, a healthy human cochlea can detect and encode sound waves across frequencies ranging from 20Hz to 20kHz.

The World Health Organization (WHO) and International Labour Organization (ILO) define noise as *unwanted sound*. Loud and unwanted sound, referred to as noise, can cause detrimental health effects in humans either auditory such as noise-induced hearing loss or non -auditory (sleep disturbance, annoyance, cognitive performance in school children, etc). It can damage the ear and affect speech intelligibility.

2.1.2 Assessment of occupational noise exposure

Noise assessment is typically done to identify and document levels which might be hazardous to the human ear. Identification of work locations and tasks with harmful noise exposure and workers who may be at increased risk of hearing loss is necessary for establishing a workplace hearing conservation programme. Prior to noise measurement in the workplace, a walk-through survey is recommended as an important part of noise hazard identification (in the risk assessment process)- (Table 2.1) to collect information necessary to describe the working environment and identify determinants for noise exposure. This is also a basic prerequisite for planning how sampling is to be conducted. Such information includes noise sources, workplace layout, types of machines and production processes, number of workers per section and their shift patterns, production capacity, working durations, changes in production processes or machinery (if any). In addition, information

is normally collected on the availability of health and safety policies, the use of hearing protection devices and the perceived noise levels on the site.

Noise exposure may vary in a workroom, with intensity of sound, with time and in distance from the noise source. Therefore, personal exposure monitoring is important to determine individual worker`s noise exposure and hence demonstrate compliance with regulations and standards e.g., noise exposure limits (occupational exposure limits (OELs) provided by national legislation, International Standardization Organisations (ISO), Regulatory Agencies (EU- OSHA, EPA, TBS *etc*) or accredited Institutions such as NIOSH.

Generally, occupational noise measurements are undertaken to; -

1. Monitor the noise exposure levels for health-based benefits of workers i.e., examine compliance with occupational exposure limits and establish the need for noise exposure reduction and employee's health surveillance at the workplace.
2. Evaluate the effectiveness of control measures
3. Establish baseline workplace noise level data, and after installation/changes of machines, tools, equipment or plants
4. Be a part of the risk assessment when noise hazard is identified in the workplace and needs to be controlled
5. Obtain information for research and knowledge advancement such as identification of factors related to the risks from noise exposure.

The two common types of devices for noise exposure assessment at workplaces are a) integrating-averaging sound level meter (SLM) mainly for area measurements and b) personal sound exposure meters (dosimeters). However, other types of normal sound level meters exist in the market.

Table 2.1. Noise Walk-through survey checklist sample.

AIM: To describe the workplace environment with respect to noise sources

Date of survey.....

1. **WORKPLACE IDENTIFICATION**
    a. Name of Industry.....
       Owner.....
    b. Location.....
    c. Address: .....
    d. Nature of work: **.....**
    e. Year started operation: .....
    f. Number of sections..... With high noise level.....
    g. Total number of employees: ..... (M/F) M= ....., F=.....
    h. Average production rate/day.....
    i. Number of shifts ..... Start at..... end at .....
    j. Does the industry have a standard map/floor plan? (Yes/No) .....
    k. If yes in (x) above can the flow plan be availed? (Yes/No
    l. Make a rough sketch if flow plan is not available
    m. Names and tittles of those participated in walkthrough survey

Name: list (*subject to scope*)	**Job title**	**Task assigned**

2. Sources of noise

Section	Equipment / machine capable of producing noise	Type of noise produced [impulse/ continuous]	Year installed	Noise control measures available to this equipment (engineering control)	No. of workers in section		Shift pattern (if available)	Availability of production line sketch (Yes/No)	Tasks performed at this section
					M	F			

3. Hazard identification

Interview <u>at least five</u> selected workers from each industry who are knowledgeable on working environment (check if there are many employees)

Ask /observe	**Yes**	**No**
<u>(observe)</u> Is a raised voice needed to communicate with someone that is only about one meter away?		
Do workers complain that there is too much noise? (Explain)		
Do workers say that they can't hear each other or hear instructions or warning signals? (describe which situation/working period)		
Do people working in the area notice a reduction in hearing over the course of the day? (This reduction might not be noticed until after work.)		
Do workers experience any of the following: (a) ringing in the ears (b) the same sound having a different tone in each ear (c) blurred hearing		
<u>(observe)</u> Are personal hearing protectors provided?		
<u>(observe)</u> If yes, are they used?		
<u>(observe)</u> Are signs, indicating that personal hearing protectors should be worn, posted at the entrance or in the work area?		
<u>(Ask)</u> Do employees undergo baseline audiometry? or any planned periodic medical examination?		

4. Training on Hearing Conservation

Determine whether	**Yes**	**No**
i. Is there any Occupational Safety and Health training conducted at workplace (verify documentation)		
ii. If yes. Does it cover hearing conservation?		
iii. Standards of noise exposure limits are available and documented?		
iv. Health and safety committees available and functional? (verify documentation)		

5. Additional notes:

2.1.3 Sound Level Meter

Sound Level Meter is a hand-held device that is normally used to measure static or stationary sound pressure levels (from noise emitting substances such as machines, equipment or tasks) over a period: Such measurements are often referred to as area measurement or noise surveys. Also, it is used for noise measurement at ear level (10–20 cm from the human ear). This device is relatively cheap, easy to use and has the advantage that a single device can be used to gather details about the sources of noise in the workplace for the purpose of noise mapping.

2.1.4 Personal noise dosimeter

Personal noise dosimeter is a specific device for measurement of personal noise exposure. The device is portable and is fitted to the worker's shoulder (10 -15 cm from the most exposed ear) for full-shift noise measurements and provides a continuous noise profile of the working shift, and thus illustrates the variation in noise exposure with different tasks and activities. However, many of the current personal dosimeters cannot measure noise level above 140dB. In addition, measured values may be confounded by worker's behaviour (accidental or deliberate) such as touching the microphone, whistling, blowing or shouting into the microphone, or even removing and replacing it before the noise accessor is due to collect it. These devices have been widely used in different noise exposure studies.

Several types of personal dosimeters exist today, it is therefore a prerequisite to check whether the instrument or device you have or intend to use or buy fits the intended purpose. For example, those equipment or devices used for research and clinical diagnosis conforms with National and International Standards. Currently, many of the available personal noise dosimeters used in research conforms with the International Standards such as the IEC 61252: 1993+AMD1:2000+AMD2:2017: Electroacoustics – Specification for personal sound exposure meters; American standard: ANS/ASA S1.25-1991 (R2020): Specification for personal noise dosimeters; European Standards: BS EN 61672-1:2013: Electroacoustics – Sound level meters specifications.

Before conducting personal measurements, it is necessary to be equipped with the following: -

- Be confident with the logistical arrangement – permission from authorities, workplace, transport, communication, ethical board/committee, research team *etc*.
- Prepare data collection devices (personal noise dosimeters- fully charged, check memory space, test for functionality, transport/storage case)
- The description of the aim for conducting the measurement
- Decide and equip on the appropriate methods for conducting the measurement or survey (full-shift, task-based or job- based). This includes deciding on the number of measurements, the number of days for data collection, list/number of workers involved along with their specific jobs and tasks.
- Prepare necessary field work items. It is best to prepare a checklist of items you may need. For example, Dosimeter carrying cases (with 5 dosimeters each), noise dosimeter calibrator, data recording sheets, pens and pencils, laptop with software and timer/watch.
- Prepare data capture, backups and monitoring plan (data collection sheets, tape recorders, camera, computer/laptop installed with software)

- Train your team and assign responsibilities/tasks

2.1.5 Instrumentation

Noise measurement devices are designed to be equally sensitive to sound as the human ear, and thus provide relevant sound pressure level measurements. They consist of; -

1. A microphone: Converts sound signals to an equivalent electrical signal
2. Signal processing: Enhances and transforms electrical signals to achieve equal loudness levels (A, B, C weighting) or a linear response. Alternatively, it performs frequency analysis by splitting signals into bands (e.g., one-third octave). The final output is the RMS value, reflecting the sound's energy.
3. A display indicating the sound level in dB or related measurement units such as dB(A).

Figure 2.1. Example of a personal noise dosimeter carried by a worker. @University of Bergen

2.1.6 Noise sampling strategies

1. **Task based approach:** This is conducted if observations suggest that separate tasks or activities are carried out in the production process. The average noise level can then be estimated for specific tasks. The individual task noise exposure levels can be modelled to a standard workday i.e. 8-hours. The strategy is appropriate also to short-duration tasks where noise levels vary significantly. It is important to consider that at least three measurements should be taken per task or activity with a minimum measurement period of five minutes (ISO 9612-2009). The difference between the three measurements should not exceed 3dB.
2. **Job based approach:** This is appropriate where job groups performing similar task(s) can be identified. Workers are randomly selected from the different job groups and measured throughout the work-shift. A minimum of five samples per job group is advised and results are average noise levels across the entire work shift.
3. **Full shift approach:** This entails continuous measurements throughout the work shift i.e. noise profiling to obtain daily noise exposure. The approach is useful for compliance with regulations and standards and in determining the need for a hearing conservation program. It is advised to take measurements over several working days (repeated measures) to obtain reliable estimates of workplace noise exposure and consider task and process variability in weeks or seasons.

2.1.7 Noise evaluation and exposure limit values

The International Organization for Standardization (ISO standard) 9612:2009 provides an appropriate engineering method for measuring and calculating

noise exposure level at the workplace. Estimates obtained through this method may provide useful information for planning and implementing noise control measures. The two devices, i.e. integrating-SLM and personal noise dosimeters are recommended in this ISO standard for conducting workplace noise exposure assessment.

Several countries have set regulations and standards prescribing the equivalent sound pressure level (8-hr, A-weighted) that must not be exceeded. It is therefore important to consult and comply with the set values. However, for practical purposes, here is the summary for occupational noise exposure limit values stipulated by ISO, NIOSH (US), OSHA (US) and EU directive 2003/10/EC (Table 2.2)

Table 2.2. Examples of occupational exposure limit values

Standard	**Equivalent sound Pressure level ($L_{eq,8h}$)**	**Action value (Lower)**	**Action Value (Upper)**	**Peak Value (Z or C)**
ISO	85 dB (A)			
NIOSH	85 dB (A)			
OSHA (U.S)	90 dB (A)*		85 dB (A)	140 dB (Z)
EU Directive 2003/10/EC	87 dB (A)	80 dB (A)	85 dB (A)	135/137/140 dB(C)

*Criterion level

2.1.8 Steps

1. Identify noise hazards and sources: Conduct a thorough inspection of the work environment to identify for example, machinery, equipment, or processes that generate significant noise levels and characteristics such as intermittent and or continuous noise sources.
2. Identify workers at risk from noise exposure: Assess the work patterns and locations of workers to identify those who spend time in noisy environment or near noise sources. Consider such factors as frequency and duration of exposure and proximity to the noise sources.
3. Estimate likely exposure to noise. Use noise measurement devices such as sound level meters or dosimeters, and techniques (worst case, task-based or full-shift measurements) to collect data on noise levels. Calculate the average daily noise exposure (or noise dose) for each worker (in decibel) over an eight-hour period.
4. Identify appropriate measures to eliminate or reduce exposure to acceptable levels according to hierarchy of controls considering factors such as cost, effectiveness and feasibility.
5. Record actions taken. Maintain detailed records of noise risk assessment process, including identified hazards, exposed workers, measurement data, and control measures or interventions implemented. Ensure that these records are updated regularly and reviewed periodically to reflect any changes in the workplace.

2.1.9 Parameters

- The Equivalent average sound pressure level: (A- weighted or C- weighted; continuous or intermittent) depending on the set measurement objective: This represents a constant noise level that, if applied over the same amount of time as the duration of the measurement, would lead to the same exposure as the varying noise level of the actual working process.
- Noise dose (expressed in the percentage of the maximum allowed noise level): This represents the collected dose of noise the worker was exposed to over the measured time.
- Eight (8) hours for a day is regarded as a standard working hours for many countries and has been adopted into various standards (European Union, ISO, ANS/OSHA). Thus, Noise exposure to the maximum A-weighted equivalent average sound pressure level over an 8-hour workday [Time- Weighted Average, TWA in dB (A)] of 85 dB (A) [OSHA standard] corresponds to a Dose of 100%. There are several noise exposure calculators for estimation of daily noise exposure. These types of calculators compute the daily noise exposure that an employee is subjected to allowing the employee to analyse the risk and an employer to meet health and safety requirements. For example, the UK Health and Safety Executive- noise exposure calculator, available from: *HSE - Noise: Exposure Calculator*.

Table 2.3. Noise measurement sampling sheet

S/No	Date of sampling	Personal ID. No.*	Job title	Description of tasks during sampling duration	Start Time	End Time	Sampling time	Noise level (dB)		Notes
								LAeq	**Lpeak (max)**	

2.2 Vibration exposure at work

Vibration is described as the mechanical movement of a solid or liquid to and from its equilibrium position. Occupational exposure to vibration is a well-established physical risk factor across various industries for over a century. Consistent exposure to vibration may cause neurological, circulatory, muscular disorders as well as body discomfort. In this book we focus on two main types of vibration at work i.e., the whole-body vibration and hand-arm vibration.

2.2.1 General concepts of whole-body vibration at workplace

Whole body vibration (WBV) occurs when the body is supported on a surface which is vibrating, for example when sitting on a seat in a vehicle or standing on a vibrating floor. WBV might be a health problem in vehicles

such as locomotives, dumpers, bulldozers, excavators and dozers. Transport, construction, farming, forestry and mining are workplaces where WBV often is present.

In humans, WBV exposure of 0.7-100 Hz has been associated with an increased risk of vibration related adverse health outcomes. The risk depends mainly on the WBV exposure level (intensity), frequency and the duration of exposure. The vibration related health effect seems to be related with the acceleration of the tool which makes the basis of the exposure metrics for vibration i.e., the root-mean squared sum (RMS) acceleration in metres per second.

Globally, the prevalence of WBV exposure varies widely due to differences in occupation, technological advancement, the use of machinery and tools, and work practices. WBV is associated with low back pain (lumbar disc degeneration), neck pain, cervical disc degeneration, motion sickness, autonomic disturbance, as well as digestive and reproductive effects, although the causal relationship for some of these effects are not yet well established.

2.2.2 Factors affecting whole body vibration exposure include:

a. Individual factors such as body mass index (BMI).
b. Work organisation factors such as shift work, working posture, repetitive work, truck loading and unloading

c. Environmental factors such as road terrain
d. Factors related to mobile equipment (e.g. dumper, truck) such as size and type of the vehicle, suspension system, maintenance, driving speed, seat design and driving/operation characteristics.

2.2.3 Occupational exposure assessment of whole-body vibration

There are several factors to consider when conducting an occupational assessment of vibration exposure in the workplace (Table 2.4). After the field measurements are performed, using for example, the whole-body vibration meter, then the exposure levels should be evaluated using a whole-body vibration calculator to determine the recommended duration of work at this exposure level.

These types of calculators calculate the daily vibration exposure that an employee is subjected to allowing the employee to analyse the risk and the employer to meet health and safety requirements.

One example of a calculator to use for free is from Health and Safety Executive (HSE), UK: *https://www.hse.gov.uk/vibration/wbv/calculator.htm*.

It calculates the daily vibration exposure, typically normalized to an eight-hour reference period (A8) in Root Mean Squared value (rms) and Vibration Dose Value (VDV) i.e., the magnitude and duration of vibration an employee is subjected to during their workday.

Table 2.4. Example of an information list for use during whole body vibration assessments in vehicles

	Description
Vehicle name and number	
Place, company	
Date of measurement	
Model type, production year	
Deck type (or belts)	
Seat type (short description)	
Daily use of machine in minutes	
Work performed during measurement	
Surface driven on during measurement	
Weather conditions during measurements	
Height and weight of driver	
Measurement time	
Measurement results (general limit value: 1.1 m/s^2, action value: 0.5 m/s^2) Equivalent value, X-axis: Equivalent value, Y-axis: Equivalent value, Z-axis: Sum-value:	
Comment - maximum time of use recommended for this vehicle	

2.2.4 Measurement instruments

There are several vibration measurement instruments for WBV that meet the ISO 8041, ISO 2631 standards, available from various manufacturers. The instrument most often used in occupational health settings is a whole-body vibration dosimeter. This is integrated with a seat-pad and provides continuous monitoring of vibration exposure. The instrument is a triaxial accelerometer, connected to a computer which can log the vibration movements in three axes over time. In a vehicle, measurements can be carried out at the operator–seat interface of the mobile truck (figure X). The seat pad accelerometer is placed in a way that the x-axis is in the sagittal plane, y-axis in the coronal plane and z-axis in the vertical plane. The computer will (most often) give you the total vibration exposure calculation (in m/s^2), as well as the measurements in each of the axes. Some newer instruments of this type are wireless, and there is no wire between the seat pad and the computer. However, the distance between the pad and the computer might be restricted to a few metres.

Figure 2.2. Measurement of whole-body vibration using an instrument with an accelerometer inside a seat pad. The seat pad is connected to the computer/logger with a thin wire ©IP Nyarubeli

2.2.5 Evaluation of data and occupational exposure limits

The raw data from field measurements, are processed according to the procedures and guidelines used, for example the ISO 2631-1 (1997) by calculating weighted average (8-h equivalent) vibration level (A8) for each measurement exposure time using the vehicle vector sum root mean square (rms) vibration level for the three axes, A_w and estimated exposure time. Results are interpreted depending on the objective for WBV. The ISO standard include specific weighting curves (Wd,Wk, Wf) to account for different directions and frequencies of vibration. For example, results are reported in acceleration values (m/s^2) and then compared with the standards for WBV occupational exposure limits. Some countries have their own exposure limits, based on the ISO recommendations - i.e., the Tanzania Bureau of Standard (TBS). 2018 Mechanical Vibration and shock — Evaluation of human exposure to whole-body vibration. TZS 1398-1: 2018 – ISO 2631-1: 1997.

Limit values of vibration are of two types, limit value and action value.

a) Exposure Action Value (EAV)- the daily exposure value, averaged over 8-hours at which employers are required to take action to control exposure, and provide information and training to exposed employees. The EAV for WBV is set at a daily exposure of 0.5 m/s^2 A(8).
b) Exposure Limit Value (ELV)- the maximum exposure averaged over 8-h to which an employee may be exposed

to on a single day. ELV should aim to reduce exposure as low as reasonably possible. The ELV for WBV is 1.15 m/s^2.

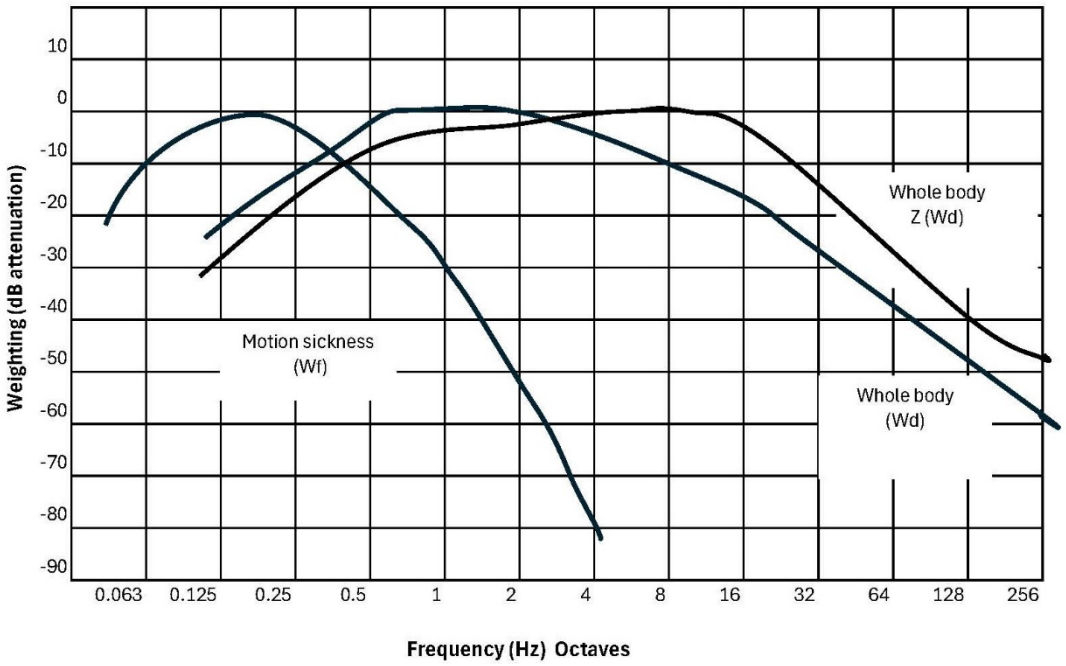


Figure 2.3. Example of the Whole-Body weighting curves from ISO 2931 standards. © ISO 2931 standards

2.2.6 General concepts of hand-arm vibration at workplace

Vibration affecting the hands and arms are caused by using hand-held tools. The mechanical vibrations are transmitted through the fingers, hands and arms when operating such tools. This type of tools is often used in manufacturing (e.g. metalwork, grinding), quarries, road construction, mining, forestry (e.g. chain saws), dentistry and many types of hand-craft jobs.

Work with vibrating hand-held tools may cause both acute and chronic health effects. The acute symptoms are numbness and reduced sensibility. The most common chronic health effect is hand-arm vibration syndrome (HAVS), which is also called traumatic vasospastic disease. The symptoms are attacks of white, bloodless fingers. The attacks are painful, and the worker cannot work during the attack. The workers may also develop chronic disturbances in peripheral nerves in fingers, hands and arms. Arthritis and musculoskeletal pain are also often related to the vibration exposure.

2.2.7 Occupational exposure assessment of hand-arm vibration

Vibration from hand-held tools can be measured using specialised instruments equipped with accelerometers that detect vibrations in three axes. The accelerometer

can be attached directly to the tool (often using adhesive) or placed in a pocket on special gloves designed for this purpose. The instrument is connected to a computer/logger via a thin wire, or alternatively, a wireless instrument kit may be used.

After the measurement, you receive the vibration results for each of the three axes as well as the overall vibration magnitude.

Figure 2.4. An example of HAV dosimeter ©University of Bergen

Exposure standards

Few countries have specific standards for hand-arm vibration (HAV) due to the lack of clear understanding about the relationship between vibration dose and the development of HAVS (Hand-Arm Vibration Syndrome). Most recommendations are based upon ISO standards, such as ISO 5349.2-2013. The European Union has established widely used and accepted exposure action value and exposure limit value for HAV.

a) Exposure Action Value

If daily vibration exposure is likely to exceed an A(8 hours) of 2.5 m/s^2, action should be taken to reduce exposure to below this value.

b) Exposure Limit Value

Controls must be implemented to ensure that workers are not exposed to a daily vibration exposure (A(8 hours)) exceeding 5.0 m/s^2 under any circumstances..

2.2.8 Standard and measurements

Obtaining instruments for measuring hand-arm vibration (HAV) can sometimes be challenging. In such cases, it is often practical to rely on tables with previously measured values, such as Table 2.5.

Table 2.5. Examples of vibration assessments for several work tools (Source: HSE, UK)

Class of plant	Type of plant	Vibration magnitude
Road breakers	Typical	12 m/s^2
	Modern tool designs, good operating conditions and trained operators	5 m/s^2
	Worst tools and operating conditions	20 m/s^2
Demolition hammers	Modern tools	8 m/s^2
	Typical	15 m/s^2
	Worst tools	25 m/s^2
Hammer drills/combi hammers	Typical	9 m/s^2
	Best tools and operating conditions	6 m/s^2
	Worst tools and operating conditions	25 m/s^2
Needle scalers	Modern tool designs	5-7 m/s^2
	Older tool designs	10-25 m/s^2
Scabblers (hammer type)	Typical	20-40 m/s^2
Angle grinders (large)	Modern vibration-reduced designs	4 m/s^2
	Other types	8 m/s^2
Angle grinders (small)	Typical	2-6 m/s^2
Clay spades/jigger picks	Typical	16 m/s^2
Chipping hammers (metal-working, foundries	Typical fettling	18 m/s^2
	Modern tool designs	10 m/s^2
Pneumatic stone-working hammers	Vibration-reduced hammers and sleeved chisels	8-12 m/s^2
	Older tools, conventional chisels	30 m/s^2
Chainsaws	Typical	6 m/s^2
Brush cutters	Typical	4 m/s^2
	Best	2 m/s^2
Sanders (random orbital	Typical	7-10 m/s^2

Alternatively, there are free online HAV-calculator (can be downloaded on computer) that can assist in calculating exposures such as the one from HSE; *https://www.hse.gov.uk/vibration/assets/docs/simple-hav.xlsx*. In this simple Excel sheet calculator, you need to inter vibration magnitude (m/s^2) and exposure duration (hours/minutes) for up to six machines or processes in the white areas. Tool types can be entered manually or selected from a drop-down list; and then the yellow cells will automatically calculate and display partial exposure for each tool/process in m/s^2 A(8) and exposure points, and the average HAV daily exposure in m/s^2 A(8) and exposure points, based on the partial exposures.

For example,

You are an industrial hygienist at a construction site, and you aim to assess the daily vibration exposure for a worker using various tools such as Angle grinder (100-180mm), Hammer drill and a chainsaw. Using the table Z above, the specific vibration magnitude of angle grinder = 4 m/s^2, Hammer drill = 8m/s^2 and chainsaw =5 m/s^2. The worker spends a total of 5hr and 55 minutes working with different tools (2:30 hr with angle grinder, 2:15 hr with hammer drill and 1:10 hr with chainsaw). Then, using the HAV- calculator,

a) Enter the data into HAV calculator (vibration magnitude and duration for each tool)
b) For each tool, the calculator will compute the partial exposure points based on the vibration magnitude and duration
   - Partial 8-hour average vibration exposure (A8): angle grinder = 2.2 m/s^2(A8), Hammer drill = 4.2m/s^2(A8), and chainsaw =2.3 m/s^2(A8).
   - Partial exposure Points: angle grinder = 80 Hammer drill = 288 and chainsaw =84.
c) The calculator will sum the partial exposure points to determine the total daily exposure in m/s^2 A(8) and points.
   - Daily exposure points = 80+288+84 = 452 points
   - Daily HAV exposure = 5.3m/s^2(A8).

Table 2.6. Example of HAV calculation. ©IP Nyarubeli

Company name/work area:	Construction site Z								
Employee ID and or task name:	XXXXXX								
Tool **Use drop-down list for HSE recommended initial tool magnitude value (range for tool shown in backets) or manually add tool type and/or magnitude in this column and the Vibration magnitude in "User column**	**Vibration magnitude** m/s^2		**Task** Points per hour	**Time to reach EAV** hh:mm	**Time to reach ELV** hh:mm	**Exposure duration**		**Partial exposure** m/s^2 A(8)	**Partial exposure** Points
	HSE	**User**				hours	mins		
Grinders – Angle (100-180mm) [3-10]		4	32	3:07	12:30	2	30	2,2	80
Drills – Core (78-107mm) [6-8]		8	128	0:46	3:07	2	15	4,2	288
Chainsaws [5-7]		6	72	1:23	5:33	1	10	2,3	84
INSTRUCTIONS: Enter vibration magnitudes and exposure durations (for an individual worker or a task carried out by several workers) in the white area. Results are displayed in the yellow areas. Additional information such as company name, worker name may be added if printing or saving the calculation.								**Daily exposure** m/s^2 A(8)	**Daily exposure** points
								5,3	452
								WARNING: Exposure above ELV (400 points)	
Exposure calculation by:								**Calculation date:**	03.10.2024
Job role:	Industrial Hygienist								

Interpretation: the total daily exposure of 452 points exceeds the HAV- Exposure Limit Value (ELV) of 400 points. This indicates that the worker's exposure is above the allowable workplace exposure limit, and immediate action is required to reduce exposure.

2.3 References

European Union. Exposure action value and exposure limit value for HAV, EU 2002/44/EC Physical Agents (Vibration) Directive

Gerger H, Søgaard K, Macri EM, Jackson JA, Elbers RG, van Rijn RM, Koes B, Chiarotto A, Burdorf A. Exposure to hand-arm vibrations in the workplace and the occurrence of hand-arm vibration syndrome, Dupuytren's contracture, and hypothenar hammer syndrome: a systematic review and meta-analysis. J Occup Environ Hyg. 2023 Jul;20(7):257-267

HSA Whole body vibration calculator: https://www.hse.gov.uk/vibration/wbv/calculator.htm

HSA Hand-arm vibration at work. https://www.hse.gov.uk/vibration/hav/index.htm

International Labor Organization, ILO. Vibration, 2024: https://www.ilo.org/topics/labour-administration-and-inspection/resources-library/occupational-safety-and-health-guide-labour-inspectors-and-other/vibration

ISO 5349.1-2013: Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements.

ISO 5349.2-2013 Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 2: Practical guidance for measurement at the workplace.

Patterson F, Miralami R, Tansey KE, Prabhu RK, Priddy LB. Deleterious effects of whole-body vibration on the spine: A review of in vivo, ex vivo, and in vitro models. Animal Model Exp Med. 2021 Mar 23;4(2):77-86.

Basner, M., et al. (2014). "Auditory and non-auditory effects of noise on health." The Lancet **383**(9925): 1325-1332.

Gardiner K. (2005) Noise. In: Occupational Hygiene, 3rd edition, Eds. Gardiner K, Harrington JM, Oxford, UK: Blackwell Publishing

HSE (2021). Controlling noise at work. The control of noise at work Regulations 2005, L-108.3rd edition- UK, HSE Book. Available from: L108: Controlling noise at work (hse.gov.uk)

Chapter 3. Pesticide Exposure Assessment

Bjørg Eli Hollund and Meaza Gezu Shentema

3.1 General concepts on pesticide exposure

3.1.1 What pesticides are

Pesticides are a group of chemical compounds used in the fight against microorganisms that are undesirable to humans. Pesticides are used for controlling pests, killing organisms like insects, vertebrates, worms, plants, fungi, and bacteria. Due to these characteristics, pesticides may unfortunately also cause harm to human health. Therefore, the use of pesticides needs to be authorized and used in a proper way. It is important to be able to assess the exposure to pesticides at workplaces where these substances are used.

There are many thousands of pesticides on the market, and they are available as in commercial formulations, both liquids and solids (e.g. pellets and powders). According to the Food and agriculture organization (FAO), the use of pesticides in 2021 was about 3,5 mill tons annually in the world, which is doubling since 1990. Asia had the highest level of pesticide export in 2021, while Brazil had the largest use of pesticides that year.

Each pesticide does not operate with absolute specificity, the products intended to kill one microorganism might be toxic against a wide range of organisms, and the mechanisms for pest control may overlap with other chemicals.

The main types of pesticides:

- Insecticides – kill insects
- Herbicides – kill malicious plants
- Fungicides – kill fungus
- Bactericides – kill bacteria
- Rodenticides – kill rodents

According to World Health Organization (WHO), more than 200 000 people are killed annually from pesticide chemicals used in agriculture and farming. The health effect of pesticides depends on the chemical nature and solutions. Most health problems are caused by long term exposure, but acute intoxications, with symptoms such as headaches, nausea, respiratory problems, vomiting, dermatitis, as well as death, are also well known. Long term effects that are described are cognitive, motor, sensory, and neurological disorders.

3.1.2 Where pesticides are used

Pesticides are widely used in agriculture, forestry, fishery and food industries. The products are used in open fields, but also indoors such as inside the plants (greenhouses).

3.1.3 How pesticides are used

Pesticides are often available as liquids and are sprayed on the crops. Farmers can be exposed to the pesticides when they are mixing, loading, or spraying the pesticides, but also when they are in direct contact with treated vegetation, and when they are

cleaning the equipment at the end of the day. Pesticides can also be used as solid material, for instance as pellets that are spread in the environment.

3.1.4 Exposure routes

Farmers can be exposed to aerosols, and the main body uptake is by the respiratory systems. They can also be exposed through the skin. Pesticides can also be absorbed by the gastrointestinal tract, but this is always due to accidents.

3.1.5 How to get information about the pesticides

The active ingredients in the pesticides differ, and it can be difficult to get information about the content and ingredients. However, some countries have major restrictions on export and import of pesticides and regulations that require development of safety data sheets (SDS) that describe about the pesticides in use. However, it is more common that the use is less regulated, and it can be difficult to find SDS.
Labelling and SDS follow the same recommendations as other chemicals in Europe, but in other parts of the world, the information, and the regulations about this can be scarce.

3.1.6 Handling and risk reduction

Before handling different pesticides it is important to obtain information about these chemicals is important, and all types of labelling and information are useful. Use of personal protection equipment is necessary while handling the chemicals, and education of the workers is very important. Protective equipment is for instance respiratory protective masks and overalls, gloves, socks and shoes to protect the skin. When spraying the workers also need to wear safety glasses.
Pesticides should be stored and handled in a safe manner; this is important to avoid accidents and acute intoxications.
Exposure assessment is important to control the working conditions of the workers exposed to the pesticides.

3.2 Organophosphates and carbamates exposure

3.2.1 General concepts

Organophosphates are phosphoric esters or tropospheric acid esters, whereas carbamates are esters of N-methyl carbamic acids (Fig1-2).
Organophosphates and carbamate pesticides have similarity both structurally and mechanistically. These pesticides affect the target organism system through their cholinergic effect. They disrupt neurotransmission to alter pest behaviour or survival. The same mechanism of effect through which they do affect the target organism may also can be a reason to affect non-target organisms like humans. These compounds are described in detail here since several methods for assessment of this type of exposure exist. This is unfortunately not the case for many other pesticides.

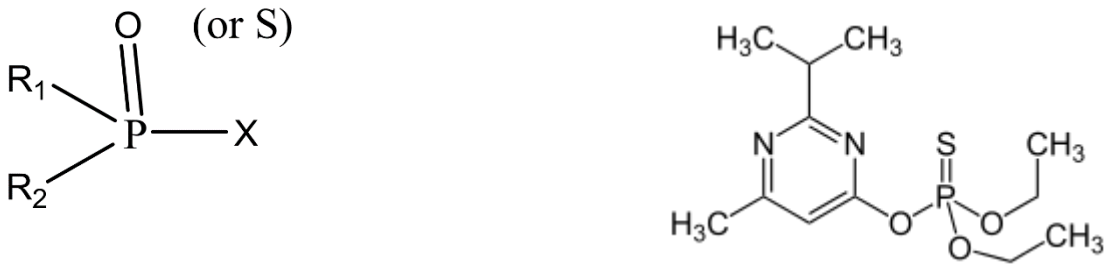


Figure 3.1. General structure of organophosphate pesticides (Left) and an example of Organophosphate (Diazinon) Chemical structure (right)
© Mdeni, N.L.; Adeniji, A.O.; Okoh, A.I.; Okoh, O.O. Analytical Evaluation of Carbamate and Organophosphate Pesticides in Human and Environmental Matrices: A Review. Molecules 2022, 27, 618. https://doi.org/10.3390/molecules27030618

Figure 3.2. General structure of carbamate pesticides (Left) and an example of carbamate (Carbaryl) chemical structure (Right)
© Mdeni, N.L.; Adeniji, A.O.; Okoh, A.I.; Okoh, O.O. Analytical Evaluation of Carbamate and Organophosphate Pesticides in Human and Environmental Matrices: A Review. Molecules 2022, 27, 618. https://doi.org/10.3390/molecules27030618

In the nervous system, acetylcholine transmits messages to the next nerve and the cholinesterase enzyme will activate the breakdown of acetylcholine into acetic acid and choline and this will be a mark of end of message transfer. But in the presence of organophosphate and carbamate exposure, the cholinesterase enzymes will bind to these pesticides reducing the amount of cholinesterase enzyme ready to catalyse the breakdown of acetylcholine. Thus, the nerve signal continues, although it might not be needed, because there will be an excess amount of acetylcholine. Workers exposed to cholinesterase-inhibiting pesticides (Organophosphates and carbamate) are reported to develop different health problems.

Organophosphate phosphorylation with acetylcholinesterase is not reversible whereas carbamates to acetylcholinesterase is reversible. In case of mild intoxication, individuals might develop headaches, sweating, miosis, and tiredness which might fade away within 24 hours if exposure ceases. Moderate intoxication will result in weakness of the muscle, bradycardia, vision disturbance, stomach pain, vision disturbance, tremors, and ataxia. Besides, exposure to high doses might result in serious intoxication leading to respiratory failure and even death.

3.2.2 Organophosphate or carbamate exposure assessment techniques

Dermal Exposure assessment
Pesticide exposure quantification can be done using the patch method in which exposure is quantified by the amount of contamination on the worker's skin. It uses pesticide-absorbent cloth or paper patches attached to defined areas of the body. The exposure happening to the workers will then be measured from paper patches and extrapolated to the whole body. The analysis of pesticide residues on absorbent patches will be determined by using different methods such as gas chromatography-mass spectrometry and liquid chromatography-mass spectrometry. However, these methods for dermal exposure assessment of pesticides are not standardized, and results are difficult to interpret. The methods are in a developing phase.
Also, since this method assumes that exposure happens equivalently to the whole body it might over- or under-estimate the exposure based on the part of the body sampled for exposure.

Inhalation Exposure assessment
Personal air sampling is one method for measurement of airborne concentrations of pesticides in the breathing zones of workers.
Equipment required for personal air sampling:

- sampler/glass tube
- sampling pump

Sampling

- Calibrate each personal sampling pump
- Connect the sampler with the correct filter/adsorbent with each personal sampling pump
- Adjust the flow rate to 0.2-1L/min.
- Mount the sampler into the workers breathing zone
- Record the start time of the sampling
- Record the end time of the sampling
- At the end of the sampling tile seal the samplers on both ends and prepare for shipment

The samples are transported to a qualified laboratory, and the analysis will be done specifically to the pesticides needed to be analysed. The lab will notify the results. Often high-performance liquid chromatography is used for these analyses, sometimes with fluorescence detection.

Note: The type of pesticides determines the type of sampler tube needed for sampling. In the case of volatile pesticides samplers and filters/adsorbents specific to volatile chemicals are needed for sampling. It is necessary to have close contact with the laboratory to be able to perform the sampling correctly. These analyses are not performed in all countries.

Biomonitoring techniques
There are two types of cholinesterase, acetylcholinesterase (true) and butyl-cholinesterase (pseudocholinesterase). Worker's exposure to cholinesterase-inhibiting pesticides is estimated based on the level of cholinesterase enzymes in the blood. This is usually measured using Ellman or Michel's techniques.

A) Blood sampling and analysis in the Ellman Technique

Ellman technique is of colorimetric types which is based on choline release and its reaction with colorogenic reagents due to the breakdown of acetylcholine. The cholinesterase level determination by the Ellman technique involves using different test kits produced by manufacturers. Erythrocyte acetylcholinesterase test- mate photometric analyser kit can be mentioned as one example of test kits that have been used in different studies in Tanzania.

B) Blood Sampling and analysis using the Michel's technique

Michel's techniques measure acetylcholinesterase levels by the resulting change in pH of the serum or red blood cells following the addition of acetylcholine/butyl-choline chemicals.

Reagents needed:

* Acetylcholine chloride substrate (0.165M)
- Buffer solution

Sampling:

- Take blood samples from the veins of the worker using a vacuum tube serum separator or EDTA. This needs to be performed by qualified personnel
- Place the tube into an ice pack for shipment into the laboratory
- Separate serum by centrifugation at the laboratory

Analysis:

- Take 0.1ml of serum sample using a micropipette and place it in a suitable beaker
- Add 5 ml of distilled water.
- Add 5ml of the buffer solution, mix well
- Place in an incubator at 25°C for 10 minutes
- Read pH_1 of the sample
- Add 1 ml of 3% acetylcholine with rapid mixing, not the time.
- Allow to stand for one hour in the thermostat at 25°C
- Read pH_2 of the sample.
- Repeat the above procedure without the addition of serum sample & and record pHB (PH of the blank)

Calculation: Michael unit (MU)= $\frac{[(PH_1 - PH_2) - PH_B] \times 100}{t_1 - t_2}$

Interpretation of findings of biomonitoring

Cholinesterase has a wide range of normal values that makes it difficult to interpret the findings from a single measurement into normal or abnormal values. For this reason, a person who will be engaged in pesticide exposure is recommended to have his/her cholinesterase baseline measurement before he/she is even exposed to pesticides. Then, after being engaged in the pesticide handling job, there is a need to have periodic measurements of cholinesterase level to determine whether the exposure is affecting workers' cholinesterase for early prevention of potential risks.

3.3 References

Fabian CL, Binder CR. Dermal Exposure Assessment to Pesticides in Farming Systems in Developing Countries: Comparison of Models. Int J environ Res Public Health 2015; 12: 4670-4696.

Food and Agriculture Organization of the United Nations: Pesticides use and trade 1990-2021. https://www.fao.org/3/cc6958en/cc6958en.pdf (retrieved 12.12.2023)

Jaipieam S, Visuthismajarn P, Siriwong W, Borjan M, Robson MG. Inhalation exposure of organophosphate pesticides by vegetable growers in the Bang-Rieng subdistrict in Thailand. Journal of environmental and public health. 2009: 1-6.

Kapeleka JA, Sauli E, Sadik O, Ndakidemi PA. Biomonitoring of acetylcholinesterase (AChE) activity among smallholder horticultural farmers occupationally exposed to mixtures of pesticides in Tanzania. Journal of environmental and public health. 2019.

Mdeni NL, Adeniji AO, Okoh AI, Okoh OO. Analytical evaluation of carbamate and organophosphate pesticides in human and environmental matrices: a review. Molecules. 2022;27(3):618.

National Institute of Occupational Safety and Health (NIOSH). Manual of Analytical Methods: 5600 Organophosphorus Pesticides: US Department of Health and Human Services, Public Health Service, version 5th Edition, 2020. .https://www.cdc.gov/niosh/nmam/ (retrieved 24.01 2024).

Strelitz J, Engel LS, Keifer MC. Blood acetylcholinesterase and butyrylcholinesterase as biomarkers of cholinesterase depression among pesticide handlers. Occupational and environmental medicine. 2014;71(12):842-7.

Vale A, Lotti M. Organophosphorus and carbamate insecticide poisoning. Handbook of clinical neurology. 2015;131:149-68.

Chapter 4. Gases and vapour exposure assessment

Bjørg Eli Hollund and Magne Bråtveit

4.1 General concepts and definitions

4.1.1 Gases

Gases are agents whose physical state is a gas at normal temperature and pressure. A gas has no fixed volume or shape; it takes the volume of the working area.

Inorganic gases typically do not contain carbon-hydrogen bonds. Some common examples are oxygen, nitrogen, carbon dioxide, ammonia, hydrogen, chlorine. Organic gases contain carbon and hydrogen atoms, and often other elements like oxygen, nitrogen, sulphur, and halogens. Some examples are methane, propane, ethylene and formaldehyde.

Gases may be inhaled and can sometimes cause adverse health effects for employees. Some gases are essential (as oxygen), but some may displace the fresh air and cause suffocation. Some gases are toxic and are harmful for people to inhale (as carbon monoxide, hydrogen sulphide, hydrogen cyanide). Symptoms may include irritation of the eyes or nose, cough, asthma and allergy and shortness of breath.
From a health perspective the two key factors which are important when assessing exposure from gases are the chemical composition of the gas (toxic effect), and if the oxygen-level in air is reduced. The air concentration of gases is normally expressed in ppm (parts per million).

4.1.2 Vapours

Vapour arises from evaporation of materials which usually exist as liquids at normal temperature and pressure. The vapours that have been most in focus in occupational health are a group of chemicals called organic solvents. Organic solvents are carbon-based substances capable of dissolving or dispersing other substances. Some of the most common organic solvents are acetone, toluene, benzene, xylene, ethyl acetate, hexane, heptane, dichloromethane, methanol, ethanol, etc.

Organic solvents are used for millions of purposes which alert us to think more about its health hazards. Several organic solvents have low boiling points, volatilize readily at room temperature and become available for inhalation. Almost all the organic solvents are hazardous to health, uptake is by inhalation and skin contact. Due to the high lipophilicity of organic solvents, they can easily enter and affect the brain. Health effects of organic solvents can be headache, dizziness, tiredness, blurred vision, behavioural changes, unconsciousness, and even death. At high doses they might be anaesthetic. Carcinogenic organic solvents include benzene and trichloroethylene.
Exposure dose and symptoms will depend on the toxicity of the specific pollutants the workers are exposed to, the concentration of the pollutants, the daily exposure time (hours and years) and the frequency of exposure.

4.2 Sampling of gases and vapours

When assessing an employee's exposure to gases and vapours three main methods can be used. These methods are active and passive sampling and use of direct reading instruments, all with different advantages and disadvantages. In active sampling, a tube or a filter is connected to a pump, similar to aerosol sampling (see Chapter 1, Figure 1.2), while in passive sampling pumps are not used. Active and passive sampling are the primary methods used for full-shift, personal measurements of contaminants to compare with occupational exposure limits (OELs).

4.2.1 Contact with the analysis laboratory

- When planning exposure measurements in an industry one should contact the analysis laboratory to provide them with important information related to the workplace and to hear their recommendations on many aspects related to sampling.

- Information needed for the laboratory: The laboratory needs information on the type of industry and the relevant chemicals for sampling and analysis. Such information is vital to recommend sampling and analysis methods.
- Sampling method: Laboratories can advise on the correct sampling method (active/passive sampling, filters, sorbent tubes, etc.) needed for collecting samples.
- Sample volume and duration: They can provide guidance on the appropriate sample volumes and sampling durations to ensure that collected samples are adequate for analysis. Is the total capacity of the collecting medium sufficient to cope with the loading of the contaminant given the intended sampling rate over the proposed sampling period?
- Does the presence of high-water vapour levels or the presence of particulates in the air affect the collection characteristics?
- Appropriate analytical methods: Laboratories can recommend the most suitable analytical methods for the chemicals. Is the sampling device (and collection medium) suitable for collecting the contaminant of interest and is the medium compatible with the subsequent analytical method?
- Sample preservation and shipping instructions: Guidelines for the preservation of samples to prevent degradation or contamination during transport. How should the samples be packed and sent to the laboratory?
- Regulatory standards: Laboratories are aware of regulatory requirements and standards and can help ensure that your sampling strategy complies with these regulations.

4.2.2 Active sampling

a) Active sampling of inorganic gases on impregnated filters or sorbent tubes

Many inorganic gases can be collected on impregnated filters or impregnated sorbent tubes. Impregnated filters/tubes can be packed in standard air sampling cassettes and connected to a pump similar to aerosol sampling (see Chapter 1, Figure 1.2).

Examples are:

- Potassium hydroxide-impregnated filters for determination of hydrogen fluoride
- Sodium iodide-impregnated filters for determination of nitrogen dioxide
- Sulfuric acid-impregnated silica gel tubes for the determination of ammonia

The pollution will react with a chemical reagent on the impregnated filters/tubes and form a stable chemical product. After the end of sampling the samples should be in a refrigerator until they are sent to a laboratory for analysis as soon as possible.

b) Active sampling of organic solvents on sorbent tubes

The most common sampling method for organic solvents in air is sampling on sorbents. In active sampling the sorbent tube is connected to a pump (Figure 4.1). Air is pumped through the sorbent tube, usually at a fixed flow rate between 20-200 ml/min. The sorbent tube has different capacity for different solvents. It is important to be in contact, and ask for advice at the analysing laboratory, to be sure that sampling is performed according to the requirements. For organic solvents the most common air flow rate is 50 ml/min. Thus, a sampling time of 3-4 hours, gives a sampling volume of 9-12 litres.

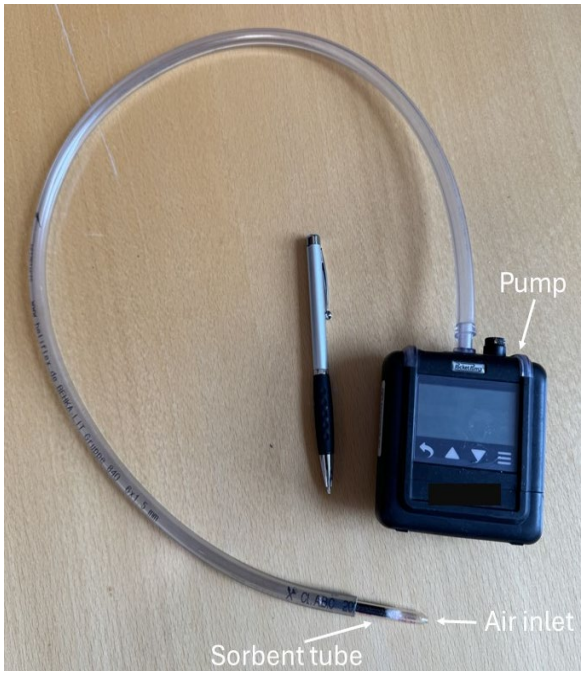


Figure 4.1. Active sampling with use of pumps and a sorbent tube for sampling of organic solvents. ©University of Bergen

After the end of sampling, sorbent tubes or dosimeters are stored in a refrigerator. The samples should be sent to the laboratory for analysis as soon as possible. Most of the sorbent tubes have an analysing part and one control part. If more than 25% of the component is in the control part, the tube is considered overloaded, and the measured value (sum of main and control part) must be considered as a minimum value.

The most used sorbents are: Active charcoal, silica gel and organic polymers (Tenax, Chromosorb 106 or Amerlite XAD-2) used in ATD-tubes for thermal desorption. Active charcoal is the sorbent that is mostly used. There are a few components where you have to use another sorbent, such as silica gel when measuring methanol, and some ketones.

In case ATD-tubes are planned to be used you need to be in contact with the laboratory. The choice of adsorbent must be adapted to the analysis method used. This method is more sensitive, and the sampling time can be reduced compared to other sorbents. After the end of sampling, the ATD tubes should be stored at room temperature before the samples are sent to the analysis laboratory as soon as possible.

Some organic compounds are reactive and unstable and are therefore not suitable for direct collection on sorbents. These compounds therefore react in the collection step with a suitable reagent and form a stable derivative that can be analysed in the laboratory after sampling. Organic compounds where derivatization in the collection step is commonly used include aldehydes like formaldehyde, isocyanates/ diisocyanates, amines, and acid anhydrides.

Checklist and sampling worksheet

The checklist and the worksheet are basically similar to the one in Chapter 1 for aerosols, however with other flow rates and with sorption tubes instead of a sampling head for aerosol.

Calculation of results

Concentration of contaminant

(in mg/m^3) = (m_f + m_r - m_b)/(D x V)

Where:
m_f = mass of contaminant in front section in mg
m_r = mass of contaminant in back up section in mg (control part)
m_b = mass of contaminant in blank in mg

D = desorption efficiency
V = sampling volume in m^3

Generally, for active sampling:
Equipment needed: Calibrated pumps, impregnated filters or sorbent tubes
Advantages: Measure gases over the 8-hours working day, mean exposure
Disadvantages: The samples must be sent to the laboratory, and sometimes the exposed filters/tubes must be stored in a freezer.

4.2.3 Passive sampling of organic solvents on dosimeters

Passive sampling is performed without using a pump. Pollutants in the working atmosphere are collected by diffusion onto the sorbent sampler. The sampler is called a diffusion sampler or a dosimeter and is attached in the breathing zone of the worker (Figure 4.2). After sampling, the dosimeters must be sealed and stored in a refrigerator prior to analysis at the laboratory.

Information recorded in the air sampling worksheet when using passive sampling is similar to what is used for active sampling, but without flow rates as pumps are not used (Table 4.1).

Figure 4.2. A dosimeter for sampling of organic solvents is attached in the breathing zone of the worker. ©University of Bergen

Table 4.1. Example of an air sampling worksheet for sampling of organic solvents on dosimeters.

Date	Sample ID	Employee	Job tasks	Time 1 start	Time 2 stop	Sampling Time (min)	Analysed amount (µg)	Air conc. (mg/m^3)	Air conc. (ppm)

The amount of contaminant adsorbed to the dosimeter per time unit depends on the sampler design, the diffusion coefficient of the contaminant and the concentration in the air.

The time weighted average of the concentration of contaminant in mg/m^3 can be calculated like this:

Concentration (in mg/m^3) = W(µg) x A /r x t

where:

- W =Mass of contaminant collected (in µg)
- A =1000 x 24.45 /Sampling Rate*
- r = Recovery coefficient*
- t = Sampling time (in minutes)

* Information provided by manufacturer

Alternatively, the concentration of contaminant in ppm can be calculated like this:

Concentration (in ppm) = W(µg) x B/ r x t

where:

- W = Mass of contaminant collected (in µg)
- B = 1000 x 24.45/Sampling rate* x molecular weight
- r = Recovery coefficient*
- t = sampling time in minutes

*Information provided by the manufacturer

Advantages of dosimeters

- Easy to use
- No pump, batteries or tubing, no calibration
- Light weight
- Less expensive

Limitation/Disadvantages

- Need air movement 0.13 m/sec
- Cannot be used for low vapour pressure organics e.g. glutaraldehyde
- Cannot be used for reactive compounds such as phenols and amines
- Humidity
- "Sampling rate" needs to be stated by manufacturer

4.2.4 Colour indicator tubes for instant measurements

A simple quick method for measuring different gases and vapours is to use colour indicator tubes (Figure 4.3). Colour indicator tubes are available for a number of gases and vapours, and there are several producers of such tubes. The tubes contain a sorbent coated with a substance-specific reagent that, when reacting with the gas or vapour in question, causes a colour change in the tube. The length of the colour zone is read directly on a scale on the tube. Samples with indicator tubes are taken with adapted pumps, often-manual piston pumps, with a displacement of 100 ml. The number of pump strokes is specific to each type of tube. Sampling time is from a few

seconds to several minutes. Results are just an instant measurement. Most of the tubes must be connected to a pump, while some tubes are for long-time measurement by diffusion-based reactions.

Equipment needed: Indicator tubes for a specific gas or vapour and a pump

Advantages: Easy to use, instant result

Disadvantages: Interference between the gases, not an exact result, just an indicator of instant concentration.

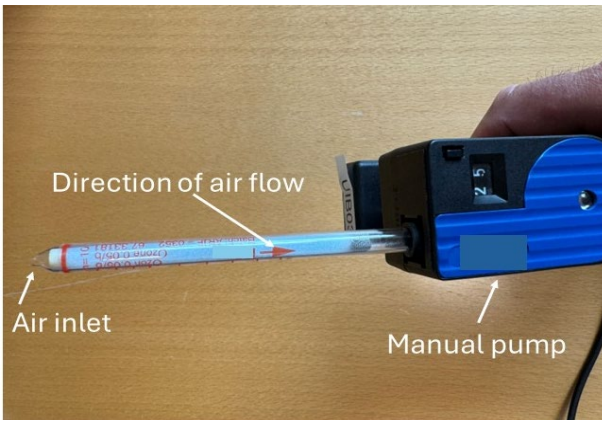


*Figure 4.3. A colour indicator tube for instant measurement of ozone connected to a manual pump***.** *©University of Bergen*

4.2.5 Direct-reading instruments for gases and vapours

Monitoring for hazardous substances for testing compliance with Occupational Exposure Limits requires measurement of personal exposure levels. However, real-time monitoring, using portable direct reading equipment can be a valuable supplement to traditional personal measurements to characterise the exposure. Using direct-indicating instruments, variation in degree of exposure over time can be mapped. Furthermore, it might be used to identify pollution sources and leaks, and to assess the efficiency of control measures to reduce emission of hazardous contaminants at the workplace.

Using portable direct reading equipment, can be helpful at determining the 'where and when' of peak exposures which may occur throughout a work period. This is particularly relevant where the acute effects of a substance could be immediately dangerous to life or health, e.g. when it is foreseeable that asphyxiants and/or explosive gases or vapours may be present, so that immediate action can be taken to prevent or mitigate risk of exposure. The information from direct reading instruments, when combined with exposure assessments, can enhance details of an exposure profile and lead to a more detailed determination of where exposure controls are needed. Many direct reading instruments are able to measure a range of hazardous substances, whether this is gases/vapours or dusts/aerosols. Direct reading instruments may either be calibrated for the hazardous substance to be measured (i.e. the reading relates directly to the hazardous substance of interest) or require a calibration factor to be applied (i.e. the reading is adjusted using the calibration factor in order to correlate to the hazardous substance of interest). As with all monitoring equipment, direct reading equipment needs to be calibrated and maintained by a competent person according to the manufacturer's instructions.

Advantages using direct reading instruments

- Continuous, direct reading measurements
- Output: Time weighted average (TWA), Peak levels
- Data logging

Limitations using direct reading instruments

- Expensive
- Needs frequent calibration
- Lack of specificity, cross sensitivity
- Need for intrinsically safe instruments
- Battery life
- Sensors: Finite life, lack of range

A number of different measuring principles are used in direct-reading instruments for gases and vapours. The instruments and the principles vary from relatively simple to complex. Some examples of different types are listed here:

- Electrochemical cells/sensors
- Photoionization detectors (PID)
- Flame ionisation instruments (FID)
- Infrared spectrophotometers (IR, FTIR)
- Mass spectrometers (MS)

We will shortly describe the two most commonly used types of direct-reading instruments for gases and vapours in the working environment, electrochemical cells/sensors and photoionization detectors (PID)

a) Electrochemical sensors

Among electrochemical sensors there is a large assortment intended for measurements on persons (Figure 4.4). The most widespread principle for measuring inorganic gases in the working atmosphere is based on electrochemistry. The principle is based on diffusion of gas molecules across a membrane into a chemical system where a chemical reaction occurs. The change in electrode potential is proportional to the gas concentration that is continuously recorded as a function of time. A disadvantage is that the sensor often has cross-reaction with other gases and vapours. Cross sensitivity means that an instrument sensor can give an erroneous reading from the presence of an air contaminant it was not designed to measure. Calibration is important, and the sensors have a limited lifetime.

There are electrochemical sensors for several gases including nitrogen oxide, sulphur dioxide, hydrogen sulphide, ammonia, carbon monoxide, hydrogen cyanide and chlorine gas.

Figure 4.4. Example of an electrochemical sensor for measurement of inorganic gases. ©University of Bergen

b) Photoionization detector (PID)

A Photoionization Detector (PID) monitor is a device used to detect and measure volatile organic compounds (VOCs) and other gases in the air (Figure 4.5). Typically, the PIDs are nonspecific VOCs or total hydrocarbon detectors, and can respond to many compounds. Therefore, they may require supplementary methods to identify specific compounds. The PIDs utilises ultraviolet (UV) light to ionise the gas

molecules, which allows for the detection of a wide range of chemical compounds. The ionised particles create a current, which is measured by the detector. The amount of current is proportional to the concentration of the gas in the air. The monitor then converts this current into a readable concentration value, usually displayed in parts per million (ppm) or parts per billion (ppb).

PIDs are available as portable handheld devices for field use or as fixed installations for continuous monitoring in industrial environments. Regular calibration with known standards is necessary to ensure accurate measurements.

Figure 4.5. Examples of photoionization detection (PID) instruments for measurement of non-specific, volatile organic hydrocarbons (VOCs). A hand-held instrument (left), and a personal monitor (right). ©University of Bergen

4.3 Comparison with Occupational Exposure Limits (OELs)

OEL is the maximum value for the average concentration of a chemical substance in the breathing zone of a worker in a fixed reference period of eight hours.
Comparison with OELs for a chemical should be done for groups of workers exposed to approximately the same exposure level. This can be the case when the employees perform the same tasks with the same materials and processes, they perform the tasks in the same way and with the same frequency. The measurement results for each similar exposure group (SEG) are assessed separately. A SEG can consist of one or more employees and the same employee can be part of several SEGs.

Exposure to one chemical

In the simplest cases the workers are exposed to only one chemical. Then, the result from the exposure measurement is compared with the OEL for that specific substance.

Exposure to several substances at the same time

The exposure is not necessarily acceptable even if the measurement result for each individual substance is acceptable. This is because when several different chemical substances occur together, they can have a greater health effect together than the "sum" of the effects they have individually (synergistic effect). If workers are exposed to more than one substance, this must be considered both when taking the measurements and when evaluating the measurement results.

If the substances have **a similar effect on humans**, the combined exposure with a comparable effect can be assessed based on the addition formula for additive effect (E_{add}). This applies, for example, to organic solvents.

Additive effect of a mixture of chemical substances with a similar effect on humans is calculated by the addition formula:

- $E_{add}= (C_1/OEL_1)+(C_2/OEL_2)+(C_3/OEL_3)+...+(C_n/OEL_n)$

where

-"C" indicates the measured concentration over 8 hours of the chemical substances 1,2,...,n

-"OEL" indicates the occupational exposure limit for the respective chemical substances.

If this sum (E_{add}) exceeds 1.0, then the additive effect of the mixture is exceeded.

4.4 References

Health and Safety Executive, UK. EH40/2005 Workplace exposure limits, Fourth Edition, 2020 .https://www.hse.gov.uk/pubns/priced/eh40.pdf

Health and Safety Executive, UK. G409 Exposure measurement: Air sampling. 2022. https://www.hse.gov.uk/pubns/guidance/g409.pdf

NIOSH Manual of Analytical Methods (NMAM) 5th Edition (R. Andrews & P. F. O'Connor, Eds.), 2020. https://www.cdc.gov/niosh/nmam/pdf/NMAM_5thEd_EBook-508-final.pdf

Occupational Hygiene Training Association (OHTA). Measurement of hazardous substances. OHTA Student manual, 2023. https://ohtatraining.org/students/fmanuals/manuals/ohta501/

SKC Ltd. Air Sampling Basics. Step by Step Guide, 2023 https://www.skcltd.com/images/pdfs/224-G1.pdf

Chapter 5. Radiation Exposure Assessment

Ole Jacob Møllerløkken

5.1 General concepts

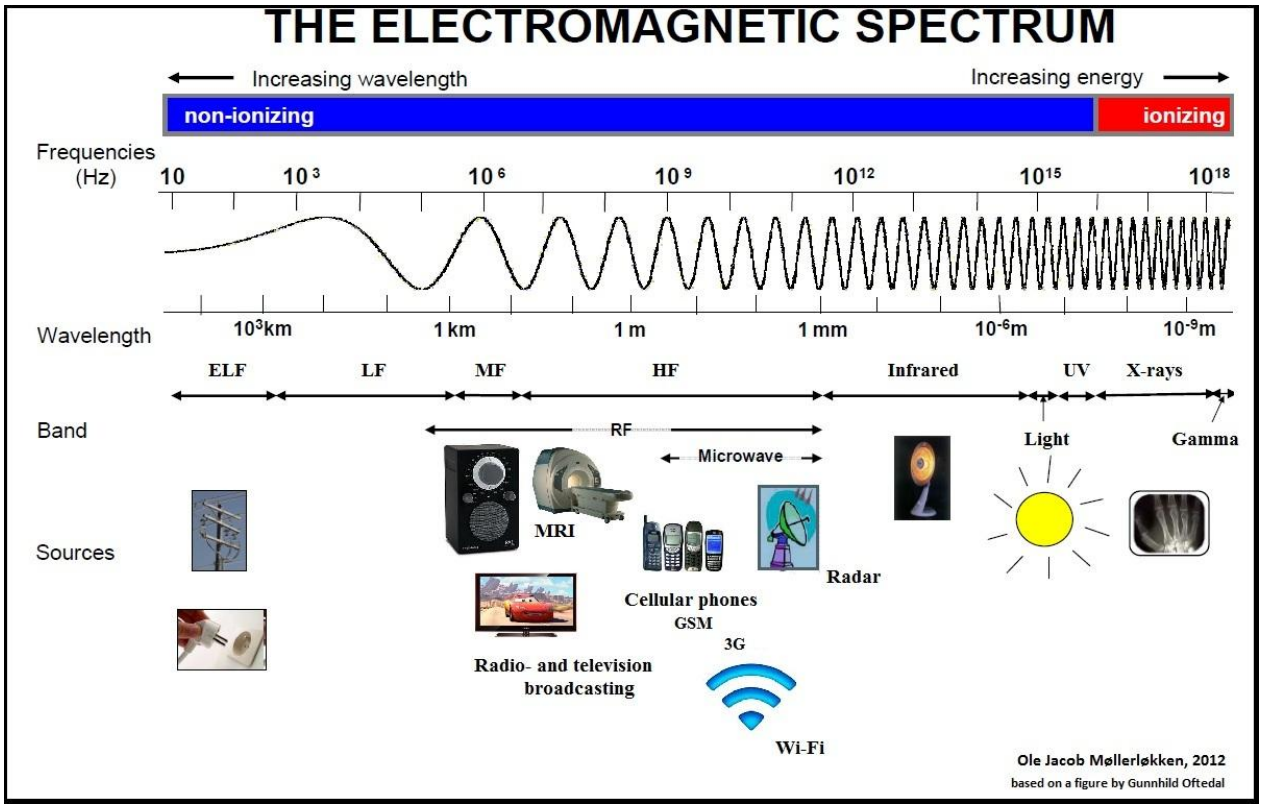


Figure 5.1. The electromagnetic spectrum. ©OJ Møllerløkken

Radiation is divided into non-ionizing and ionizing electromagnetic fields and is a way of transferring energy. The illustration above illustrates the electromagnetic spectrum, energy per radiation beam increases from left to right, with the highest energy containing in the ionizing part of the spectrum.

All objects that are hit by radiation will absorb some of that radiation, best illustrated by standing in the sun, some of the radiation will be transferred through the object and some will be spread by the object, for instance light passing through a prism. The absorption is depending on the type and magnitude of the radiation, the time span of exposure and the tissue exposed, as different tissues will absorb different amounts of energy. This can be illustrated by the difference of a metal- and wooden bench in the sun, the bench made of metal will get much warmer compared to the wooden one even though the energy received is the same. The radiation surrounds us everywhere, originating both

from space, from the ground and from man-made sources like x-ray machines, power lines and cellular phone technology.

5.2 Ionizing radiation

Figure 5.2. General symbol for ionizing radiation ©Colourbox

Ionizing radiation possesses enough energy to cause ionization of molecules or atoms, thereby leading to active and potentially damaging processes in cells and living things. Ionizing radiation most often is alfa- and beta-particle radiation, these are electrically charged particles which has short range, but which can lead to health damages due to massive energy transmission into tissues. Gamma-radiation comes from radioactive materials, has lower possibility to transfer energy, but much higher penetration ability.

Exposures for electromagnetic fields are everywhere and not only man-made. Being a planet in space we are continuously bombarded with solar radiation and other radiation from space which gives us a certain amount of ionizing radiation exposure. Also, some natural minerals contain radiation, such as Uranium.

The mining industry therefore is important in this aspect. The ground is full of natural ionizing radiation, which is emitted from minerals in the ground, making the amount of exposure higher in mines and other under-ground facilities, and leading to a necessity of being aware of this. One of the main risks is exposure a gas called Radon. It is formed when Thorium and uranium decays and forms a radioactive noble gas named Radon.

Another important occupation in regard to ionizing radiation is the health sector. Ionizing radiation is used extensively, especially for X-ray and ɣ-ray technology, but also emerging is the use of radioactive tracers, and -medicines.

Work outside also cause radiation exposure from the sun. Lastly it is important to remember work with radioactive waste / material. This can be waste from mines, energy production, medical uses and other types of material.

5.2.1 Planning exposure measurements

The facility, or area, must be mapped in forehand. If you are to measure ionizing radiation in a building for instance when checking for radon exposure, the activity in the building, ventilation procedures etc is important to map. If you are to map workers at an X-ray institute for instance, or surgeons using x-ray it is very important to have precise knowledge of their work tasks, and who will be most exposed, so that the mapping will be relevant and correct. This will also decide what type of measurement is needed, the time span of the

measurement and how many measurements is needed.

The inclusion criteria for preventive measurements of personnel can vary between countries, and it is important to be familiar with the regulations concerning the specific setting. Especially it is important to be familiar with the relevant emergency procedures and plans for handling accidents, and other unplanned events. Both the governments, and the different facilities are responsible to have active risk assessments and action plans for this.

As an example from mapping workers who are exposed to radiation at work in the health sector, there exists some international guidelines that many countries follow.

In these, workers are categorised into categories A or B.

Category A are workers who can be exposed to an effective dose above 6 milliSievert/year, or an equivalent dose above 150 milliSievert/year to skin and extremities, or an equivalent dose above 15 milliSievert/year to the eyes.

Category B are workers not classified in class A.

The employer is responsible for mapping the individual radiation dosage of all workers in category A, for instance by wearing personal dosimeters. This shall also be done for workers categorized as B but who is estimated to have an effective dose exceeding 1 milliSievert/year. If personal dosimetry is not possible the dosage shall be based on dose calculations, or representative measurements. The results of the measurements and calculations shall be made available for the workers and the employer must store the date at least for 30 years after the last exposure. Also, the data often is reported to a national registry.

5.2.2 Assessment of exposure

Figure 5.3. The person is using a Geiger-counter to measure the radiation level in the vegetables. ©Colourbox

The exposure for ionizing radiation can be measured continuously by an apparatus which measures the amount of Becquerel. A Becquerel meter, known as a Geiger-counter, measures the number of radioactive particles and gives a precise and live-time measure of the exposure, typically used after accidents or to investigate if certain materials are radioactive.

Another way of categorizing ionizing radiation is through monitoring the exposed persons or -areas with dose-tags. These absorb ionizing radiation and after a certain amount of time they can be send in for analysis giving a quantity to the exposure received, typical used by radiologists at hospitals.

Bequerelmeters:

Often, we use the halftime to estimate the amount of radiation. Since radioactive substances are unstable isotopes, the disintegration can be measured through Becquerel. This measures the number of emitted particles, which equals the number of disintegrations per second (1 Bq = 1 disintegration pr second).

Bequerel can be given as Bq/m^2, Bq/m^3 or Bq/kg for instance depending on what is relevant.

Dosimeters:

Dosimeters measures the quantity of radiation. Dosimeters is developed to map ionizing exposures both on people and in areas. Typical methods for dosimetry is:

- Geiger-Müller tubes
- Tubes filled with Argon (gas); radiation will cause an electric pulse that can be counted.
- Ionisation chamber
- This method also utilizes electric pulses caused by the radiation to measure the dose.
- Scintillation counter
- Radiation causes visible light in different amounts which is measured by a sensor.
- Thermoluminescence

This instrument captures the radiation in crystals, when these later are heated they emit visible light proportional to the radiation dose.

Personal mapping/specific mapping with dose tags:

Another very important preventive measure in this exposure is monitoring the exposed workers or areas. The tags can measure the exposure over time and give an estimation of the overall exposure. This is necessary to keep the workers safe from low-grade exposures over time and it may also be used as a measure of how thorough the workers are in preventing exposures.

Other methods also exist.

5.2.3 Analysis and interpretation of results

Analysis of ionizing dosimeters is a specialist's task; these are therefore both delivered and collected by either the authorities (often used in mapping of specific occupational tasks like in health facilities) or by private institutes who have special laboratories for these analyses.

When interpreting the results, it is very important to relate it to the purpose. For instance, a high reading of radiation in a building at night when the ventilation is off, is most likely not relevant if the building is used during daytime and with ventilation. Measurements are only of value if it is correctly interpreted in relation to the task and purpose for the measurement.

Often the dose is given in two terms:

- Absorbed radiation dose (Gray – Gy). This describes the amount of radiation energy a material has absorbed.
- Effective radiation dose (Sievert – Sv). This describes also the damage the radiation gives to the different materials.

The difference of these terms can be described by thinking about a metal bench in the sun, versus a wooden bench. Both benches receive the same absorbed radiation dose, but the effective radiation dose will be different since the metal bench will get warmer than the wooden bench.

An example of practical use of this is described by the health authorities in Norway:

"A diver from the fire department is moving towards a radioactive source. On him he has an alarm dosimeter which has a first limit set at 100 microSievert/hour. This gives the fireman a warning that radiation other than natural radiation exists. If he stands still at this point for a long time (100 hours) he will have received an effective dose of 10 milliSievert which is 50 % of what a worker can received during a full year.

If the fireman needs to proceed closer to the source "the hot zone" specific

measurements have to be done to know what radiation the fireman will be exposed to. The dose will increase rapidly since the dose is reduced significantly with distance from source. If the distance is doubled the radiation dose is only ¼ of the original dose.

Permissible levels, laws and regulations

Radiation, and protection from such is most often regulated by a special national or geographical area radiation authority who basis their recommendations on international regulations. Specifically, two organs are important in this respect, the International Commission on Radiation Protection (ICRP) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Both organisations are non-governmental and consist of scientists throughout the world who specialize on radiation. They consider all new published literature and produces guidelines on exposure from this. The guidelines are based on accepted knowledge from published work and include a safety factor accounting for unknown effects.

5.3 Non-ionizing radiation

Figure 5.4. Example of warning sign for electromagnetically radiation, for the non-ionizing part there exist not only one sign, but several different. ©Colourbox

The non-ionizing part of the spectrum do not have the ability to ionize molecules or atoms, but can hurt us in other ways, all depending on the amount of radiation and the time span of exposure.

For non-ionizing electromagnetic field exposure, the occupations experiencing the highest exposures are those involved in plastic welding and other uses of radio-frequency fields (microwaves). Work close to high-current lines is another occupation known- to expose the workers to excessive amount of non-ionizing fields, especially when the lines are hot (carrying electricity). Welders are also exposed, especially when using high current welding. The cable itself is surrounded by high fields, but more important is the radiation caused by the welding. The health sector has many workers exposed to high levels of electromagnetic fields. Especially those working with magnetic resonance imaging (MRI) and those working with different types of diathermies are exposed. MRI uses both static magnetic fields, radio-frequency fields and gradient magnetic fields to produce pictures of tissues. The workers are mainly exposed to the static magnetic fields. In diathermy radio-frequency fields are used to give different amounts of heating in the tissues of patients. The exposure of the worker depends on the apparatus in use and the procedure conducted.

5.3.1 Planning of exposure measurements

As for ionizing radiation the prework is most important in assessment of exposure. Mapping of radiation sources, calculating distances and carefully interviewing people to understand how the radiation exposure is

perceived and if it is possible and correct to measure. Many countries also have made available maps describing the radiation at different locations based on cell phone antenna towers and likewise.

In occupations, especially concerning high voltage, it is possible and often necessary that the workers wear alarms detecting high current and thereby giving an alarm to the worker. These alarms detect the electric field and is used mostly as a security measure to avoid electric shocks. The magnetic field is much more difficult to measure and requires often specialized equipment. Often authorities can be contacted for this and consulted with. For instances with magnetic field exposure, it is most important that the workers are educated on the exposure and how it works, and what safety measures which are important. For instance, no magnetic objects in strong magnetic fields.

5.3.2 Assessment of exposure

For non-ionizing electromagnetic fields, the quantification is most often made by theoretical calculations and exposure models. For most of commercially available systems the regulations continuously strive for lower exposures, and for cell phones, for instance, the exposure in a new model is many thousand times lower today compared to in the 1990's.

In MRI, where the exposure to magnetic field is extreme, the fields are measured in production since the magnitude dictates how far away the magnetic force will affect metals and electric instruments. The exposure must be measured separately for electric- and magnetic fields using different measurement meters which correspond to the specific electromagnetic frequency in question. These measurements are done in relation to installation of the machines and the manufactures are normally responsible for this and the installation. It is also possible to measure this after installation, but it requires specialists and specialists' equipment.

5.3.3 Analysis and interpretation of results

Permissible levels, laws and regulations

Radiation, and protection from such is most often regulated by a special national or geographical area radiation authority who bases their recommendations on international regulations. Specifically, two organs are important in this respect, the International Commission on Radiation Protection (ICRP) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Both organisations are non-governmental and consist of scientists throughout the world who specialize on radiation. They consider all new published literature and produces guidelines on exposure from this. The guidelines are based on accepted knowledge from published work and also include a safety factor accounting for unknown effects.

5.4 References

International Commission on Radiological Protection, https://www.icrp.org/

International Commission on Non-Ionizing Radiation Protection, https://www.icnirp.org/

WHO guidelines; https://www.who.int/teams/environment-climate-change-and-health/radiation-and-health

Occupational radiation protection: https://www-pub.iaea.org/mtcd/publications/pdf/pub1145_web.pdf

Chapter 9.6 Radiation. In: Gardiner K, Rees D, Adisesh A, Zalk D, Harrington M. Pocket consultant Occupational Health, 6th Edition, Wiley and Blackwell, 2021, pages 208-215.

6. Indoor Environment Exposure Measurements

Bente E. Moen

6.1 General concepts

Indoor environment is an expression that most often refers to indoor non-industrial exposure, including indoor environment and exposure inside transport vehicles. The terms *indoor air* and *indoor climate* are also often used. This is different from conditions that are specific to exposures in industrial settings, such as agriculture, mining, and production. Such settings are typically covered by specific work safety legislation or guidelines, while the indoor environment is described in general regulations.
The term *indoor environment* usually refers to the combination of the seven factors: Thermal-, atmospheric, acoustic, actinic (lighting and radiation), mechanical, psychological, and aesthetic environments. In this chapter, air quality, temperature, humidity, air conditioning, noise, radon exposure and lightning will be mentioned. Hopefully this text can be helpful for understanding when measurements of such factors are needed. It is necessary to have knowledge about this, as there are several unserious companies in the market of indoor air environmental issues, trying to sell unnecessary instruments and analyses to people without this knowledge.

6.2 Air quality in an office environment

The indoor air may contain large numbers of chemicals, particles, and biological agents, but mostly in very low concentrations. This makes risk assessments complicated and challenging, and it has been much discussed among occupational scientists. The Scientific Committee on Health and Environmental Risks in the European Union (SCHER) has written a text on the risk assessment of indoor air quality. SCHER concludes that it is important to focus on the following sources of pollution in indoor air: Tobacco smoke (passive smoking), any open fires, building materials, furniture, pets and pests, use of household products, as well as conditions that lead to the growth of moulds. In indoor environments, exposures are always complex mixtures of substances from different sources. Due to the complexity of indoor air pollution and its variability with time, estimation of health risks associated with this exposure is rarely feasible.
WHO has developed guidelines for indoor air quality that cover indoor settings where the general population or especially susceptible population groups such as children, asthmatics etc. are potentially exposed to indoor air pollution. Examples of workplaces of this type are schools, hospitals, day care centres, libraries, and nursing homes.

6.2.1 Measurements of the air quality

The measurement methods of air quality will differ greatly, depending on what is needed to measure. Specific dust types and chemicals in a working environment might be measured using active measurement methods as described in other chapters of this book. However, there might be different recommendations for limit values for pollutants in indoor, office environments, than in industrial worksites.

Particles: Direct reading instruments might be used, for instance to register particle exposure. Particulate matter (PM), especially particles of the size 10 micrometres (PM_{10}) has been measured in several studies of indoor environments. Instruments for logging over time exist.

Volatile organic compounds (VOCs) in indoor areas, can also be measured, using for instance absorption tubes (Tenax) or specific instruments. This has been popular among indoor air scientists, but the results from such measurements are difficult to interpret.

Biological agents: Measurements of biological factors (microbes, virus, fungi) in the work environment have several challenges. Mainly, such methods are used in infection medicine, to assess if a biological agent is present or not, and we are more used to taking samples from patients than from the environment. Methods for measurements of biological agents in the environment are for instance:
-Air sampling for direct microscopy analysis, using small cassettes which are coated inside with an adhesive substance
-Surface sampling for fungal spores, for instance by touching a surface with a tape and checks the tape for spores

One challenge is that these methods are seldom clear when it comes to standardization of measurement procedures and interpretation. It is possible to take material samples and analyse these for the presence of biological agents or not. However, the lack of normal values for biological agents makes the results difficult to interpret.

6.3 Temperature, humidity, CO, CO_2 and datalogging

6.3.1 Room temperature – comfort temperature

There are four main variables that influence the temperature in an environment: Air temperature, relative humidity, radiant temperature, and wind speed. These variables can be measured, but you need to have the correct instruments, and you need to learn how to use them.

Fig. 6.1. Wet bulb and dry bulb thermometer. © Colourbox

We can use the following instruments:
A thermometer (sometimes called a dry-bulb thermometer) is used to measure air temperature in the shade. Air temperature can vary from below zero to up to about 50°C.
A wet-bulb thermometer is used to measure humidity.

A globe thermometer is used to measure radiant temperature, which can be quite different from air temperature. The thermometer's bulb is placed in the middle of a 15 cm diameter hollow black copper sphere. The black globe absorbs radiation and warms the air inside.
An anemometer is a wind speed gauge. There are many different expressions used for temperature, and it is necessary to know the difference between them if you read literature on this topic.

Temperature guidelines: During working hours, the temperature in all indoor workplaces must be reasonable. There are no clear laws for minimum or maximum working temperatures, e.g., when it's too cold or too hot to work. Some countries have guidelines, suggesting levels of temperature for certain types of work. For instance, a minimum of 16ºC or 13ºC is suggested for persons performing physical work. There's no guidance for a maximum temperature limit. The risk of developing heat stroke is high at temperatures above 40ºC.

6.3.2 Humidity indoors

Relative humidity is important for evaluation of the temperature, and it can be wise to measure humidity when you measure the temperature. For instance, workers often feel that the air is 'too dry' when the problem is that the temperature is too high. The measurements are needed to be able to regulate the environmental factors correctly. Data logging instruments for the indoor air environment exist, and these can measure temperature and humidity simultaneously. Some of these instruments also log levels of CO and CO_2.

6.3.3 Carbon monoxide

Carbon monoxide (CO) in outdoor air is formed by incomplete combustion, and the main source is traffic. Carbon monoxide binds to haemoglobin in the blood, which reduces the transport of oxygen to the tissues. At concentrations normally found in city air, carbon monoxide does not affect healthy people. The concentration must be close to zero in indoor air, the administrative norm in workplaces is 25 ppm. This gas is often measured as a part of an indoor environment study, as exhaust from heavy traffic may get into buildings.

6.3.4 Carbon dioxide

Carbon dioxide is a colourless and odourless gas, in solid form "dry ice". Carbon dioxide (CO_2) is formed by combustion and produced by the body's metabolism and is therefore found in exhaled air. At the levels recorded in indoor air (up to 9000 mg/m^3), no toxicological, physiological, or psychological changes are seen. The presence of CO_2 will therefore not trigger health damage except in very extreme work situations.
However, CO_2 has been used as a general indicator of air ventilation indoors. Simple CO_2 measurements provide a picture of the air change in a room where people are gathered. Based on indicator properties for poor air quality and air demand, it is recommended that the level should be below 1800 mg/m^3.

6.3.5 Logging of the indoor environment

There are instruments that combine measurement of temperature, humidity, CO, and CO_2.
These instruments are often combined with a computer and can perform data logging of the parameters over longer periods. The loggers can also combine measurements of other variables, like airflow or illuminance. This combined logging can be useful and practical. To perform these measurements at the same time saves time. These loggers come with instructions about their use, which need to be followed carefully. It is also important to place the logger in the right spot of the area that will be mapped.

6.3.6 Ventilation

To evaluate the ventilation system in general in a building requires technical understanding and competence and is seldom performed by health personnel. However, it must be mentioned that ventilation is an important part of the indoor environment.
A tip for those who will check the airflow easily is to use smoke tubes to visualize where and how the airflow behaves. Slight air movements can be seen by the naked eye using such tubes.
Smoke tubes produce smoke. You break off both ends of the tube and attach a rubber squeeze bulb to one end. When you squeeze the bulb, a chemical reaction produces white smoke. These tubes are inexpensive and easy to use.

6.4 Air conditioning

Air conditioning (A/C) is the process of removing heat from an enclosed space to achieve a more comfortable, cooler environment inside for instance a house or a vehicle. This can be achieved by different methods, and they of course mean a lot for the workers inside the building. To evaluate the type of air conditioning and the function, special technical expertise is needed. A specific challenge for health is the occurrence of legionella disease.

6.4.1 Legionella

In many countries with high outdoor temperatures, air conditioning is an important part of the indoor air environment. It is important to know that these installations may be a source for the Legionella disease, legionellosis. Other important infection sites are cooling towers, shower facilities, bubble baths, air conditioning and ventilation systems. Legionella causes an airborne infection, a lung disease from the bacteria Legionella.

The Legionella disease varies in severity from a mild febrile illness to a serious and sometimes fatal form of pneumonia and should be prevented.
Companies with air conditioning must be aware of the problem and control and clean the relevant pipes and equipment regularly. The control is done by taking samples of the water in the mentioned facilities and needs to be a part of a preventive plan for water safety. The samples must be analysed for the bacteria in microbiological laboratories. Some countries have specific environmental regulations on how to control and prevent the Legionella problem.

6.5 Sounds (noise) in the office environment

The sound level in the office environment is seldom so high that it can affect the hearing of the workers. However, annoying sounds might be present and may cause a problem for workers who try to concentrate. This type of sound might for instance be caused by ventilation fans, computer fans and other people talking. The table below, (Table 6.1), illustrates the recommended levels of sound, both in the office environment and in the industry.

Table 6.1. Suggested guidelines for sound levels at work

Group	Work type	Recommended sound level	Location of work
I	Concentration work or need for conversation with other people	**Below 55 dB(A)**	Teaching Research Meeting rooms
II	Conversation with other people is important	**Below 70 dB(A)**	Receptions Train, bus Shops
III	Work with machines and tools	**Below 85 dB(A)**	Workshops/industry Mining/agriculture Building sites

6.6 Lighting in offices

The level of lighting you need at work depends on the task you are performing. There are no clear rules and regulations for optimal lighting level, but several institutions and countries have developed some useful guidelines.

How is light measured?
The level of light is measured in LUX, using a light meter. The table below, (Table 6.2), gives an indication of some typical light levels measured in lux.

Table 6.2. Typical light levels in different situations

Illuminance	Example
1 lux	Full moon
50 lux	Family living room
80 lux	Hallway
100 lux	Very dark overcast day
400 lux	Sunrise or sunset on a clear day Well-lit office area
10 000 – 25 000 lux	Full daylight
32 000 – 130 000 lux	Direct sunlight

Some examples of light-level recommendations are given in Table 6.3

Table 6.3. Recommendations for light levels at different work activities (Health and Safety Executive, United Kingdom)

Work activity	Average illuminance needed
Movement of people, machines, and vehicles on construction sites	50 lux
Work requiring limited perception of details, for instance in kitchens	100 lux
Work requiring perception of details in factories, offices, shops	200 lux
Work requiring perception of fine details in electronic factories, textile production, and normal office work	500 lux

6.7 Radon

Radon is a colourless gas. Radon can be a problem in houses built on certain types of rock, for instance in Mexico, Canada and some Nordic countries. The radon levels in Africa are not known, due to lack of measurements. Radon is formed as one intermediate step in the normal radioactive decay chains through thorium and uranium. The decay product of thorium and uranium is radium. The decay product of radium is radon. When radon decays, it produces new radioactive elements called radon daughters or decay products (also called progeny). Unlike the gaseous radon itself, radon progeny are solids and stick to surfaces, such as dust particles in the air. If such contaminated dust is inhaled, these particles can stick to the airways of the lung and increase the risk of developing lung cancer. The risk of lung cancer due to radon is seen among miners as well as persons living or working in houses with radon exposure. However, adverse effects from radon in houses can be prevented by correct building techniques and ventilation. Radon can be measured by specific track detectors that are put in a room for a certain period of time (e.g. 2 months) and later sent to specific laboratories for analysis. Another method is to use an electronic device which must be placed in the measurement area for e.g. 2 months before the mean exposure level is calculated.

6.8 References

Bridger RS. Introduction to Human Factors and Ergonomics, fourth edition. Chapter 9. Working in hot and cold climates/ Comfort and the Indoor Climate, CRC Press, 2018: 332-336.

Chen J. A review of Radon Exposure in Non-uranium Mines – Estimation of Potential Radon Exposure in Canadian Mines. Health Phys 2023;124:244-256.

International Labour Organization (ILO). Physical Hazards - Indoor Workplace Lightening, 2014, 24 July. https://www.ilo.org/caribbean/projects/WCMS_250198/lang--en/index.htm

The Scientific Committee on Health and Environmental Risks (SCHER). Opinion on risk assessment on indoor air quality. European Commission, 2007. https://ec.europa.eu/health/ph_risk/committees/04_scher/docs/scher_o_048.pdf

Wolter N, Carrim M, Cohen C, Tempia S, Walaza S, Sahr P, de Gouveia L, Treurnicht F, Hellferscee O, Cohen AL, Benitez AJ, Dawood H, Variava E, Winchell JM, von Gottberg A. Legionnaires' Disease in South Africa, 2012-2014. Emerg Infect Dis. 2016 Jan;22(1):131-3.

World Health Organization. WHO guidelines for indoor air quality: selected pollutants 2010, Jan 1. https://www.who.int/publications/i/item/9789289002134

World Health Organization Legionella and the prevention of legionellosis, 2007. ISBN 9241562978. https://www.who.int/publications/i/item/9241562978

Chapter 7. Heat exposure assessment

Abera Kumie

7.1 General concepts in heat

Heat is the thermal energy transferred between systems due to a temperature difference. The temperature is a factor both at home and at workplaces. We describe an object as being cold, warm, or hot using our skin sensors. The heat perception is a form of energy that flows from one body to another due to temperature differences. The temperature gradient is a force that drives heat from an object with a relatively high temperature to an object with a lower temperature. We use temperature measurements as a method for evaluation of this environmental factor. Usual units of temperature are either degrees Celsius (°C), degrees Fahrenheit (°F), or kelvins (K).

Many workplaces generate heat through the operation of machines (e.g. textile and garment factories), from ovens (e.g. foundries), or from the surface of produced objects (e.g. molten metal in metallurgy). Heat can also be transferred into a working environment through roofs and walls as a result of solar radiation in the daytime.

As much as heat is useful in the operation of factory processes, excess heat can be hazardous to workers and impact their health.

7.1.1 Thermoregulation

The human body is homeostatic. Nature has made our body to have a normal temperature of 37°C. Our body has adapted to regulate the temperature changes using internally built physiological systems that communicate wisely with the outside environment. Assume you are in a metal factory where a melting process takes place, and the temperature is high. Ask yourself how you are exposed to this heat. Heat transfer depends on many factors: the amount of heat an object has such as air and surface areas, the characteristics of air in terms of its temperature and relative humidity, the presence of radiant energy; and personal factors such as clothing pattern.

Convection: Natural convection is effective when there is a flow of air from one side to the other in the form of wind. In most cases, relatively cold air moves outside to workplaces through openings such as windows. The cold air then takes away the hot air current from the surfaces of the human body and workplaces, thereby leaving a cooling effect.

There is forced convection when fans remove hot air from an object (the use of a ceiling fan, wall-mounted fan, table fan, and exhaust fan in a ventilation system).

Conduction: Heat transfer via direct contact with a stationary object (liquid and solids). It is a transfer of heat between two materials from high to low heat energy areas through direct contact. Touching a hot metal surface is a good example of how you feel hot on the hand. Heat from the hand can be transferred to a cold metal surface by touching it.

Radiation: Heat transfer over a distance via electromagnetic waves in workplaces. Radiation does not require a medium, like convection and conduction. Radiation heat passes through the air; can be blocked or reflected by a medium, or even it can be reflected after the body has adequately

heated after absorbing the heat wave. The solar radiation warming the earth's surface is a good example. Likewise, heat from hot surfaces (boilers, hot machines, hot ceilings, and walls) heats our bodies through radiation because of the relative temperature difference.

Evaporation: Sweat evaporating from our skin surface has a cooling effect because of the loss of heat in the form of water vapor. The intensity of the cooling effect via evaporation depends on how the surrounding air is cold and with low humidity. Opening doors and fans facilitate evaporation faster by using convection.

7.1.2 What is heat stress?

Heat stress is the overall heat load to which an employee is exposed from the combined contributions of air temperature, humidity, air movement, radiant heat, and clothing requirements. Heat stress occurs as a result of the body's inability to maintain its core temperature which is accompanied by symptoms such as dizziness, sweating, pain in the muscles, and skin rashes. Heat exhaustion can in the worst-case cause heat stroke which may culminate in death. It is important to control the temperature at the workplaces, to avoid serious consequences of heat.

7.2 Measuring heat exposure

The body's heat comfort depends on factors at the workplace. The following environmental factors for heat comfort are advised to be controlled at a workplace where heat might be a challenge.
Suggested recommendations for the different factors are indicated.

Environmental factors for heat comfort

1. Air temperature: 65-78°F (18-25°C)
2. Relative humidity: 20-80% (30-60% some sources)
3. Air velocity in general: 0.1-0.12 m/s, or
   0.1-0.2 m/s at 20°C room temperature
   0.30 - 0.45 m/s at 23°C room temperature
   0.3 - 0.9 m/s at 26°C room temperature
4. Sunlight radiation (in the ambient) must be limited to get penetrated from the outside
5. Surface temperature of the objects in indoor workplaces

Several different expressions are used for temperature assessment, some of which there are defined here:

Dry-bulb temperature:	Air temperature registered by a thermometer freely exposed to air
Wet-bulb temperature:	Measured by a thermometer whose bulb is covered by a whet sock
Absolute humidity:	Mass of water per unit mass of dry air.
Relative humidity:	A percent of the maximum saturation humidity at the dry bulb temperature
Heat index:	A calculation of heat stress which combines temperature and relative humidity.

7.2.1 Simple temperature measurement

Temperature is measured using a thermometer. There are different types, for instance, liquid thermometers that detect variations in the volume of a liquid in a container. Coloured alcohol can be used. Mercury was a common liquid for this purpose in earlier days but is not used in modern thermometers. Temperature can also be measured by electric devices.

7.2.2 Dry-bulb temperature

Dry-bulb temperature is the temperature of air measured by a thermometer freely exposed to air but shielded from radiation.

7.2.3 Wet-bulb temperature

Wet-bulb temperature is measured by a thermometer which shows the temperature of air cooled to 100% relative humidity. These thermometers have their bulb wrapped in a cloth called a 'sock'.

7.2.4 Wet Bulb Globe Temperature Meter (WBGT)

To evaluate the physical workplace climate, it is necessary to use several different monitors. This might be difficult, cumbersome, and time-consuming. Instead, many people use an instrument based on Wet Bulb Global Temperature (WBGT). This instrument combines the measurements of several of the relevant environmental factors.
Wet bulb globe temperature meters measure and display a WBGT Heat Stress Index in °F or °C and can be used both indoors and outdoors. Unlike simple temperature measurements, this type of meter combines all four environmental heat factors (air temperature, humidity, radiant heat, and air movement). This meter combines three sensors, a dry-bulb thermometer, a natural wet-bulb thermometer, and a black globe thermometer.
There are cheap and simple thermometers of this type. They operate with the use of small batteries and are mainly used to identify spots of heat stress in real time. The data cannot be stored on these instruments, you need to read the results and note them yourself.
Some people calculate 'heat stress' or 'metabolic rate' or workload by adding information about for instance clothing to the results from the WBGT meter. These calculations are difficult to perform as well as to interpret.
The thermometer results in degrees are probably the best kind of measures we have of heat stress. There are efforts to make scales out of clothing and so on as well, but this information is more useful for improvement of the work situation.

7.2.5 Monitoring temperature by data logger

Some instruments, measuring WBGT, log the temperature during longer time periods, and are very useful for assessment of temperature in an area where the temperature changes during the day or week. The instruments can be placed in an environment and be left there for logging over a longer period of time.
The proper site selection for such long-term measurements is very important. There should be an initial quick survey with the visit accompanied by the Department manager to find out where heat stress is likely to be present. The number of workers and the time they spend in that specific

workplace should considered for the site selection. Once the site is determined, then the instrument is mounted 1.1m above the floor for standing individuals and 0.6 for seated individuals using a tripod; and about 1 m from the hot object (Figure 7.1).

Figure 7.1. Deploying the WBGT instrument for areal measurement ©A. Kumie

7.3 Temperature standards

There is no specific guidance for a maximum temperature limit. The risk of developing heat stroke is high at temperatures above 40ºC. Some countries have guidelines, suggesting levels of temperature for certain types of work. The reason for the lack of guidelines might be the complexity of temperature evaluations, where it is needed to evaluate not only the temperature itself, but also other factors.

Table 7.1. Standards for work situations and temperature (Wet-bulb temperature), ACGIH

Work/rest format	Light work	Moderate work	Heavy work
Continuous work	30	26	25
75 % work, 25 % rest	30.5	28	26
50 % work, 50 % rest	31.5	29	28
25 % work, 75 % rest	32	31	30

7.4 References

OSHA Technical Manual Section III, Chapter 4 (Heatstress). **https://www.osha.gov/otm/section-3-health-hazards/chapter-4** ; https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html

ACGIH TLVs 2017. **https://mhssn.igc.org/2017%20ACGIH%20-%20Heat%20Stress%20TLV.pdf**

Department of Health and Human Services; Centers for Disease Control and Prevention; National Institute for Occupational Safety and Health, USA. Criteria for a Recommended Standard Occupational. Exposure to Heat and Hot Environments. Revised Criteria 2016

Health and Safety Executive (HSE): Heat stress in the workplace A brief guide. https://www.hse.gov.uk/pubns/indg451.pdf

.

Using the Heat Index: A Guide for Employers. https://www.osha.gov/SLTC/heatillness/heat_index/pdfs/all_in_one.pdf

OSHA-NIOSH INFOSHEET: Protecting workers from heat illness. https://www.cdc.gov/niosh/docs/2011-174/pdfs/2011-174.pdf?id=10.26616/NIOSHPUB2011174

Department of Occupational Safety and Health. Ministry of Human Resources, Malysia. Guideline on heat stress management at Workplace 2016. https://www.dosh.gov.my/index.php/legislation/guidelines/industrial-hygiene-1; https://www.dosh.gov.my/index.php/legislation/guidelines;

Budd GM. Wet-bulb globe temperature (WBGT) – its history and its limitations. J Sci Med in Sport 2008; 11:20-32.

Chapter 8. Lighting assessment in the workplace

Teferi Abegaz

8.1 General concepts and definitions

Light has the properties of a wave and a particle. Specific wavelengths are sensed by receptors in humans, which then convert them into images. These wavelengths exist between 400 and 700nm. Light also has the property of a particle. The intensity of the light varies according to the number of particles. Bright light has many particles, and dark light has fewer particles. These particles of light are called “photons”.
The speed of light in a medium depends both on the medium and on the wavelength of the light. A prism can be used to split up a beam of white light into a rainbow. Each wavelength of light is refracted through a different angle. Longer wavelengths are found on the red end of the spectrum, whereas shorter wavelengths are found at the blue end.

Luminous Flux: The power of visible light emitted by a light source. The unit is lumen (lm). The luminous efficiency is the ratio of the luminous flux to the electrical power consumed (lm/W). It is a measure of a light source’s economic efficiency
Illuminance: The measurement of the amount of light illuminating and spreading over a given surface area. It is measured in lux (lumens per square meter) or foot-candles (lumens per square foot)
Luminance: The amount of light reflected from a surface. It is that quantity of radiant flux that expresses its capacity to produce a visual sensation. The SI unit is candela per meter square.

8.1.1 Sources of light

Natural and artificial light are the two primary sources. The sun is the primary source of natural light. In the workplace, there are several kinds of lightbulbs as an artificial light source, such as LEDs, fluorescent lights, and incandescent bulbs. Each of these distinctively produces light.
Incandescent light is radiated electromagnetic energy that is emitted across all wavelengths, when we see all wavelengths, things appear white.
Fluorescent lights are technically outside of our visible range; they are ultraviolet and below 400nm. However, an interaction with a coating on the inside of their tubes makes it visible white light that we can use.
LED lights are a little more complex and achieve white light through a mixture of red, green, and blue LEDs or methods similar to fluorescents

The interaction of light with matter
When a light ray hits a point on an object the following properties will happen: -

- Some of the light gets absorbed and is transformed into heat energy.
- Some gets transmitted through the object possibly bent, through refraction
- Some gets reflected, it could be reflected in multiple directions at once
- When the light wave encounters an obstacle or a nonuniformity in its medium, the strong and weak waves radiate out beyond the obstacle, and this is called diffraction

Spectral power distribution of light
Our perception of the colour of an object depends on the colour of the light and the object itself reflects light. Usually described by two properties,

- The correlated colour temperature (CCT) and
- Colour rendering index (CRI).

Correlated colour temperature (CCT)
It is the way to determine the brightness of light through the measurement of the temperature increase of a black object exposed to the light. The light energy is transformed into heat energy, and the amount of heat energy absorbed in a given amount of time can be related to the power absorbed by a body with a known heat capacity. The Planckian (or blackbody) radiators offers a useful method to characterize the colour appearance of a light source; given a specified chromaticity diagram, the temperature of the Planckian radiator whose chromaticity is closest to one of the light sources under consideration is called the CCT of that light source.

Colour rendering index (CRI) Ra
The degree to which a particular type of lamp will provide surface colours identical to reference colours from the reference light sources (daylight for light sources with the same CCT above 5000 K and Planckian radiator for light sources with a CCT below 5000 K). No distortion of the surface colours is implied by excellent colour rendering. The metric is known as the Colour Rendering Index (CRI). A light with a high CRI will enable an object's colour to appear more realistic, whereas a low CRI implies an object looks unnatural. The ideal colour rendering is CRI = 100; very good colour rendering is CRI > 90; decent colour rendering is CRI > 80; and colour rendering should not be chosen in a workplace if the CRI is less than 80.

8.2 Health risk of light exposure

Due to insufficient light at work, a worker may experience *visual fatigue, which may cause p*ainful irritation (burning) of the eyes, tear flow and red eyes. This condition might be the cause of headache and fatigue. Insufficient light may also cause awkward postures for a worker. For example, getting closer to the task or looking at it from a different direction introduces unusual postures that may lead to strain, such as neck pain or pain in the back.

8.3 Light measurement

Lighting measurement is conducted to determine or verify lighting or illuminance level for tasks or activities involved in the related work area. To assess how well the work area is illuminated the general illumination level and specific task area illumination should be measured.

General illumination measurements and standards
The purpose of general lighting is to meet the lighting requirements and its uniformity for a specific type of work activity, such as factory, warehouse, office, or reception. There are no clear guidelines or standards for optimal lighting levels, but several institutions and countries have developed suggestions. Table 8.1 illustrates the ILO suggestion on optimal light requirements in different workplaces.

Table 8.1. Minimum and average lighting intensities suggested as requirements for different types of work (International Labour Organization, 2014)

Activity	Typical Location	Average Illuminance (lux)	Minimum Illuminance (lux)
Movement of people, machines, and vehicles	Lorry Park, corridors, circulation routes.	20	5
Movement of people, machines, and vehicles in hazardous areas; rough work not requiring any perception of detail	Construction site clearance, excavation, and soil work, loading bays, bottling and canning plants	50	20
Work requiring limited perception of detail	Kitchens, factories assembling large components, potteries	100	50
Work requiring perception of detail	Offices, sheet metal work, bookbinding	200	100
Work requiring perception of fine detail	Drawing offices, factories assembling electronic components, textile production	500	200

Measurement for specific tasks or activities
Certain jobs or work activities could be visually demanding and need greater lighting than the surrounding workspace. Under these conditions, local lighting might be designed near the specific task. The lighting measurement should be taken at the task position to determine whether the lighting for a particular task is sufficient.

Light measurement procedures in the workplace
For measurement of illumination, a lux meter is normally used. Measure points must be decided, and the workers must be informed about the plan of measurements. The measurements need to be performed, registered and summarized in a report.

1. Make the Lux meter ready
The first step in the light measurement procedure is to make ready the measuring devices. The lux meter is a direct reading digital device, portable and very simple to use. There are different models of light measuring devices (Lux meters) available on the market and they are easily accessible at affordable prices.

2. Determine the measurement locations
The following steps are important to conduct easements for general lighting:

Step 1: Measure the length and width of the room, and the height of lighting above the working plane

Step 2: Calculate the room index to determine the number of measurement points in the work area:

$$Room\ Index = \frac{L \times W}{H_m(L+W)}$$

Where:
L: Length of room (m)
W: Wide of room (m)
H_m: Height of lighting above the working plane (m)

Step 3: Determine the minimum measuring points

Minimum number of measuring points = $(x+2)^2$, where "x" represents the room index value taken to the nearest whole number; except that for all values of RI equal to or greater than 3, x is taken as 4. (Table 8.2).

Table 8.2. Minimum number of measurement points for measuring average illuminance in rooms of different proportions.

Room Index	**Number of Measurement Points**
Below 1	4
1 and below 2	9
2 and below 3	16
Above 3	25

If the aim of the measurements is to measure the light at specific working sites, you should choose four (4) representative points. For instance, the central front section of a typical writing desk or counter, where the task position is generally located, could be divided into four equal sections (Figure 8.2).

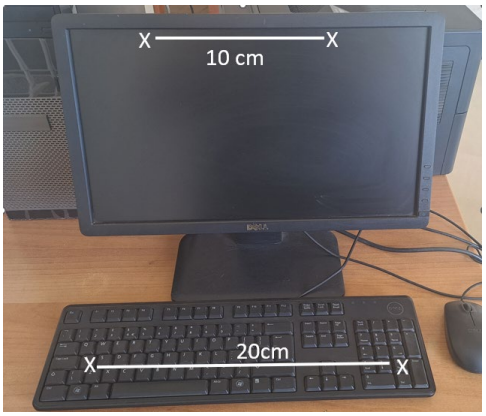


Figure 8.1. Measurement point (X) for a computer. ©T. Abegaz

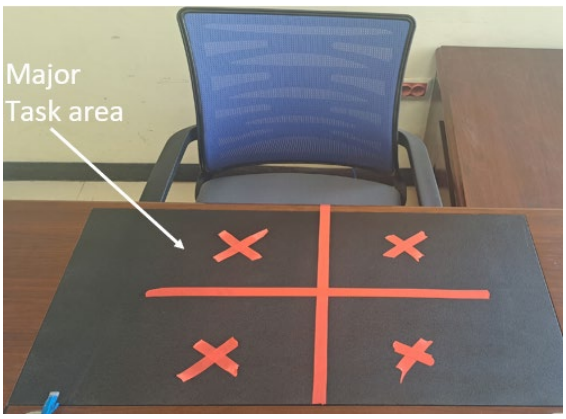


Figure 8.2. Measurement points for a specific task area. ©T. Abegaz

3. Conduct the light measurements

The following activities are basic in light measurement

- Before any reading is taken, the lux meter should be exposed to the lighting for at least 3 - 5 minutes to allow it to reach equilibrium
- The lamp in the installation should be lit for some time to allow it to reach a stable condition before a measurement is taken

- The zero reading of the lux meter should be checked and adjusted as necessary
- The voltage applied to the lighting installation should be checked to ensure that it is at an appropriate level.

It is recommended to measure the lighting at the work plane's height. If no designated plane is available for the work, the measurement should be made roughly 0.85 meters above ground. In a horizontal plane, the light sensor of the lux meter should be placed horizontally (Figure 8.3), if it is an inclined plane the lux meter should be read on such a plane. Likewise, if the object is to be read vertically, the work plane must also be vertical (Figure 8.4).

The method for measuring illumination differs slightly if the task position is at a computer. At the keyboard location, two measurement points are taken, spaced 20 cm apart, and two more points are measured, spaced 10 cm apart, on top of the screen. For accurate results, the lux meter's sensor needs to be positioned horizontally. During measurement, the assessor should avoid obstructing the normal light path and should move sideways back and forth to ascertain that he/she is not blocking the light falling on the light sensor. Or just put the sensor down on the table and not hold it, to avoid any shadow on it.

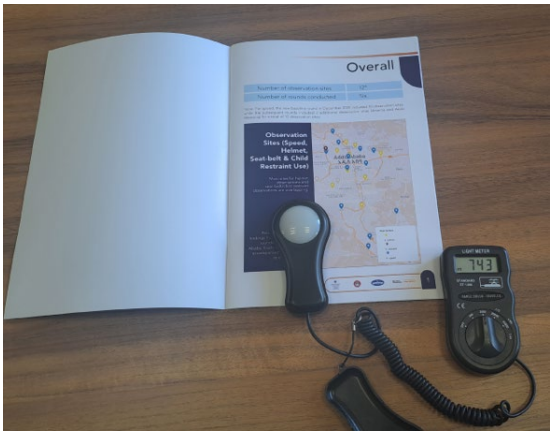


Figure 8.3. The sensor of the light meter placed on the work plane. ©T. Abegaz

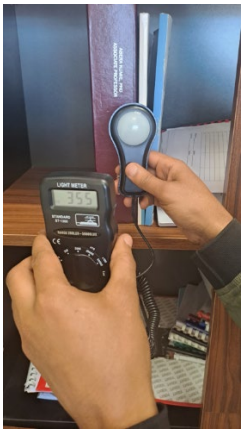


Figure 8.4. The light sensor is placed vertically if the object is read vertically. ©T. Abegaz

4. Evaluation and interpretation of the illumination measurements

Uniformity of Illuminance

Variability in illumination or uniformity of illumination must be considered when evaluating the lighting of a working area and its immediate surroundings. The ratio of the lowest to the average value represents the homogeneity of the illumination. Considering the average illuminance only may result in lower illuminance in certain areas which may endanger the safety of employees.

$$Uniformity\ of\ illminance = \frac{Maximum\ illuminance}{Mean\ illuminance}$$

Where:

- The maximum illuminance means the highest reading observed on one of the points we took the reading

- The mean illuminance means the average of the illumination level measured on all the points

- The uniformity of the illuminance measured should be:
- Not less than 0.5 for general lighting; and
- Not less than 0.7 for task or activity

Illuminance Ratios

It is critical to consider how the illumination in the work area interacts with that of adjacent locations. Significant variations in illumination levels between them could potentially compromise safety in areas with high movement is required. This issue is most frequently seen when someone is working in an interior space and is exposed to a variety of illuminations for an extended time, or when they are moving between an inside and an external workspace, which exposes them to abrupt changes in illumination. The suggested minimum is 5 to 1 to prevent risk and discomfort.

$$Diversity\ of\ illuminance = \frac{Maximum\ illuminance}{Minimum\ illuminance}$$

8.4 References

Crowell B. Optics: Book 5 in the Light and Matter series of introductory physics textbooks www.lightandmatter.com

International Labour Organization (ILO). Physical Hazards Indoor Workplace Lighting. ILO Occupational Safety and Health brief No. 3c, 2014. https://www.ilo.org/caribbean/projects/WCMS_250198/lang--en/index.htm

Richard J. D. Tilley. Color and the optical properties of materials: an exploration of the relationship between light, the optical properties of materials and color, 2011. ISBN 978-0-470-74696-7 (cloth) – ISBN 978-0-470-74695-0 (pbk.)

Chapter 9. Biological monitoring of metal exposure

Alexander M. Tungu, Israel P. Nyarubeli, Meaza Gezu and Bente E. Moen

9.1 The meaning of biological monitoring

Biological monitoring can be defined as "*the detection of substances (biomarkers) in human biological samples and comparing to reference values"*. In occupational settings, biological monitoring involves examination of workers' biological materials to determine hazardous substances, metabolites, and biochemical or biological parameters. Biological monitoring requires the understanding of the concept of *toxicokinetics*, *toxicodynamics* and the *exposure-outcome relationship* of a chemical substance. In a nutshell, *toxicokinetics* deals with *absorption, distribution, metabolism, and elimination* of a specified chemical agent. *Toxicodynamics,* on the other hand, deals with the understanding of the early adverse effects and pathogenic mechanism of a chemical substance. The concept of exposure-outcome relationship involves the understanding of the relationship between the external exposure, the internal dose, and the adverse health effects of a chemical substance.

Generally, BM aims to ensure that the current or past exposure of a worker is not harmful, by detecting potential excessive exposure before recognizable adverse health effects occur. Biological monitoring aims to enable exposure assessment of specific chemical substances and the estimation of the actual workers' risks. It also enables characterization of the exposure pathways and can reveal susceptibility of the worker. In addition, BM aims to enable interpretation of results at group or individual level.

9.2 The concept of biological markers

A biological maker (biomarker) is any substance, structure or process that can be monitored in body tissues or fluids. It predicts or influences health or assesses the incidence or biological behaviour of a disease. A biomarker is generally considered as an early sign (reversible) of exposure, effect, or susceptibility with possible adverse health outcome. Biomarkers can broadly be classified as *biomarkers of exposure*, *biomarkers of susceptibility and biomarkers of effect or disease* as briefly elaborated below and in Figure 9.1.

9.2.1 Biomarkers of exposure

A biomarker of exposure is any substance, metabolite or a product of interaction measurable in a body compartment or body fluid. Biomarkers of exposure can be used to identify and measure a chemical agent in tissues or body fluids, metabolites of a compound or physiological outcomes of the exposure. For example, detection of lead in blood indicates a recent exposure to lead (measuring unchanged chemical), detection of bromine in blood after methyl bromide exposure (measuring chemical metabolites), and detection of carboxy-haemoglobin after exposure to carbon monoxide (measuring the product of

interaction with tissues at site of action, also known as biologically effective dose).

9.2.2 Biomarkers of susceptibility

This is another group of biomarkers apart from the biomarkers of exposure and effect. However, biomarkers of susceptibility are not generally used in routine biological monitoring**.** Nevertheless, a biomarker of susceptibility is a measure of the ability to respond adversely after exposure to a specific substance. Biomarkers of susceptibility can be inborn or acquired defects that make some individuals more vulnerable to specific exposures. For instance, a genetic defect for 6-aminolevulinic acid dehydratase (ALAD) increases susceptibility to lead poisoning; the ability to acetylate amines (Slow or rapid) is genetically determined and varies with ethnic origin; and low levels of anti-trypsin due to genetic defects increase the risk for developing emphysema.

9.2.3 Biomarkers of metal exposure

A biomarker of effect is any measurable alteration associated with an established or potential health impairment or disease. The measurable alterations can be biochemical, structural, functional or behavioural. The alterations can be early biochemical or functional that can be natural adaptation or disease. Biomarkers of effect are markers of reversible non-adverse effects of the exposure. They can further be classified as *biomarkers of early biochemical change, biomarkers of reversible non-adverse effects*, *biomarkers of pathological damage*. *The Biomarkers of early biochemical change* are markers of a biochemical change that is reversible and non-adverse. For instance, the inhibition of delta-amino laevulinic acid dehydratase caused by lead, elevated levels of Zinc protoporphyrin in blood following lead exposure that impairs haemoglobin production, and the inhibition of pseudocholinesterase activity by organophosphates. The *biomarkers of reversible non-adverse effects*: these are markers for early detection of health impairment. For instance, **u**rinary excretion of alpha1 and beta2 micro-globulins due to lead, cadmium, and mercury exposure; increased zinc protoporphyrin in blood, coproporphrin in urine, δ-aminolaevulinic acid in urine (ALA-D) and δ-aminolevulinate dehydratase in blood following lead exposure; and reduction in plasma and erythrocyte cholinesterase activities/serum cholinesterase depression after exposure to organophosphates. The *biomarkers of pathological damage or disease* are markers of damage to a given organ or tissue, such as increased levels of transaminases in liver dysfunction and presence of albumin urinary excretion in kidney dysfunction (albuminuria).

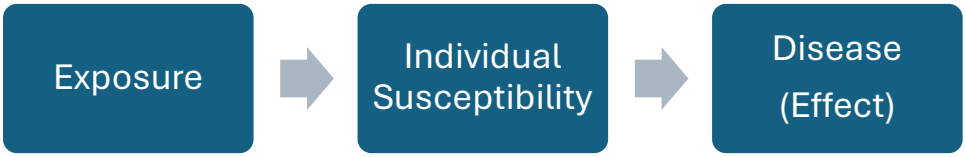


Figure 9.1. A negative effect or disease may occur after chemical exposure, but individual susceptibility may be of importance for the development of such an effect.

9.3 Biomarkers of exposure: Metals as examples

A metal is a material that serves as an excellent conductor of both electricity and heat. Metals play a crucial role in various industrial processes and production lines. They are significant for instance in battery production, paint manufacturing, operations in foundries, mining activities, and welding. However, it's important to note that certain metals can pose a risk of poisoning to workers. This may occur through inhalation of metal fumes or absorption through skin, leading to both acute and chronic intoxications in work environments.

Metals can contribute to various health problems, as outlined in Table 9.1, each exhibiting distinct symptoms. While some metals may cause acute intoxications, others can also lead to chronic health problems or intoxications.

Table 9.1. Health effects of metals

Metal	Kidney	Nerve	Liver	Gut	Lung	Blood	Bone	Repro	Skin	Heart
Arsenic		+	+	+	+	+		+	+	+
Cadmium	+	+		+	+		+			+
Chromium			+		+				+	
Lead	+	+		+		+		+	+	
Mercury	+	+		+	+			+		
Nickel		+			+				+	

Given the potential health hazards associated with exposure to metals, it becomes crucial to establish surveillance methods for monitoring the exposure of workers to metals in the workplace. For some metals, biomonitoring is possible (Table 9.2). Lead and mercury are used in the text as good examples of substances that can be bio-monitored among workers to make them safe.

Table 9.2. Metals and biomonitoring methods used

Metal	Type of possible biomonitoring
Arsenic	Whole blood Urine Hair Finger- or toenails
Cadmium	Whole blood Red blood cells Urine
Lead	Whole blood
Mercury	Whole blood Red blood cells Urine
Nickel	Plasma/serum Urine
Tin	Whole blood Urine
Uranium	Urine

9.3.1 Lead

Lead is a relatively inert heavy metal. It is present in both its pure metallic form and in various organic and inorganic compounds. There is no useful purpose of lead in human body. Workers can encounter lead in numerous occupational settings, as it is utilized in smelting operations, metal production, electronics manufacturing, paint formulation, ceramics, battery assembly, and plastics production. Additionally, workers may face lead exposure during activities such as welding, painting, and metal recycling. Exposure to lead at work can occur through inhalation of lead fumes or accidental ingestion. Notably, lead possesses a unique characteristic of accumulating in the skeleton. Its half-life in blood is approximately 30 days, contrasting with 10 to 20 years in bone. The primary route of lead excretion is through urine. Organic lead compounds distinguish themselves from other forms of lead by their ability to be absorbed through the skin and cross the blood-brain barrier.

Acute health effects resulting from low doses of lead exposure include fatigue, constipation, sleep disturbances, colic, neuropathy, and anaemia. At high exposure levels, lead can lead to heart arrhythmias and respiratory symptoms.
Chronic health effects of lead exposure vary depending on the form of lead. Inorganic lead may cause neuropathy (primarily in adults), and encephalopathy (primarily in children). Organic lead exposure may result in central nervous system symptoms. Certain lead compounds, such as lead acetate, are classified as carcinogenic, while others may have adverse effects on reproduction.

Biomonitoring of lead in blood
Biomonitoring of lead in blood is a crucial measure to detect and monitor potential exposure among workers. Regular blood samples can help prevent intoxication and associated health issues. Typically, annual blood lead level assessments are adequate, but if levels are elevated, more frequent testing may be necessary, as outlined below:

Table 9.3. Recommended levels of lead in blood

Recommended levels of lead in blood, as suggested by Centers for Disease Control and Prevention (CDC), US. The values are given in Micromole Pb/l fullblood

< 0,5	Reference area for a general population
0,5-1,0	This level shows a slight increase of lead in the blood, that probably has no consequences for general health. Pregnant women should not exceed 0.5.
1,0-1,5	This level indicated elevated blood lead, and the exposure should be reduced. <new blood samples should be performed every 2nd month.
>1.5	Workers with this level should be removed from the exposure, and improvements should be done at their workplace.
>2,0	Clearly elevated lead level, and the worker should be removed from the exposure/work
>2,5	Absolutely unacceptable, symptoms from the nervous system may occur
>2,9	Alarmingly high lead level, high risk of developing symptoms of lead intoxication

In many countries the limit value of blood lead levels is 0,5 micromole per litre of blood. Workers must be removed from the area of work immediately if blood levels are higher than 10–20. Subsequent measurements must be made to demonstrate that the worker's blood lead level has decreased to below the limit values before they may return to work.

9.3.2 Mercury

Mercury is a significant metal found in various chemical forms, including both organic and inorganic compounds. It remains fluid at room temperature and readily evaporates, making it easily inhalable and posing numerous adverse health effects, rendering it hazardous to workers.

Metallic mercury finds application in batteries, instruments, and devices, and serves as a catalyst in various chemical processes, often present in the work environments of chemical industries. Furthermore, it is utilized as an amalgam in dental repairs, potentially exposing dentists to mercury. Organic forms of mercury, such as methylmercury, are employed as fungicides on grains.

Primary workplace exposures typically occur through inhalation of mercury vapours (from metallic mercury), though skin absorption is also possible. Mercury compounds can traverse the placental barrier, posing risks to foetal health. The half-life of inorganic mercury in the human body is approximately 60 days, whereas organic mercury compounds have a longer half-life of about 70-80 days. Inorganic mercury compounds are excreted through urine, while organic mercury compounds are primarily excreted via faeces.

Acute exposure to mercury can lead to respiratory symptoms, and at high levels of exposure, it may progress to lung oedema. Chronic exposure to mercury poses risks to both the peripheral and central nervous systems. Inorganic mercury can result in renal diseases, characterized by heightened excretion of proteins in the urine. Additionally, certain organic mercury compounds are classified as carcinogenic, and they may also have adverse effects on reproductive health.

Biomonitoring of mercury in urine

Mercury exposure can be monitored through both blood and urine sampling methods. Blood mercury levels are particularly effective in detecting methylmercury, whereas urine levels are less influenced by this specific compound. Typically, in occupational settings, surveillance of mercury exposure relies on urine samples, taken once a year, unless high mercury values have been detected. It is essential that urine samples are collected in the morning and adjusted for creatinine levels, as fluid intake can affect mercury concentration.

Table 9.4. Recommended levels of mercury in urine

Recommended levels of mercury in urine, as suggested by Centers for Disease Control and Prevention (CDC), US. The values are given in nanomole/liter urine	
< 25	Level for normal population
<50	Suspected elevation of mercury. Pregnant women should not work with this exposure level, and the workplace exposure should be examined
>100	Possible elevation of mercury, and exposure at the workplace should be reduced
>250	Clearly elevated mercury levels, and the exposure of the worker should be stopped, and the workplace exposure reduced

9.4 Diagnosis of metal intoxications

The examples given above, for biological monitoring of lead and mercury, inform about surveillance of workers who in principle are healthy. The reason why we do this kind of monitoring is to discover if they are exposed to metal at a higher level than recommended. If the samples taken show higher exposure levels than recommended, action must be taken to avoid disease from developing. Many workers with higher levels of metal in blood than recommended do not have any symptoms of disease and do not know about it, as symptoms of disease and the disease itself most often develop at higher exposure levels than found in the tests. However, it may happen that a worker addresses health personnel because he/she has developed symptoms of disease and suspects a metal intoxication. In such situations, a blood test or urine test is not sufficient, and a physician must be consulted. The following procedure is recommended for the physician:

1) Obtain a detailed occupational history, focusing on
   a) The patient's symptoms and their relation to the work
   b) The character of the hazardous exposure at work
   c) The quantity and duration of the hazardous exposure at work
   d) Ask for presence of similar symptoms among co-workers

2) Supplementing information should be sought at the workplace to confirm type of exposure

3) Clinical examination must be performed, with special focus on the symptoms the patient describes

4) Laboratory samples must be performed, both to confirm the exposure and to search for signs of disease.

One must be aware that normal values for the agents of exposure in the general population may differ i geographic regions and must be checked for different countries.

Suspecting lead poisoning

- Lead in blood (B-lead) – levels should be below 0.5 micromol/L*
- Blood samples need to be transported in special glasses. Contact the laboratory before sending any samples.

Suspecting mercury poisoning

- B-mercury -levels should be below 25 nmol/L

- U-mercury should be below 25 nmol/L (creatinine should be checked as well) *

*(*These normal values are Norwegian normal values, 2024)*

9.5 Chelation therapy

Sometimes, when an intoxication by heavy metals has been diagnosed, chelation therapy might be indicated. This is a treatment that involves the administration of specific agents – chelating agents – that will remove heavy metals from the body. This kind of treatment can be very useful when a worker has very high exposure levels of metals in blood or urine, but the treatment can also be dangerous. The treatment may cause several types of side effects, and if the treatment is performed wrongly, it may lead to death. Therefore, this kind of treatment should be done only by experienced specialists and is not a part of routine work in occupational health services.
Chelation therapy is preferred for metal poisoning by mercury, iron, arsenic, lead, uranium, and plutonium. Dimercaprol (British anti-Lewisite-BAL) is an example of a chelator. BAL is mainly used to treat acute poisonings by arsenic, gold and lead.

9.6 Ethics related to biological monitoring

Biological monitoring in the workplace presents several ethical dilemmas, particularly regarding the relationship between workers and management. In research there might be conflicts between workers and researchers as well. Medical surveillance plays an important role in identifying occupational hazards and assessing the impact of workplace exposure to toxic substances. These measures are meant to serve the interests of workers, society, government, and industry. However, there are challenges in the area, and the workers might not agree with the opinions of employers or researchers.
The central questions revolve around the moral obligation of workers to participate in surveillance and screening initiatives aimed at enhancing occupational health. There might be a clash of interests between the worker and the management, and this can significantly influence the perception of the need of such medical surveillance.
Disagreement about the control over data generated by monitoring procedures may also be a source of conflict.
Ethical considerations arise regarding the workers' obligation to participate in monitoring procedures aimed at understanding occupational diseases. The necessity of establishing such obligations and whether they should be fulfilled voluntarily or through compulsion are pivotal questions. Furthermore, the principle of informed consent, crucial in medical research, is challenged in workplace investigations involving invasive procedures.

The challenges in this kind of research can be summarized by these key terms:

-Participation: Voluntary or not? In research we strive for voluntary participation.
-Who will have access to the results? Only the researchers or anyone else? It is important to tell workers participating that no individual results will be given to employers.
-Follow-up of diseases discovered among workers: Will this be done? It is important to plan and explain this before the worker enters the study.

-Follow-up of work problems: Is the employer willing to improve the workplaces? How can this be handled if problems are revealed? The researcher must have a plan for this.

The difference between clinical research and workplace monitoring underscores the necessity of informed consent and respect for personal dignity. While mandatory participation may be justified under extraordinary circumstances at work, one must be aware of a different situation when research is performed at a workplace.
In conclusion, the ethical dimensions of biological monitoring in the workplace highlight the delicate balance between individual rights, collective interests, and public health imperatives.

9.7 References

OSHwiki/European Agency for Safety and Health at Work. Biological Monitoring. Available at https://oshwiki.osha.europa.eu/en/themes/biological-monitoring-biomonitoring (Last accessed: 19/06/2024).

Gardiner K, Rees D, Adisesh A, Zalk D, Harrington M. Pocket consultant Occupational Health (Biological monitoring) 6th Edition. Wiley Blackwell, 2022, pp290-297.

Gerhardsson L. Diagnosis and treatment of metal poisoning general aspects. In Handbook on the Toxicology of Metals (5th Edition), 2022: pp 663-684.

Koons AL, Rajasurya V. Cadmium Toxicity. In StatPearls, National Library of Medicine, StatPearls Publishing 2023 https://www.ncbi.nlm.nih.gov/books/NBK536966/

Martinez-Morata I, Sobel M, Tellez-Plaza M, Navas-Acien A, Howe CG, Sanchez TR. A State of the Science Review on Metal Biomarkers. Curr Environ Health Reports 2023;10:215-249.

World Health Organization. WHO guideline for clinical management of exposure to lead, Geneva, 2021. ISBN-13: 978-92-4-003704-5.

Ye B-J, Kim B-G, Jeon M-J et al. Evaluation of mercury exposure level, clinical diagnosis and treatment for mercury intoxication. Ann Occup Environ Med 2016; 28:5 https://www.ncbi.nlm.nih.gov/books/NBK575274/

Chapter 10. Lung function assessment

Alexander M. Tungu, Hussein Mwanga and Gro Tjalvin

10.1 General concepts

Lung function testing is vital in the assessment of respiratory conditions. As a general rule, the assessment of respiratory conditions involves history taking, physical examination and carrying various investigations. A detailed occupational history is pivotal in making a proper diagnosis and plays a key role in ruling out non-occupational conditions. Therefore, obtaining details regarding duration of employment, type of exposure, duration of exposure, and presence of airway symptoms such as dyspnoea, cough with or without sputum, severity and chronicity of the respiratory symptoms is important. Physical examination and investigations lung such as function test (LFTs) follow routine procedures as for non-occupational respiratory assessment.

LFTs are also important in the screening, diagnosis, management and monitoring of occupational respiratory conditions such occupational asthma and chronic obstructive pulmonary disease (COPD). In this chapter, we describe some of the commonly used tests in lung function assessment such as Spirometry and Peak Expiratory Flow Rate (PEFR) and Fractional Exhaled Nitric Oxide (FeNO). Other tests such as Cardio-pulmonary Exercise Testing (CPET), Diffusing Capacity of Carbon Monoxide (DLCO) and radiological investigations are beyond the scope of this chapter. Nevertheless, we recommend further reading on such tests as they are important in the assessment of cardio-pulmonary conditions.

10.2 Spirometry

Spirometry is a vital tool in the assessment of general respiratory health. It is the most performed pulmonary function test in respiratory medicine. Spirometry measures the maximal volume of air that a person can inspire and expire with maximal effort. It is an important and valuable test for the diagnosis, management and monitoring of patients with lung diseases. Spirometry also plays an essential role in the assessment of severity and prognosis of pulmonary diseases as well as in research such as epidemiological surveys, clinical research, and derivation of reference equations. The most important indices reported in a spirometry test include the total exhaled volume, known as the forced vital capacity (FVC); the volume exhaled in the first second, known as the forced expiratory volume in one second (FEV_1); and their ratio (FEV_1/FVC).

Indications

Spirometry is the cornerstone of respiratory health evaluation in the workplace. It plays a key role in the prevention of work-related lung disease. The main aim of spirometry in the workplace is to identify workers who should have further evaluation for possible disease. The common indications for spirometry are provided in Table 10.1.

Table 10.1. Indications for spirometry

Diagnosis
To evaluate symptoms, signs, or abnormal laboratory test results
To measure the physiologic effect of disease or disorder
To screen individuals at risk of having pulmonary disease
To assess preoperative risk
To assess prognosis
Monitoring
To assess response to therapeutic intervention
To monitor disease progression
To monitor patients for exacerbations of disease and recovery from exacerbations
To monitor people for adverse effects of exposure to injurious agents
To watch for adverse reactions to drugs with known pulmonary toxicity
Disability/impairment evaluations
To assess patients as part of a rehabilitation program
To assess risks as part of an insurance evaluation
To assess individuals for legal reasons
Other
Research and clinical trials
Epidemiological surveys
Derivation of reference equations
Preemployment and lung health monitoring for at-risk occupations
To assess health status before beginning at-risk physical activities

Modified from Graham B et al, 2019.

Contraindications

Table 10.2 lists relative contraindications that need to be considered before conducting spirometry. If a patient experiences pain during spirometry, the test should be discontinued. Risks and benefits of the test should be evaluated for each worker before conducting spirometry.

Table 10.2. Relative contraindications for spirometry

Due to increases in myocardial demand or changes in blood pressure
Acute myocardial infarction within 1 week
Systemic hypotension or severe hypertension
Significant atrial/ventricular arrhythmia
Noncompensated heart failure
Uncontrolled pulmonary hypertension
Acute cor pulmonale
Clinically unstable pulmonary embolism
History of syncope related to forced expiration/cough
Due to increases in intracranial/intraocular pressure
Cerebral aneurysm
Brain surgery within 4 weeks
Recent concussion with continuing symptoms
Eye surgery within 1 week

Due to increases in sinus and middle ear pressures
Sinus surgery or middle ear surgery or infection within 1 week
Due to increases in intrathoracic and intraabdominal pressure
Presence of pneumothorax
Thoracic surgery within 4 weeks
Abdominal surgery within 4 weeks
Late-term pregnancy
Infection control issues
Active or suspected transmissible respiratory or systemic infection, including tuberculosis
Physical conditions predisposing to transmission of infections, such as haemoptysis, significant secretions, or oral lesions or oral bleeding

Modified from Graham B et al, 2019.

Equipment preparation

All spirometers must meet the most current American Thoracic Society/European Respiratory Society (ATS/ERS) standards. Both volume–time and flow–volume real-time displays are required for optimal quality control. Technicians must visually inspect the quality of each manoeuvre before proceeding with the next. Spirometry outcomes should be reported at BTPS (body temperature, ambient barometric pressure, saturated with water vapor). Calibration verifications must be undertaken at least daily or more frequently as specified by the manufacturer, using a 3-L syringe. In addition, operators are encouraged to know their own usual FEV_1 and FVC, which allows them to conduct a quick, rough check if they suspect a problem.

Patient preparation

At the time of making an appointment for spirometry, workers should be instructed to avoid the activities listed in Table 10.3. Before testing, operator should check whether the worker has adhered to the provided instruction. Operators should provide all the necessary instructions regarding the test and make sure that the worker is as relaxed as possible before and during the tests. It might be necessary to remove dentures unless they are well-fitting. If the test is conducted to diagnose a chest disease such as asthma or COPD, bronchodilator medications should be withheld.

Table 10.3. Activities that should be avoided before spirometry

Smoking and/or vaping and/or water pipe use within 1 hour before testing (to avoid acute bronchoconstriction due to smoke inhalation)
Consuming intoxicants within 8 hours before testing (to avoid problems in coordination, comprehension, and physical ability)
Performing vigorous exercise within 1 hour before testing (to avoid potential exercise-induced bronchoconstriction)
Wearing clothing that substantially restricts full chest and abdominal expansion (to avoid external restrictions on lung function)

Modified from Graham B et al, 2019.

Performing spirometry

Spirometry should be conducted by a technician who has completed an appropriate practical training. Refresher courses are vital to maintain to the acquired skills. It has been argued that a well-motivated and enthusiastic technician is perhaps the most important component in successful pulmonary function testing. Technicians should explain, demonstrate, and actively coach clients to perform maximal inspirations, hard and fast expiratory blasts, and complete expirations.

The American College of Occupational and Environmental Medicine (ACOEM) recommends that occupational testing should be conducted while standing, unless a worker has experienced fainting in the past, or is believed to be at risk from fainting or falling. A chair without wheels should be placed behind the subject, and the technician must be ready to assist the subject into the chair if needed. Testing posture should be recorded and kept consistent over time whenever possible. When interpreting serial results over time, changes in test posture need to be taken into account. Disposable nose clips are recommended.

Technicians should strive to achieve the ATS/ERS criteria for a valid spirometry test, i.e., *firstly,* recording three or more acceptable curves that are free of technical flaws; and *secondly*, FVC and FEV_1 repeatability of less than or equal to 150 millilitres. Failure to achieve FVC repeatability is often caused by sub-maximal inhalations.

To achieve an acceptable manoeuvre, four distinct phases need to be completed: *firstly,* maximal inspiration; s*econdly,* a "blast" of expiration; *thirdly,* continued complete expiration for a maximum of 15 seconds; and *fourthly*, inspiration at maximal flow back to maximum lung volume. The details of an FVC manoeuvre are provided in Table 10.4 below. Acceptability, usability and repeatability criteria for FEV_1 and FVC are provided in detail in the ATS/ERS standard.

Spirometry test reports should include values and curves from all acceptable curves (or at least 3 best curves). The largest FVC and largest FEV_1 should be used for interpretation, even if they come from different curves.

Table 10.4. Procedures for FVC Manoeuvres

Wash hands (or use an approved hand sanitizer)
Prepare the patient
● Dispense hand sanitizer for the patient ● Confirm patient identification, age, birth sex, ethnicity, etc. ● Measure weight and height without shoes ● Ask about activities that should be avoided before the test, medication use, and any relative contraindications and note any respiratory symptoms
Instruct and demonstrate the test
● Position of the mouthpiece and nose clip ● Correct posture with head slightly elevated ● Inspire rapidly until completely full ● Expire with maximal effort until completely empty

● Inspire with maximal effort until completely full ● Confirm that patient understands the instructions and is willing to comply
Perform manoeuvre
● Have patient assume the correct posture ● Attach nose clip, place mouthpiece in mouth, and close lips around the mouthpiece ● Breathe normally ● Inspire completely and rapidly with a pause of ≤2 seconds at total lung capacity ● Expire with maximal effort until no more air can be expelled while maintaining an upright posture ● Inspire with maximal effort until completely full ● Repeat instructions as necessary, coaching vigorously ● Repeat for a minimum of three manoeuvres, usually no more than eight for adults ● Check FEV_1 and FVC repeatability and perform more manoeuvres as necessary
Perform manoeuvre (expiration-only devices)
● Have patient assume the correct posture ● Attach nose clip ● Inspire completely and rapidly with a pause of ≤2 seconds at total lung capacity ● Place mouthpiece in mouth and close lips around the mouthpiece ● Expire with maximal effort until no more air can be expelled while maintaining an upright posture ● Repeat instructions as necessary, coaching vigorously ● Repeat for a minimum of three manoeuvres, usually no more than eight for adults ● Check FEV_1 and FVC repeatability and perform more manoeuvres as necessary

Modified from Graham B et al, 2019.

Quality checks

Before interpretation of the test, it is vital to conduct a series of logical data quality control checks. It is important to check the calibration data to be sure that the spirometer is reading correctly. It is expected that a calibration check must have been done prior to the test. It is also important to check that the subject's details specifically age, sex, height and ethnicity have been correctly entered.

If these subject details are incorrect, the normal predicted values will be incorrect. The next step is to check if the appropriate reference values have been used. Final step before interpretation of the results is to check the acceptability and repeatability of the test. It is recommended to use the acceptability and repeatability criteria provided by the ATS/ERS.

Table 10.5. Acceptability Criteria

Where on blow	***Exact part of blow***	***Explanation and specifics guide***
Start of test	1. Start	✓ No hesitation or false start evidenced by
		✓ Extrapolated volume (BEV) less that 150mls or less than 15% of the FVC-whichever is greater
		✓ Time to start must be 150mls (PEFT)
	2. Rise to peak	✓ Steep upright rise to a peak with no hesitation, artefact or sloping
	3. Peak	✓ Must be tall and pointed, not round or flat
		✓ A "rule of thumb" (estimate) should be a peak that falls to the left of the FEF25% predicted mark on the flow/volume graph
Middle of test	4. Downward curve	✓ Should be smooth and continuous with no cough, artefact, glottis closure, leak etc
End of test	5. End of test	✓ The flow volume graph should descend gracefully onto x axis with no drop off and volume time graph should reach a plateau
		✓ EOT volumes are: The subject cannot continue to blow out further The subject should not continue to blow out further

Modified from the Pan African Thoracic Society Manual for Spirometry, 2018

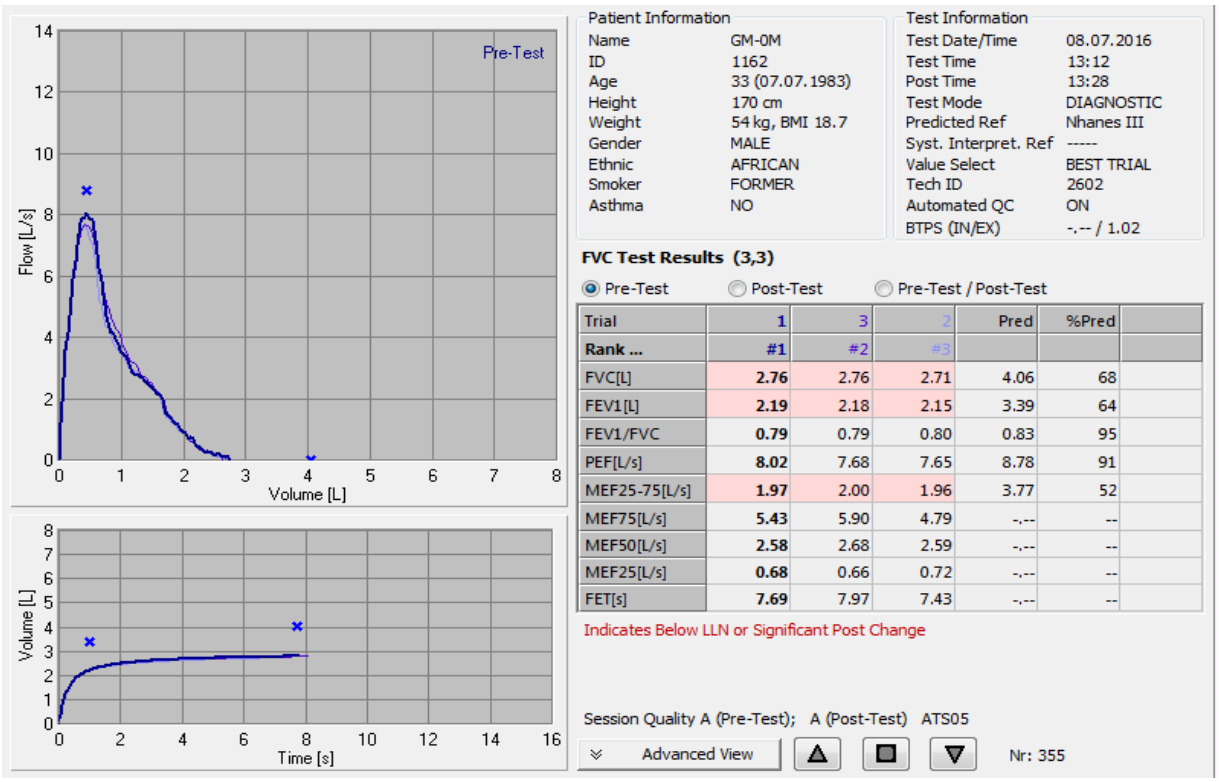


Figure 10.1. Test that meets all acceptability and repeatability criteria. @H. Mwanga

10.3 Bronchodilator responsiveness testing

Bronchodilator responsiveness testing is conducted to determine the degree of improvement of airflow following bronchodilator administration as measured by changes in FEV_1 and FVC. The ATS/ERS standard has not specified the choice of bronchodilator, dose, or mode of delivery and left it to the experts involved to decide based on what is needed from the test. It is recommended to have a written test protocol for every facility conducting bronchodilator responsiveness testing.

As noted above, a worker may need to withhold bronchodilators before testing if the aim of the test is to make a diagnosis. Withholding times for various bronchodilators are listed in Table 10.5. It is not required to withhold inhaled corticosteroids or leukotriene modifiers. The procedure involves a worker first performing baseline (pre-bronchodilator) spirometry to achieve three acceptable FEV_1 and FVC measurements and then a bronchodilator is administered and finally three or more additional post-bronchodilator acceptable FEV_1 and FVC measurements are obtained after the specified wait time.

According to the recent ATS/ERS technical standard, a significant response to bronchodilator is defined as a postbronchodilator increase of >10% of predicted value in FEV1or FVC. Previously, a postbronchodilator increase of ≥12% accompanied by 200 millilitres increase in FEV1 or FVC was considered significant.

Table 10.6. Withhold times for bronchodilators

Bronchodilator	***Withholding time***
Short-acting β_2-agonist e.g., salbutamol	4 to 6 hours
Short-acting muscarinic antagonist e.g., ipratropium bromide	12 hours
Long-acting β_2-agonist e.g., formoterol or salmeterol	24 hours
Ultra long-acting β_2-agonist e.g., indacaterol, vilanterol, or olodaterol	36 hours
Long-acting muscarinic antagonist e.g., tiotropium, umeclidinium, aclidinium, or glycopyrronium	36 to 48 hours

Modified from Graham B et al, 2019

Interpretation of Spirograms

Interpretation of spirometry results should always consider the full clinical picture of the worker. A three-step interpretation algorithm is presented in Figure 10.2. *Firstly*, FEV_1/FVC ratio should be assessed to determine if obstructive impairment is present. *Secondly*, FVC is evaluated for a possible restrictive impairment. *Thirdly*, FEV_1 is assessed if the FEV_1/FVC ratio indicates a possible obstructive impairment.

The use of cut-off points such as 80% of predicted value for FEV_1 and the 0.70 cut-off for the FEV_1/FVC ratio are known to cause false positives and false negatives, and hence strongly discouraged. Instead, it is recommended to use the 5th percentile LLN for all indices to determine an abnormality. A "possible physiologic variant" may be observed in healthy individuals when FEV_1/FVC is barely

abnormal, while FEV_1 is greater than 100% of predicted. It is vital to be cautious when interpreting values that are either just above or just below the LLN.

It is widely known that lung function varies with age, sex, height and ethnicity. Therefore, in the interpretation of spirometry, results need to be compared with the appropriate predicted (reference) values derived from healthy individuals of the same age, sex, height and ethnicity. The 2012 Global Lung Initiative multi-ethnic reference equations (GLI_{2012}) were the largest dataset ever produced. The GLI_{2012} included data pooled from four ethnic groups: Caucasians, Blacks, South-East Asians and North-East Asians.

However, the GLI_{2012} lacked data from Black African population. The 'Blacks' equations in the GLI_{2012} were solely derived using data from African Americans in the United States. The GLI_{2012} also provided a composite "Other" equation for populations lacking reference equations and for individuals of mixed ethnic origin. The GLI_{2012} "Other" equations were found to have the best fit for the South African black African and mixed-ethnicity populations and have been recommended for the interpretation of spirometry in these South African populations.

Two major findings were noted from a recent cross-sectional analysis of 586 high-quality spirograms from a random sample of the general population in 4 regions in Tanzania aged 23-73 years*: Firstly*, the GLI_{2012} 'Other' equations performed poorly compared to the 'Black' equations; *Secondly,* both GLI_{2012} 'Other' and 'Black' equations accurately predicted FEV_1/FVC but poorly predicted FVC and FEV_1: 'Other': mean z-score ± SD of -1.17±1.18 for FVC, -1.14±1.16 for FEV_1, and -0.11±1.20 for FEV_1/FVC; 'Black': -0.51±1.11 for FVC, -0.52±1.17 for FEV_1, and -0.05±1.14 for FEV_1/FVC. A mean spirometry z-score of > ±0.5 is considered clinically significant i.e., poor fit for the tested population.

Nevertheless, the recent recommendation regarding the use of GLI "race-neutral" approach to pulmonary function test results interpretation has resulted into a major debate. The GLI "race-neutral" equations also accurately predicted FEV_1/FVC but poorly predicted FVC and FEV_1 in the recent Tanzanian study.

Although up to the present time, there are no reference values that have been deemed appropriate for the interpretation of spirometry in the Tanzanian population, based on the above mentioned recent Tanzanian study, the GLI_{2012} 'Blacks' equations seem to have a better fit than other GLI equations.

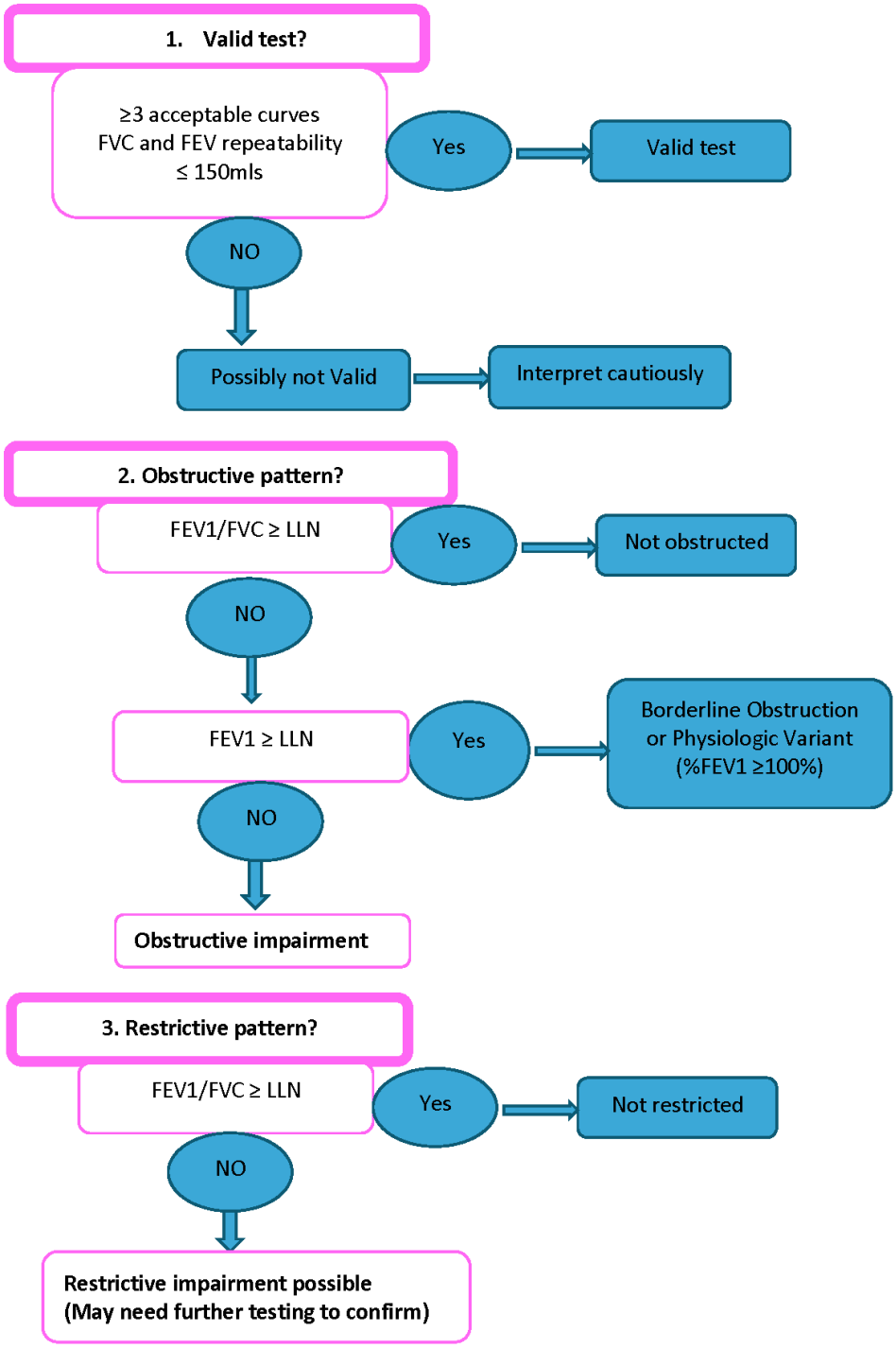


Figure 10.2. Spirometry interpretation algorithm. @A.M. Tungu

10.4 Peak expiratory flow rate

10.4.1 General concepts

Peak Expiratory Flow Rate (PEF) is defined as the maximal rate that a person can exhale during a short maximal expiratory effort after a full inspiration. The results are expressed in litres per minute. PEF measurements that are repeated over a given period of time are termed as Serial PEF measurements. PEF can be performed as a bedside test, or it can be done at home. Therefore, it is useful in determining changes in the patient's airway condition and can indicate the effectiveness of a prescribed medication.

10.4.2 Indications

PEF measurements are indicated in the diagnosis and monitoring asthma. Serial PEF measurements are indicated in the diagnosis of work-related asthma.

10.4.3 Contraindications

Generally, the PEF measurement is a safe procedure with no absolute contraindications. However, due to increased intra-thoracic, intra-abdominal and intra-ocular pressures during the manoeuvre, the following are relative contraindications:

i. Recent myocardial infarction or stroke
ii. Unstable angina
iii. Recent pneumothorax
iv. Recent abdominal surgery and
v. Recent eye surgery

10.4.4 Equipment preparation

A PEF meter can be bought in pharmacies and other stores that sell medical equipment. There are different designs, from standard PEF meters (Figure 10.3) to digital versions with a range of functions, and even Bluetooth and Apps to upload the results.

Figure 10.3. A standard PEF Meter. @Colourbox

10.4.5 Patient preparation

Precise oral and written instructions are mandatory to obtain reliable results.

10.4.6 Performing PEFR

The following are procedures for performing PEF.

Ask the patient to:

i. Move the marker to the lowest end of the numbered scale (=0)
ii. Inhale deeply with the mouth open
iii. Place the PEF meter in the mouth with lips forming a tight seal around the mouthpiece
iv. Make sure that no fingers prevent the indicator/marker from moving
v. Blow out once as forcefully as possible
vi. Repeat two more times after resetting the marker to 0 each time
vii. Write down the best result from the 3 attempts

Procedures For Serial Peak Expiratory Flow (PEF) measurements

The procedure implies PEF measurements several times a day at work AND away from work, both situations being equally important. Attention to detail is critical, and precise instructions that are understood by the patient are mandatory.

4 weeks with 2-hourly measurements and having one week off work in the middle, is recommended. There should be at least 3 consecutive days at work in any work period. Minimum criteria are ≥ 3 weeks of usual work exposure with measurements at least four times a day, or 8 days at work and 3 days away from work with 2-hourly measurements, while any medical treatment is kept constant.

10.4.7 Quality check

Potential error sources that might influence the PEF values includes suboptimal effort when performing the PEF manoeuvre, fabricated measurements, variable asthma medication, respiratory tract infections, and effects of other exposures apart from workplace agents.

10.4.8 Interpretation of PEFR results

The serial PEF measurements can be hand plotted and visually interpreted by experts (Figure 10.2), or the readings could be uploaded to a computer program that plots and interprets the data by giving different scores.

The PEF values and within-day variability on days at work are compared with the same measures on days away from work. A larger within-day variability during days at work compared to days away from work, or being > 20 % for more days at work than days away from work is considered indicative of work-related asthma.

Different patterns that might be compatible with work-related asthma:

Immediate falls in PEF (within an hour of arriving at work or being exposed to a specific exposure at work).

Delayed falls in PEF (starting later in the workday or after leaving work).

Cumulative falls in PEF over the working week (PEF deteriorating further with each day at work). Non-cumulative falls (similar falls each day).

PEF falling dramatically on the first day of exposure and becomes less as the working week progresses (rare).

Two main types of recovery patterns to the baseline PEF values: immediate (full recovery within a few hours of leaving work) and delayed (up to several days).

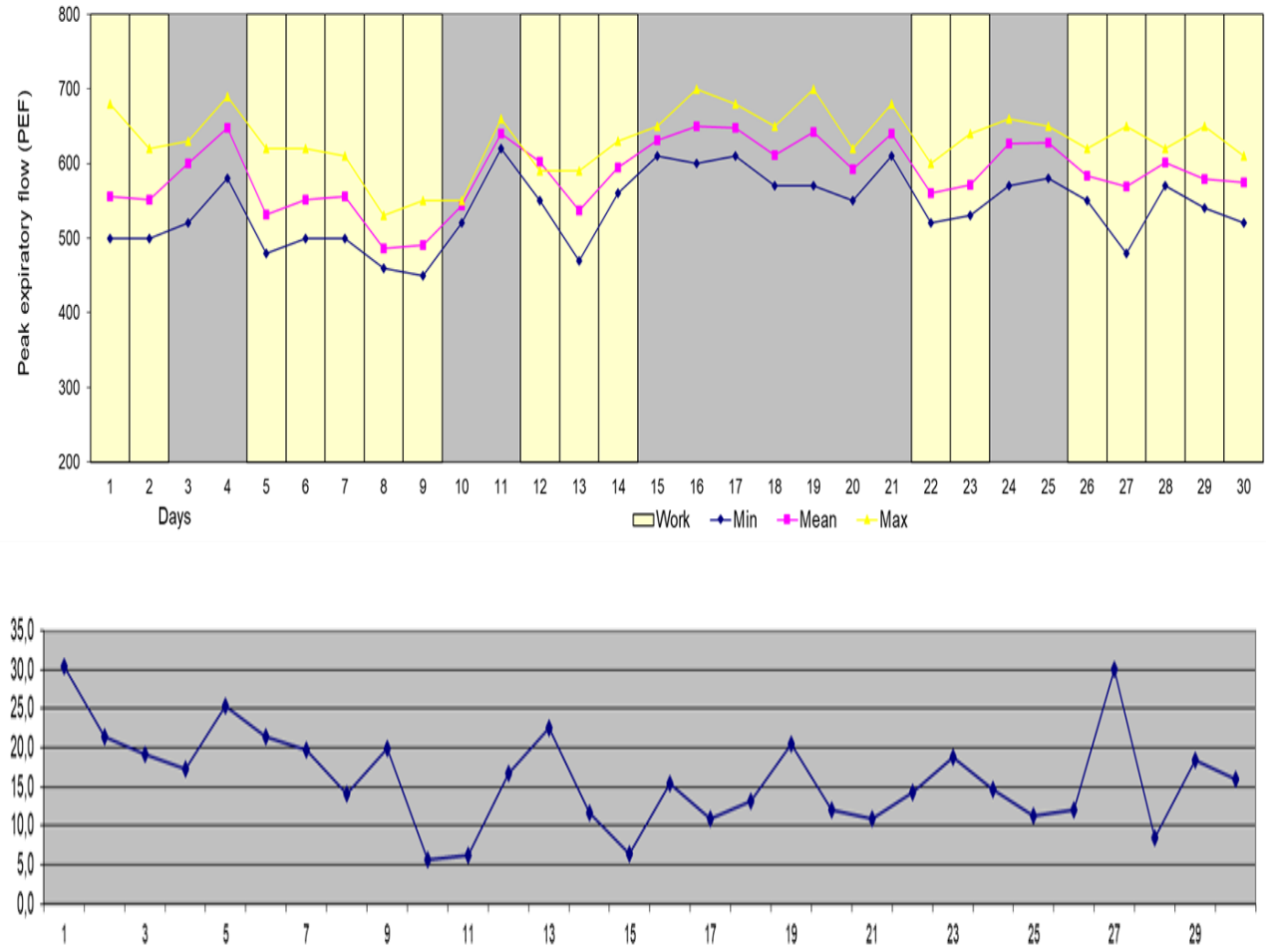


*Figure 10.4. Graphical plot of serial PEF measurements indicative of work-related asthma. In the upper part of the figure, the days elapsed are shown on the X-axis. The Y-axis shows the PEF measurements, given as the maximum value (yellow line), the minimum value (blue line), and the mean value (pink line), for each single day. The patient was **AT** work on the days indicated by the yellow bars and **NOT** at the workplace on the days indicated by the grey bars. The graph shows a tendency for the PEF-values to be lower on workdays, compared to days out of the workplace. Within the workdays, there is a tendency of more variable PEF values. The blue line in the lower part of the figure shows the PEF variability (in %) within each day, with a cut-off at 20 %, indicated by the dotted yellow line. @G. Tjalvin*

10.5 Fractional Exhaled Nitric Oxide

10.5.1 General concepts

Fractional exhaled nitric oxide (FeNO) is defined as the concentration of nitric oxide (NO) in the exhaled air, measured in parts per billion (ppb). FeNO is a surrogate marker of respiratory airway inflammation that is non-invasive, quick, and easy to measure. Workplace exposures such organic and inorganic dusts, chemical substances, and endotoxins can cause

airway inflammatory conditions, subsequently increasing FeNO levels. Therefore, FeNO measurement is a potential and valid test for detecting air inflammatory processes in occupational settings.

10.5.2 Indications

So far, there are no absolute indications for FeNO measurement. However, the American Thoracic Society (ATS) recommends FeNO measurement for management, monitoring and adherence purposes as described below.

Recommendations of FeNO Measurement for Disease Management purposes:

1. Diagnosis of eosinophilic airway inflammation
2. Supporting asthma diagnosis in situations that need objective evidence.
3. Determining likelihood of responsiveness to steroids among patients with airway inflammation
4. Guiding stepwise changes in corticosteroid dosage (step-down dosing, step-up dosing or discontinuation)
5. Assessing whether airway inflammation contributes to poor asthma control

Recommendations of FeNO Measurement for Monitoring and adherence purposes:

1. Long term observation of airway inflammation
2. Accounting for persistent and/or high allergen exposure as a factor associated with higher FeNO levels,
3. Assist in monitoring patient adherence to anti-inflammatory treatment

10.5.3 Contraindications

There are no absolute contraindications. Despite the benefits, FeNo measurements can be affected by several factors that can either lead to false positive or false negative results. For that reason, it is important to consider some of the factors depending on the purpose of examination as follows:

1. History of recent airway infections (<4weeks, infections increase FeNO levels).
2. Smoking within 24hours prior FeNO measurement (Smoking lowers FeNO levels).
3. Severe airflow obstruction (Difficulty in expiration may lead to low FeNO levels).
4. Use of corticosteroid use (Steroids lower FeNO levels).
5. Food or beverage consumption 1-hour prior FeNO measurement
6. Increased ambient NO

10.5.5 Equipment preparation

This should be carried out in accordance with the instructions from the manufacturer. As a general rule, equipment calibration should be done before conducting the FeNO measurements. Nevertheless, some devices are pre-calibrated by the manufacturer for a specified number of measurements and/or specified period of time. In that case, pre-calibrated devices may not need daily calibration until the specified measurements or period of time is exceeded.

10.5.6 Patient preparation

There are several factors that influence FeNO values. Such factors need to be considered depending on the purpose of the test. Some of these factors include medication such as corticosteroids and Angiotensin converting enzyme inhibitors (ACE-inhibitors), atopy, diet and smoking habits. Corticosteroids decrease FENO levels, therefore, individuals are advised to withhold medications for 24 hours before FeNO measurement as they lower FeNO levels. Similarly, chronic alcohol consumption and recent consumption of coffee may lower FeNO values. On the other hand, food substances rich in nitrates such as vegetables (lettuce cabbages, lettuce and spinach, may increase FeNO levels. Therefore, subjects should be advised to refrain from consuming food or beverages 1 hour before FeNO measurement. In addition, cigarette smoking is another important factor that influences FeNO levels. Smokers are advised to refrain from smoking 24-hour prior FeNO measurement as smoking lowers FeNO levels. Furthermore, respiratory infections influence also FeNO values. Upper airway viral infections such as common cold increase the level of FeNO due to nasal nitric oxide contamination. Therefore, FeNO measurements should be conducted when the infection has resolved (At least after 4 weeks).

10.5.7 Performing FENO measurements

Measurements should be performed in accordance with the American Thoracic Society/European Respiratory Society (ATS/ERS) criteria for online and offline measurement. Details of offline measurements are not included in this book. Briefly, the offline measurement technique involves collection breath samples for analysis in specialized laboratories. On the other hand, the online technique involves direct measurement of FeNO during an expiratory manoeuvre. During the manoeuvre, the subject is instructed to inhale to total lung capacity, in a surrounding will low ambient NO. Then, the subject exhales through a mouthpiece connected to the device for 10s at a pressure of 5–20cmH2O to reduce contamination of FeNO with nasal NO by the closing the soft palate. The optimal expiratory flow rate for a single breath is 50ml/s as it delivers NO from the lower respiratory tract. Some devices automatically terminate the when the exhalation pressure is sub-optimal. As the air flows through the electrochemical sensor, concentration of NO is analysed, and the device gives results at the end of the expiratory maneuverer.

10.5.8 Quality check

All measurements should be performed in accordance with the ATS/ERS criteria. Ambient NO should be recorded before the onset of FeNO measurements. In addition, factors influencing FeNO levels such as smoking, consumption of meals and beverages, recent respiratory infections should be addressed as described previously depending on the purpose of the examination.

10.5.9 Interpretation of FENO Results

The ATS categories for interpretation of FeNO values are as follows:

1. FeNO value <25 ppb indicate that eosinophilic inflammation is unlikely; thus, considered normal.
2. FeNO value between 25 and 50 ppb indicate non-specific inflammation; thus, should be interpreted in the clinical context.
3. FeNO value >50 ppb indicates significant eosinophilic inflammation.

10.6 References

Balady GJ, Arena R, Sietsema K, Myers J, Coke L, Fletcher GF, et al. Clinician's Guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association. Circulation. 2010;122:191–225.

Baur X, Sigsgaard T, Aasen TB, Burge PS, Heederik D, Henneberger P, et al. Guidelines for the management of work-related asthma. The European respiratory journal. 2012;39(3):529-45.

Bhakta NR, Bime C, Kaminsky DA, McCormack MC, Thakur N, Stanojevic S, et al. Race and Ethnicity in Pulmonary Function Test Interpretation: An Official American Thoracic Society Statement. Am J Respir Crit Care Med. 2023;207:978–95.

Dweik RA, Boggs PB, Erzurum SC, Irvin CG, Leigh MW, Lundberg JO, et al. An official ATS clinical practice guideline: interpretation of exhaled nitric oxide levels (FENO) for clinical applications. Am J Respir Crit Care Med. 2011;184(5):602-15.
Graham B, Steenbruggen I, Barjaktarevic I, Cooper B, Hall G, Hallstrand T, et al. Standardization of spirometry 2019 update. An official American Thoracic Society and European Respiratory Society technical statement. Am J Respir Crit Care Med. 2019;200:E70–88.

Khalili B, Boggs PB, Bahna SL. Reliability of a new hand-held device for the measurement of exhaled nitric oxide. Allergy. 2007;62(10):1171-4.

Masekela R, Koegelegenberg CFN, Gray DM. Guidance to the applicability of the Global Lung Initiative spirometry reference equations for South African populations. S Afr Med J. 2021;111:13186.
Moore VC, Jaakkola MS, Burge PS. A systematic review of serial peak expiratory flow measurements in the diagnosis of occupational asthma. The Annals of Respiratory Medicine. 2009;1(1):1.

Mwanga H.H., Mamuya S.H., Moen B.E., Svanes C. Validation of the 2012 Global Lung Initiative spirometry prediction equations in an East African country. European Respiratory Journal. 2023;62(S67) PA3977: https://doi.org/10.1183/13993003.congress-2023.PA3977.

Pellegrino R, Viegi G, Brusasco V, Crapo R, Burgos F, Casaburi R, et al. Interpretative

strategies for lung function tests. Eur Respir J. 2005;26:948–68.

Pralong JA, Cartier A. Review of Diagnostic Challenges in Occupational Asthma. Current allergy and asthma reports. 2017;17(1):1.Oasys and Occupational Asthma [Available from: http://occupationalasthma.com/default.aspx. (2023).

Quanjer P, Stanojevic S, Cole T, Baur X, Hall G, Culver B, et al. Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations. Eur Respir J. 2012;40:1324–43.
Ragnoli B, Radaeli A, Pochetti P, Kette S, Morjaria J, Malerba M. Fractional nitric oxide measurement in exhaled air (FeNO): perspectives in the management of respiratory diseases. Therapeutic Advances in Chronic Disease. 2023;14. doi:10.1177/20406223231190480.

Smith S-J, Gray DM, MacGinty RP, Hall GL, Stanojevic S, Mphahlele R, et al. Choosing the better global lung initiative 2012 equation in South African population groups. Am J Respir Crit Care Med. 2020;202:1724–7.

Stanojevic S, Kaminsky DA, Miller MR, Thompson B, Aliverti A, Barjaktarevic I, et al. ERS/ATS technical standard on interpretive strategies for routine lung function tests. The European respiratory journal. 2022;60(1).

Sylvester KP, Clayton N, Cliff I, Hepple M, Kendrick A, Kirkby J, et al. ARTP statement on pulmonary function testing 2020. BMJ Open Respir Res. 2020;7(1).

Townsend MC. Spirometry in Occupational Health-2020. J Occup Environ Med. 2020;62:E208–30.

Chapter 11. Hearing Assessment

Israel Paul Nyarubeli

11.1 General concepts

Workers' ears exposed to excessive continuous or impulsive sound levels above 85dB(A) are likely to have their hearing threshold increased. The increase in threshold of hearing due to noise exposure is referred to as noise-induced hearing loss (NIHL). Typically, the audiogram of the ear with NIHL shows a dip or notch at frequencies of 3-6kHz. The risk of NIHL is related to the duration and intensity of occupational noise exposure, as well as individual susceptibility to noise trauma.

The different definition or metrics of NIHL makes comparisons among studies challenging (some examples are shown in Table 11.1). It is therefore important to consider the right definition and conditions for use. Some definitions are based on hearing threshold shift from the baseline audiogram such as that of the NIOSH and the OSHA from the United States. Others use the 'noise notch' definition (a dip at 3, 4 or 6kHz with recovery at 8kHz), while others use the average threshold level estimates for one (worse or better) or both ears at selected frequencies with cut-off value of 25 dB HL.

Table 11.1. Some selected definitions for NIHL

Institution (reference)	NIHL definition/metric
WHO	Permanent decrement in hearing threshold levels (HTLs), with a characteristic reduction of hearing sensitivity at frequencies of 3, 4 and/or 6 kHz, and relatively better hearing sensitivity in surrounding frequencies (i.e., 2 or 8 kHz)
NIOSH- US (as STS)	An increase in the HTL of 15dB or more at any frequency (0.5, 1, 2, 3, 4 or 6 kHz) in either ear that is confirmed for the same ear and frequency by second test within 30 days of the first test.
American Medical Association (AMA) - hearing impairment	Hearing threshold average at 0.5, 1, 2, and 3 kHz >25dB HL, with 1.5% monaural impairment for each decibel greater than 25.
OSHA-US (STS	A 10-dB change from the baseline audiogram in the average of HTLs at 2, 3 and 4 kHz, with age correction allowed Or A 10-dB change from the baseline audiogram in the average of HTLs at 2, 3 and 4 kHz ≥ 25dB HL.
Norwegian Labor Authority	HTL ≥ 25 dB hearing level in either ear at 3, 4 or 6 kHz
Health and Safety Executive -UK (hearing impairment)	Sum of HTLs at 1, 2, 3, 4 and 6 kHz. Compare value with figure given for appropriate age band and gender in a standardized table.
ACOEM	Hearing loss (sensorineural) that is a function of continuous or intermittent noise exposure, intensity and duration, and which usually develops slowly over several years characterized by a dip sign of the audiogram at the high frequencies of 3, 4 and 6 kHz recovering at 8 kHz

11.2 Audiometry

Audiometry consists of tests of the function of the hearing mechanism. This includes tests of mechanical sound transmission (middle ear function), neural sound transmission (cochlear function), and speech discrimination ability (central integration). A complete evaluation of a patient's hearing must be done by trained personnel using instruments designed specifically for this purpose. One of the commonly used audiometry techniques is the *Pure Tone Audiometry (PTA)* that is used to test air and bone conduction. Other tests include *impedance audiometry,* which measures the mobility and air pressure of the middle ear system and middle ear (stapedial) reflexes, and *auditory brainstem response* (ABR), which measures neural transmission time from the cochlea through the brainstem.

11.2.1 Indications of audiometry

Audiometry is indicated for evaluation of the hearing ability of a person in a clinical medical setting. This can be done in a consultation with a general practitioner, or with an ear-nose-throat specialist, and audiometry is here a diagnostic tool. In occupational health, audiometry is also a diagnostic tool, but in addition the examination is used for surveillance of workers exposed to high noise levels at work.

11.2.2 Health surveillance

This is conducted to identify existing hearing losses and evaluate the effectiveness of control measures in place or hearing conservation programs. It includes pre-employment audiometry and periodic audiometry. Health surveillance is appropriate and should be mandatory to all employees at risk for developing noise induced hearing loss at the workplace. Noise exposure action value should be considered for decision making. Therefore, screening audiometry is recommended as a basic tool for this purpose.

11.2.3 Types of audiometry

1. Screening audiometry: This is performed to identify potential hearing deficiencies and may indicate threshold shift across time. The measurement is carried out by screening audiometer using a basic air conduction – Pure tone audiometry (PTA).
2. Diagnostic audiometry: This test uses both air and bone conduction audiometry to examine hearing threshold aiming at identifying hearing deterioration before being practically noticed by a person and may also be used to assess speech threshold levels.

11.2.4 Common categories of audiometry

1. Pure tone audiometry. This test records the threshold of hearing i.e., the finest sound a human ear can detect. It is widely used and still regarded as a gold standard. During the test, earphones are connected to the audiometer and pure tones of specific frequencies (e,g. 125-8000Hz) and volumes are delivered to one ear at a time. A test individual is instructed to respond to a pulse i.e., the lowest intensity tone in decibels. A bone oscillator may also be used to test bone conduction through inserting it against the mastoid bone.

2. Speech Audiometry. This test is used to assess the ability to detect and repeat spoken words at different volumes. In other words, it measures the ability of a test person to hear and understand speech. The lowest decibel level at which a test person can correctly repeat 50% of test words is called Speech Reception Threshold (SRT) and should be within + or – 10dB of pure tone average at frequencies of 0.5, 1, and 2KHz. This method is most often performed by specialists.

11.2.5 Elements of audiometry

One of the main objectives of why audiometry is performed at the workplace is to obtain information necessary to reduce the risk for developing hearing loss among workers exposed to high noise levels above 85 dB (though NIOSH estimates suggest 15% still are likely to develop hearing impairment over lifetime). Therefore, it is important that the test environment is practically appropriate to yield the lowest signal level a person can hear. To ensure this condition is fulfilled, the following elements are necessary; -

1. Ensure control of background noise that is present in the test environment. Audiometers calibrated according to the ISO standards will make it possible to test to 0 dB HTL for a hearing sensitive person. Practically, the test environment or room should be quiet enough to accommodate the lowest possible threshold of hearing. In this case for example, the test room should be away from noisy areas; close door and windows to block out external sounds, turn off any equipment or devices the generate noise like fans, air conditioners; use soundproofing materials to absorb sound.

2. It is recommended that the test environment should be quiet and free of noise interference. The test room "referred to as test booth" should be standardized and be able to attenuate ambient noise level to a point where it won't mask the test signals. Using the sound level meter, measure and record the noise level over a period (often several minutes to an hour) that capture the typical ambient noise. Be aware that, other temporary ambient factors such as wind and rain may affect noise levels. You may refer to BS EN 60645-1: 2001 Electroacoustics - Audiological Equipment - Part 1: Pure-Tone Audiometers; and ISO 8253-1:2010 Acoustics- Audiometric test methods – Part 1: Basic pure tone air and bone conduction threshold audiometry for guide.

3. Use standard earphones. These are used especially for audiometric testing (supra-aural earphones). They ensure proper fit (earphones correctly positioned on the ears to avoid any gap that could affect the test results) and this helps to ensure that hearing tests are consistent and accurate as it should be. The standard, ISO 389-1: 2017 Acoustics-Reference zero for the calibration of audiometric equipment – Part 1: Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones; provides a guide.

11.2.6 Equipment needed for audiometry

1. Otoscope. This is a hand-held device with a light and magnifying lens. It is used to examine the ear canal and ear drum for any blockage, infections, or abnormalities before conducting hearing tests (see Table 11.2 for an example of checklist for otoscope).
2. Audiometer. A machine that delivers sound at different frequencies and loudness levels through headphones or insert earphones. It is used to measure hearing sensitivity and determine hearing thresholds.
3. Ear/headphones. Devices placed over or in the ears to deliver test tones. They are used to present pure tones, speech, or other sounds during hearing test. They are often preferred for their better noise isolation.
4. Bone conductor. A small device placed behind the ear on the mastoid bone. It is used to test bone conduction hearing, which helps differentiate between conductive and sensorineural hearing loss.
5. Sound level meter. A device that measures the level of ambient sound in the test environment. It helps to ensure the test room or booth meets the required noise level standards to avoid interference with test signals.
6. Era rinse kit. A set of tools including a syringe and saline solution. It is used to clean the ear canal by removing earwax or debris that could affect the hearing test results.

11.2.7 Needed competence

A physician or special trained nurse/audiologist is needed to perform otoscopy and audiometry of the person who is about to be examined. If there is much ear wax in the ear canal, it might be needed to remove it before the examination. Be aware that if the ear is rinsed using water, the audiometry should not be performed until at least 2 days after. Water may stay in the ear canal for quite some time and can interfere with the measurements.

Table 11.2. An example of simple checklist for ear screening and otoscopy before audiometry

Introduce and ask for consent		
Participant ID	Date: *dd:mm:yyyy*	
1. Screen for presence of upper airway and ear infection symptoms Ask: Are you currently having the following symptoms: a. Nasal discharge b. Ear discharge		
2. Ask about previous noise exposure (time lapse since being exposed to loud sound) in hours 3. Document if he/she used hearing protection devices last time at work		
4. Otoscopic examination		
a. Examine wax in auditory canal (<50% of tympanic membrane visible) of each ear	LEFT EAR RIGHT EAR	
b. Exudate in auditory canal?	LEFT EAR RIGHT EAR	
c. Examine tympanic membrane	LEFT EAR normal/scarred/perforated RIGHT EAR normal/scarred/perforated	
d. Other EAR observations and Comments		

11.2.8 Instructions told to the person before audiometry:

Do you hear better out of one ear than the other? (If yes, ask which ear. If no, then start with the right ear.)

You will be hearing some faint tones, first in your <better or right ear> and then in your <other or left ear>. The tones will be pulsing so that you will hear a chain of beeps and then silence. Listen for the beeps and when you hear them <press this button> to signal that, -Yes, I hear them. The beeps will generally get fainter and fainter each time they are presented. <Press this button> whenever you think you hear the beeps. The pitch of the tones will change, first going lower in pitch and then going higher in pitch.

The test of your <other or left> ear will not begin until your ear has been tested for all the frequencies. If you are certain that you hear the beeps, you don't have to wait for the beeping to stop to <press this button>. And you don't have to <hold the button down> for as long as you hear the beeps. A simple <press and release> will do. So, if you haven' t any questions, I will put the earphones on, and we can start the test. (Answer any questions.) Please wait for me to remove the earphones when the test is over.

11. 2.9 Audiometry screening procedure

a. Make the test person comfortable with the test environment
b. Inspect the audiometer and its accessories if it's OK
c. Put the audiometer ON
d. Go through the setting and approve
e. Ensure sequence of frequencies to be measured are correct i.e. 1,2,3,4,6,8 KHz and then back to 500 Hz, 250 Hz and finally 1KHz.
f. Press the earphones to the test person and provide him/her with a response button
g. Re check if LEFT earphone is worn to the LEFT ear and vice versa
h. Provide sample test tone
i. Agree with a test person on procedure
j. Start measurement systematically while recording results in audiogram paper or any other electronic means

11.2.10 Quality control

For ensuring accurate measurements, the audiometer should always be inspected. This can be done daily (check performance quality and devices such as headphones, connecting cables), or audiometer calibration dates (this should be adhered and compiled for better results).

11.2.11 Contraindication of pure tone audiometry

PTA might not be suitable for; -

1. young children: they cannot follow and comply with the test procedures

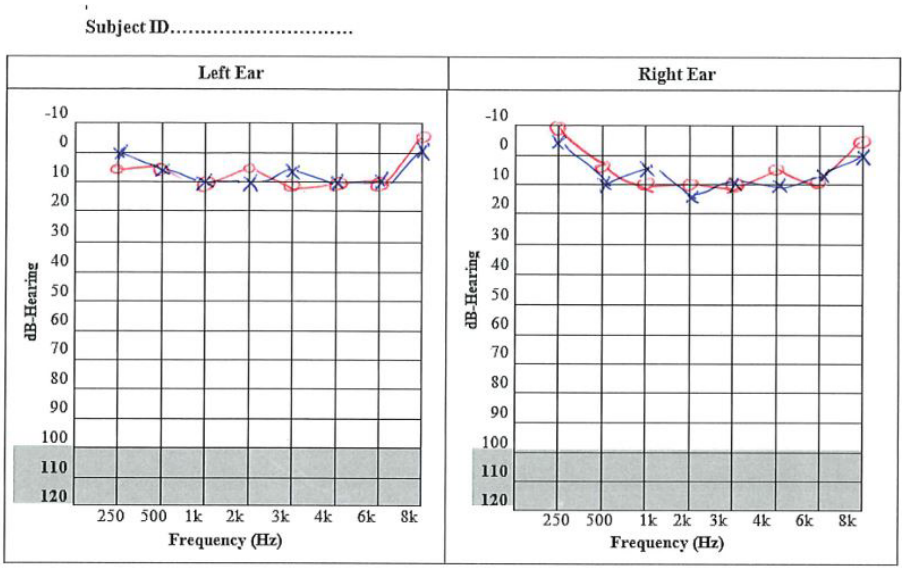
2. Agitated or confused individuals: people who are disoriented or agitated cannot provide reliable responses during test

3. Individuals with significant language comprehension impairments.

11.2.12 Audiogram report

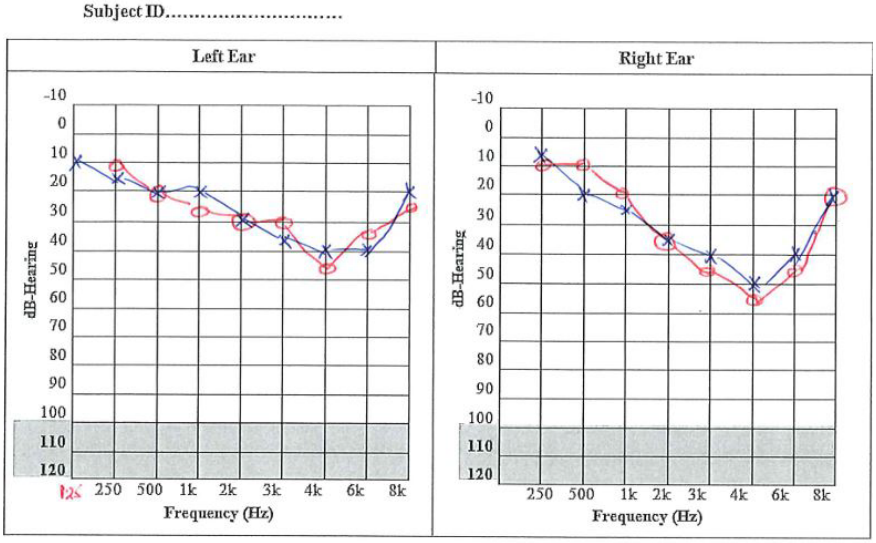
This is simply the graphical presentation of hearing sensitivity i.e., frequency (Hz) on x-axis and intensity (dB-HL) on the y-axis. It represents a picture of how a person hears at a given time and place under various frequencies tested.

11.2.13 Interpretation of audiogram



Audiogram Symbol and meaning

EAR	COLOUR	Air conduction		Bone conduction		No response at limits
		Unmasked	Masked	Unmasked	Masked	
Right	Red	○—○	△—△	]—[	>—>	↓
Left	Blue	X—X	□—□	[—[	<—<	↓
Remarks		Normal hearing audiogram				



Audiogram Symbol and meaning

EAR	COLOUR	Air conduction		Bone conduction		No response at limits
		Unmasked	Masked	Unmasked	Masked	
Right	Red	○—○	△—△	]—[	>—>	↓
Left	Blue	X—X	□—□	[—[	<—<	↓
Remarks		Noise induced hearing loss audiogram				

Figure 11.1. Normal hearing audiogram above, noise induced hearing loss audiogram below.
©IP Nyarubeli

11.3 Otoacoustic emissions

11.3.1 General concepts

Otoacoustic emission (OAE) is an acoustic energy generated by the outer hair cell receptor that disappears when the inner ear has been damaged (sounds are normally not produced in an individual with hearing loss > 25-30 dB). The presence of OAE means that the middle ear and cochlear respond normally to sound stimulation. This makes it easier to access the sensitivity of different auditory systems after exposure to high noise levels or ototoxic medicines. They can be either spontaneous OAE (SOAE), which occur continuously without external stimuli and can be measured with microphone placed in the external ear canal (500 – 4500Hz), or evoked OAE (EOAE), which requires an acoustic stimulus prior to its measurement (also categorized into transient evoked, distortion product, and stimulus frequency. In general, between 1-9% of individuals can perceive their SOAE as tinnitus while EOAE is commonly used and perceived to be effective and reliable for identifying hearing defects in infants and children below 3 years of age.

11.3.2 indication and contraindication

- **Indications**

1. Young children and newborn screening
2. Diagnosis and managing various pathologies across all age groups such as non-organic hearing loss (malingering), auditory neuropathy spectrum disorder (ANSD)
3. Functional assessment of the conductive mechanism in the ear.
4. Research purposes

- **Contraindications**

1. Middle ear dysfunction. Patient with middle ear issues e.g. Otitis media may show altered OAE responses
2. Tinnitus: It can interfere with OAE measurements
3. Outer ear infection: Active outer ear infection can affect OAE results
4. Hyperacusis

It worth to note that this method is seldom used in occupational health.

11.3.3. Hearing screening

OAEs are automated tests that assess hearing by delivering an acoustic stimulus through a small probe placed in the ear canal. The probe contains a speaker and a microphone to detect emissions. The systems produce an easily reproducible, non-invasive method to conventional hearing tests. OAEs provide a binary response (PASS or REFER) making them excellent for hearing loss screening.

- **PASS**= test protocol requires that three out of four bands or frequencies are detected indicating that there is a meaningfully low chance that they have a significant auditory disorder requiring amplification.
- **REFER**= detection criteria were not met likely due to existing hearing loss, testing conditions e.g. ambient noise or poor testing techniques.

11.3.4 Equipment and screening technique

The measurement equipment consists of a probe containing a microphone and speakers. The two play a crucial role in the system. The speaker generates the acoustic stimuli applied to the ear canal, while the microphone records the otoacoustic emission transferred back from the cochlear. The software then processes this information using averaging techniques, algorithms, and filtering to extract clinically useful information displayed on the device or computer screen.

11.3.4.1 Pre-test examination:

Perform otoscopy to inspect the ear canal for wax or other debris, or for any anatomical abnormalities. Check for ear drum perforation or any pathologic condition that can affect testing. At some times, impedance measurements may be necessary.

11.3.5 Test procedure

1. Probe placement: Insert the probe into the ear stimulator. Ensure you use the correct-sized cavity for accurate results. Attach an ear tip to the probe tip if required.
2. Protocol selection: Choose an appropriate or commonly used OAE test protocol. Consider the stimulus output level (system distortion depends on it).
3. Test execution: Start the test and allow it to run until it stops automatically.

11.3.6 Interpretation of results

OAEs results are usually categorized as

1. Present and normal: the recorded OAE meets criteria for detection and falls within normal range, the individual band or test frequency would be categorized as present and normal
2. Present and abnormal: The recorded OAE meets the SNR and other criteria for detection but falls outside the normal range.
3. Not present: The recorded OAE does not meet the criteria.

11.3.7 Clinical significance

The aim for OAEs screening is to separate individuals with auditory disorder that interfere with communication from those who do not. The screening is fast and inexpensive, provides ear-specific information, does not require behavioural response and is sensitive to outer cell function. The main challenge of OAE screening is the lack of specificity. There is a risk of sound contamination from internal sound or surrounding environment causing false positives. Distinguishing between OAE from background noise. OAE cannot distinguish between sensorineural and conductive hearing loss.

11.4 Tympanometry

11.4.1 General concepts

Tympanometry measures acoustic impedance (resistance of acoustic energy flowing from the ossicular chain to inner ear) and admittance (how easily the acoustic energy flows) in the middle ear. It is a clinical diagnostic method used to measure the physical properties of the middle ear system. It has shown to be widely used in evaluation of middle ear functioning during routine examination as it is cheap, quick and non-invasive. The

system comprises mechanical springs (tympanic membrane, ligament, muscles and tendons), mechanical mass (ossicles), acoustic springs (middle ear air volume) and middle ear volume. Some regulations such as in the UK recommend performing tympanometry in all adults and paediatric hearing assessment clinics as a prerequisite with audiometry where clinically indicated and prior to hearing aid fitting where indicated.
A single-frequency stimulus tone of 226 Hz was adopted as standard i.e., at this point, 1mmho is equivalent to the admittance of a 1cm3 volume of air at standard atmospheric pressure and room temperature suitable for ear canal examination> nevertheless, this does not apply to neonates under the age of 6 months due to highly compliant ear canals and therefore a 1KHz tone was chosen and can be able to distinguish between peaked and flat tympanograms.

Otoscopy and tympanometry give similar information. However, as the otoscopes are easy to access and easy to learn, the otoscope is more used today as a preparation part of the examination before audiometry.

11.4.2 Contraindication

Tympanometry may be contraindicated in patient with a variety of conditions which need careful screening and expert judgment such as perforation of tympanic membrane, Acute otitis media, presence of foreign body in the ear canal, otorrhea, acoustic reflex due to several medicines (alcohol, barbiturates), presence of wax or cerumen in ear canal, tinnitus, outer ear defects (stenosis or microtia), vestibular dysfunctions following ear trauma, history ear surgery and soreness in the ear among others.

11.4.3 Test procedure

11.4.3.1 Test equipment

A tympanometer is used to conduct the test and record the results. It has a probe with three ports: - a sound port that sends air into the ear canal, a speaker that sends tone towards eardrum and microphone port that records information on eardrum movements when responding to the air pressure.

11.4.3.2 Pre-test examination

1. Conduct otoscopy to inspect the ear canal for wax or other debris, or for any anatomical abnormalities.
2. Prepare effective communication strategy for your clients (consider, age, hearing level and language skills)
3. Request and document information for current ear related symptoms, ear surgery, recent illnesses related to respiratory system, any hearing difficulty

11.4.3.3 Test procedure

- Provide instructions. For example:

  "I am going to insert a soft tip into your ear canal. You will feel a small pressure in your ear for a while. You don't need to do anything, other than remain seated and calm. You may hear a sound, but you do not need to worry. The test takes a few seconds to a maximum of a minute to complete one ear. Should you find the procedure uncomfortable and want me to stop, please raise your hand."

11.4.4 Procedure

1. Insert the probe in the ear canal. The probe will create an airtight seal inside the ear canal.
2. The probe sends air into ear canal while emitting a low sound/ tone
3. The microphone records how eardrum moves in response to sound pressure
4. The tympanogram is created on the screen.
5. Test is complete

Note: This interpretation is usually subjective. Its interpretation must be carefully considered. It is necessary that other objective parameters are compared with normative data especially for children or adults and otoscopic information to interpret tympanogram fully. Interpretation of infant tympanometry should be done with caution as their ears are still compliant, hence what might be seen as a normal response may be misleading.

11.5 Auditory Brainstem Response (ABR)

There are several ways to identify hearing loss. Audiometry is the most common type of test of hearing in workplaces. However, there are alternatives that might be of interest, and one of them is to measure the auditory brainstem response (ABR). This is an emerging technology.

11.5.1 General concepts

The ear is made up of three different parts: The outer, the middle, and the inner ear. The auditory brainstem response test tells us how the inner ear and the brain pathways for hearing are working. It is an objective measurement, and there is no need for the test person to press a button or any such response for the measurement to take place. The expression auditory evoked potential (AEP) is also used for this test.

11.5.2 How the ABR is performed

You need to have a specific instrument, a type of electroencephalograph, for testing ABR. Specific electrodes must be put on the head of the test person. The electrodes are fastened to the skin using specific electrode gel and connected to the electroencephalogram computer. A positive electrode is placed at the vertex of the test person's skull, two electrodes are placed on the right and left earlobe or mastoids, and a ground electrode is placed at the forehead. The electrodes record brain wave activity in response to sounds the test person hears through earphones. The test person must lie down and rest during the test, be quiet and still and not say or do anything. The person doing the test will see the results on a computer screen and store the result in the computer and/or make a printout.
Five brain waves are registered in an ABR. The measurements done from an ABR are wave latencies, amplitudes, and intervals between the waves. Peripheral hearing loss presents with delayed latency of wave I or absence of all waveforms. Etiology can be conductive or cochlear pathology. Central hearing loss presents with a prolonged interwave peak between wave I to V.

11.5.3 Indications

The test is most often used for examinations of babies or other small children who cannot participate in a typical hearing screening. The ABR is also used in cases of suspected neurological abnormalities of the cranial nerve VIII

(acusticusneurinoma) and for diagnosis of different brainstem lesions.
In workplace settings, the test can be used for evaluation of the hearing of adults that are not able to follow instructions for audiometry due to mental problems. Also, the test can be useful if one suspects the worker of cheating and wrongly reports the hearing. This might happen if the worker can achieve benefits based on reduced hearing (e.g., compensation, new job).

11.5.4 Contraindications

ABR is not indicated for patients who can undergo traditional standard audiometry.

11.6 References

Saunders AZ, Stein AV, Shuster NL. Audiometry. In: Walker HK, Hall WD, Hurst JW, editors. Clinical Methods: The History, Physical, and Laboratory Examinations. 3rd edition. Boston: Butterworths; 1990. Chapter 133. Available from: https://www.ncbi.nlm.nih.gov/books/NBK239/

Salmon MK, Brant J, Hohman MH, et al. Audiogram Interpretation. [Updated 2023 Mar 1]. In: Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK578179/

World Health Organization, WHO: John. R. Franks(1996): Hearing Measurement in eds. preventing occupational hearing loss: a practical guide. Available from: (16) (PDF) Preventing occupational hearing loss: A practical guide (researchgate.net)

Jacobson JT. The Role of Immittance Audiometry in Detecting Middle Ear Disease. *Can Fam Physician* (1981) 27:103-9.

Young A, Cornejo J, Spinner A. Auditory brainstem response. StatPearls January 12, 2023. Bookshelf ID: NBK564321PMID: 33231991

Olusanya BO, Davis AC, Hoffman HJ. Hearing loss grades and the *International classification of functioning, disability and health*. Bull World Health Organ. 2019 Oct 1;97(10):725-728. doi: 10.2471/BLT.19.230367. Epub 2019 Sep 3. PMID: 31656340; PMCID: PMC6796665.

Barros SM, Frota S, Atherino CCT, F O: The efficiency of otoacoustic emissions and pure tone audiometry in detecting temporary changes after exposure to high sound pressure levels. *Rev Bras Otorrinolaringol* 2007, 73(5):592-598.

Young A, Ng M. Otoacoustic Emissions. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK580483/

Yasui T, Iwasaki S, Sugasawa K, Sakamoto T, Kashio A, Suzuki M, Kakigi A, Yamasoba T: Admittance tympanometry with 2-kHz probe tones in patients with low-frequency hearing loss. *Laryngoscope* 2012, 122(10):2252-2255.

Hamid M, Brookler KH: Auditory and vestibular medicine clinic:Tympanometry. *Ear Nose Throat J* 2007, 86(11):668-669. British Society of Audiology: Recommended Procedure: Tympanometry and Acoustic Reflex Thresholds, February 2024. Available from: OD104-35-BSA-Recommended-Procedure-Tympanometry-and-ART.pdf (thebsa.org.uk)

Chapter 12. Skin testing

Gro Tjalvin, Kaja Irgens-Hansen, Dorothy Ngajilo and Bjørg Eli Hollund

12.1 Contact dermatitis - general concepts

Contact dermatitis, commonly known as contact eczema, is a local inflammatory skin reaction resulting from direct and often repeated exposure of the skin to a substance. Two forms of contact dermatitis exist, namely, allergic contact dermatitis (ACD) and irritant contact dermatitis (ICD). They are clinically indistinguishable but have different pathophysiology and risk factors. ICD is the most common form of contact dermatitis, comprising 80 % of the cases of contact dermatitis. Epidemiological studies on occupational contact dermatitis often focus on hand dermatitis, as hands are frequently affected in the workplace. Allergic contact dermatitis of the hands is regarded as the most common occupational skin disease, with atopy often identified as an important risk factor.

Irritant contact dermatitis

Irritant contact dermatitis (ICD) occurs when the skin comes in direct contact with a substance that physically, mechanically, or chemically irritates the skin, causing the normal skin barrier to be disrupted. ICD is a non-immunologic skin reaction to toxic substances, either in low or high concentrations. Any substance, including water after long-term exposure, has the potential to cause skin irritation. These substances cause damage through different mechanisms, either by disrupting the epithelial barrier, by causing epidermal cellular damage or both. The exact mechanism of ICD is not well known; however, two mechanisms, either alone or in combination, have been proposed: damage to the barrier function of the stratum corneum of the skin and/or the direct effect of the irritant on the skin cells.

Occupational exposures contributing to ICD encompass a range of chemical agents prevalent in various workplaces. These include harsh cleaning agents and detergents, acids, alkalis, oils, organic solvents, oxidants, reducing agents and water (2). and industrial chemicals encountered in manufacturing and construction. Wet work is the most common skin irritant, and is a well-known risk factor in workplaces, for instance within healthcare, food service industry, and hairdressing. Wet work is defined as having wet hands more than 2 hours per working day, washing hands more than 20 times daily and using gloves more than 2 hours per working day. Wet work involves exposure to water, while physical, mechanical, and environmental factors may also contribute to the development of ICD. Friction and mechanical irritants arise from repetitive movements and tight gloves and clothing. Tight fitting may create an occlusive environment with skin irritation due to increased sweating. Environmental factors include exposures to heat, cold, humidity and UV radiation. Exposure to heat will contribute to sweating, while exposure to cold may lead to cracking of the stratum corneum. Irritants are found in several different workplaces. Different occupations

may develop ICD. Examples of workers who are exposed to irritants are workers exposed to cutting fluids in metalworking industry, workers exposed to medical disinfectants in healthcare, hairdressers who are exposed to soaps and shampoos, construction workers who can be exposed to concrete and cement and textile workers exposed to dyes.

Allergic contact dermatitis

Allergic contact dermatitis (ACD) is a delayed-type IV hypersensitivity reaction that occurs when the skin is re-exposed to an allergen to which it has been previously sensitized. The re-exposure activates the adaptive immune system, causing previously primed T lymphocytes to release a cascade of cytokines and proinflammatory factors. This leads to the formation of a well-defined erythematous plaque and intercellular oedema in the epidermis. The severity of the reaction depends on the properties of the allergen, the contact duration, and the host response, but it usually includes the formation of pruritic papules and vesicles.

ACD may be caused by several chemicals with allergenic components and can be found within different workplaces. Common contact allergens are metals (e.g. nickel, cobalt, and potassium dichromate), fragrances, preservatives (e.g. methylisothiazolinone, methyldibromoglutaronitrile and formaldehyde), resins (e.g. colophony and epoxy) and rubber components (e.g. thiurams).

12.2 Skin patch testing

Patch testing (PT) is the gold standard for identification of contact allergens which may cause allergic contact dermatitis (ACD). The skin patch testing involves placing small amounts of potential allergens on patches and placing them on the skin of the patient to see if allergic reactions develop.

12.2.1 Equipment preparation

Allergens must be identified and have a relevance to the patient's exposure and tested in the right concentration. There are different standard series of test reagents for such testing. The composition of such series varies from country to country. In addition to a standard series, additional series of allergens might be used. There are specific series of allergens for instance for hairdressers, dentists and bakers.

In addition, testing with the patients' own material is useful to expand the test battery. This is the only way to identify new allergens. When preparing for the testing, the patient can bring their chemicals into the original container, with a safety data sheet if possible. Most allergens are mixed in white petrolatum as a carrier (vehicle) (sometimes alcohol or water are used).

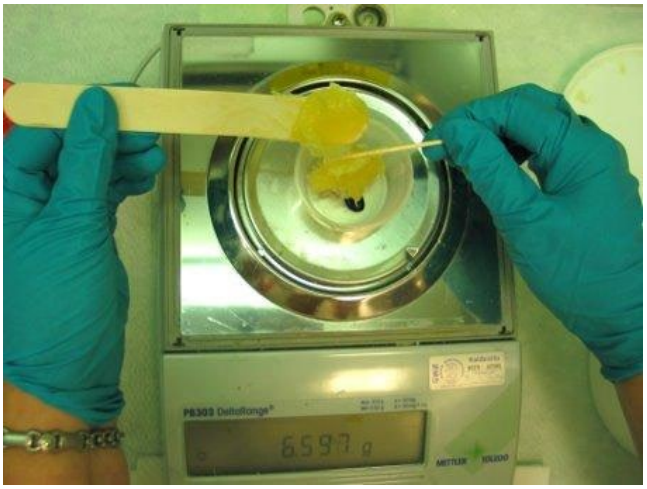


Figure 12.1. Preparing material for skin patch testing © BE Hollund

Liquid soaps, shampoos and shower gels can be tested at concentrations of 1-10% in water or petrolatum. Many solid materials can usually be tested as they are.

12.2.2 How to perform the skin patch test

a) Choose the test area. For few test products, the forearm might be used. If many substances are to be tested, the back is the best test area.

b) Clean and dry the chosen area.

c) Mark out squared patch areas on the skin test area with a filter pen, so you can recognize which product you have tested.

d) Apply a small amount of the product on the skin in each square area. Some use small aluminium cups with the products and fixate these on the skin with non-allergenic tape.

e) Leave the product on and cover the areas with gas patches if aluminium cups are not used.

f) Observe the reactions after 48 hours (96 hours might be used as well).

The patient must avoid bathing or showering during the observation period, and to avoid excessive exercise that might dislodge the allergen areas.

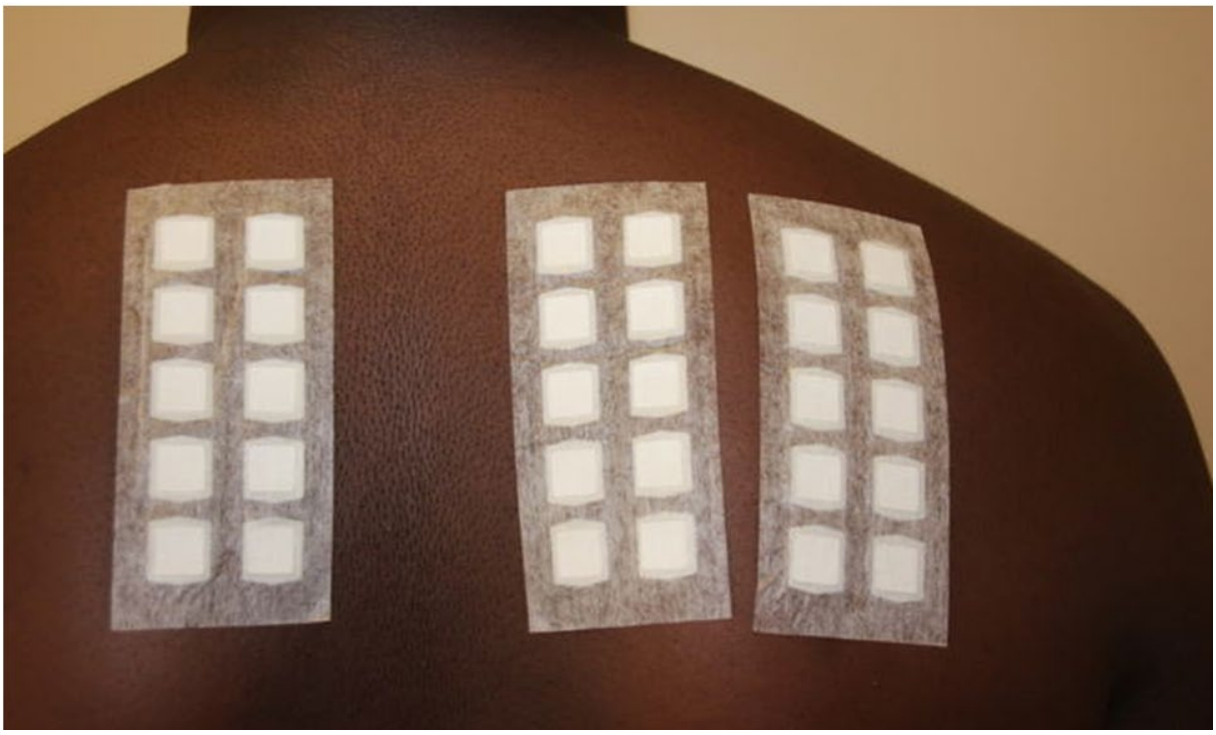


Figure 12.2. Skin patch testing on the back of a patient. © G. Tjalvin

12.2.3 Interpretation of skin patch test results

The patch testing is not difficult to perform, but the interpretation of the test requires some expertise. Physicians must have the necessary experience to interpret the results correctly. A positive reaction is a patch with visible dermatitis; with a red, vesicular or blistering area. Patch testing for skin of dark colour requires an understanding of morphological differences between a positive patch test results in

darker skin types compared to lighter skin types.

Be aware that a positive reaction is not sufficient for diagnosing occupational dermatitis. The Mathias criteria have been developed to establish occupational causation and aggravation of contact dermatitis (Table 12.1). At least 4 of 7 criteria in this table should be positive to conclude that contact dermatitis is most likely occupational.

12.3 Skin prick testing

12.3.1 General concepts

A skin prick test (SPT) detects the presence of allergen specific IgE (immunoglobulin E) on the patient's mast cells. If an allergen that the patient previously has been sensitized to is introduced through the skin, an IgE-mediated release of histamine is initiated from the mast cells, resulting in a wheal and flare reaction on the test site. This is known as an immediate hypersensitivity reaction, or Type I allergic reaction. Different allergens can be tested simultaneously because the resultant reaction to a specific allergen is localized to the immediate area of the SPT. A positive skin reaction implies that mast cells in other target organs (i.e., eyes, nose, lungs, and gastrointestinal tract) would also react upon exposure to that specific allergen. A Type 1 allergic reaction develops within a few minutes to approximately two hours after exposure to causative allergens.

12.3.2 Indications and contraindications

Indications:

SPT is indicated if the medical history suggests an allergic disorder that involves IgE-mediated immediate allergic reactions (Type I allergic reactions).

<u>SPT is used in the evaluation of (suspected):</u>

- Asthma
- Rhinitis and conjunctivitis
- Food allergies
- Occupational allergies (e.g. high molecular weight antigens, such as plant material (e.g., flour; wheat, rye, barley), mould (e.g., Alternaria, Cladosporium), animal proteins (e.g., laboratory animals (especially rodent urinary proteins), farm animals, fish, insect pests such as cockroaches, mites etc.), and enzymes (e.g., α-amylase)
- Some medication allergies (e.g. penicillium)
- Venom allergies (e.g. wasps, bees)

Contraindications:

The procedure is generally safe but should not routinely be performed in patients who are at high risk for an anaphylactic reaction to testing.

Relative contraindications include cardiovascular disease, and pregnancy, due to greater risk in the event of an anaphylactic reaction.

12.3.3 Equipment preparation

The equipment needed to perform SPT includes allergen extracts, positive and negative controls, special lancets, sharps

container, wipes to remo ve excess solution, timer with alarm, marking pen, scotch tape, ruler, and SPT results sheet. (Figure 12.3).

Figure12.3. The equipment needed to perform a skin prick test includes allergen extracts, positive and negative controls, special skin prick lancets, sharps container, wipes to remove excess solution, timer with alarm, marking pen, scotch tape, ruler, and SPT result sheet. © G. Tjalvin

Standardized allergen extracts are preferred when available. The expiry date of the extracts should always be checked. To improve the stability of the extracts, they should be stored in a refrigerator at 2-8°C when not in use.

12.3.4 Patient preparation

Before performing the test, the clinician should verify that the patient has not been taking any medications that might interfere with the test result.

<u>Recommendations on medications that possibly interfere with SPT:</u>

- Stop allergy medication (antihistamines) generally 7 days before SPT
- Stop H2-antihistamines (e.g., ranitidine) for 24 hours before SPT
- Stop anti-depressants with H1-antihistamine activity (e.g., tricyclic antidepressants and tranquilizers) 7 days before SPT (if possible)
- Avoid use of high potency topical steroids, 3 weeks before test, in places where the tests are to be applied

The SPT must be performed on normal skin, and not on skin with active dermatitis, severe dermographism and tattoos.

12.3.5 Performing skin prick test

After marking the test sites on the volar surface on the forearms, droplets of positive control (histamine), negative control (diluent identical to that of the allergen extracts) and allergen extracts are applied to the skin.

Both a positive control and a negative control is mandatory to confirm that the patient's skin is normally responsive.

The droplets must be placed 2 cm or more apart, and not within 5 cm of the wrist and 3 cm of the antecubital fossa.

A puncture device (special metal lancet) is pressed through the droplet at a 90° angle to the skin with gentle pressure for 1 second, and then pressed through the skin once more at least 2 cm aside, to make a duplicate of the test. A new lancet must be used for each extract, and the used ones are discarded into a sharp's container. Excess solution from the droplets must be wiped away sideways.

A timer with alarm should be used to make sure that all test results are read 15-20 minutes following application. A positive test appears as a wheal and flare reaction (Figure 12.4). The wheal is a smooth, slightly elevated area which is redder or paler than the surrounding skin. The flare is the red zone surrounding the wheal reaction. The size of the wheals is measured in millimetres (mm) using a ruler.

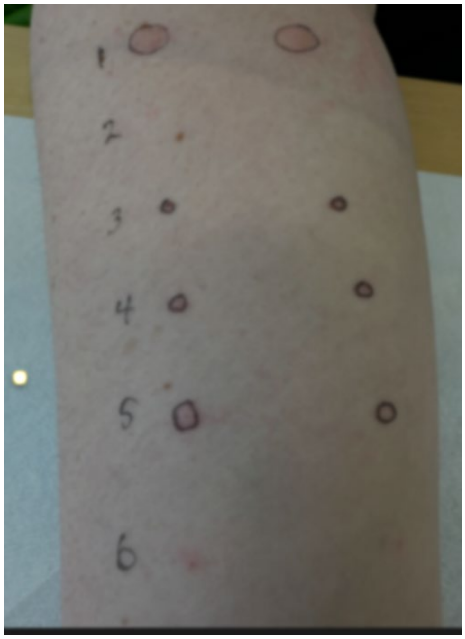


Figure 12.4. Results from skin prick testing. This patient has a positive SPT for extract 5, indicated by a wheal that is > 3mm. For extracts 3, 4 and 6 the SPT is negative, indicated by no wheal (6), or a wheal < 3 mm (3 and 4) with a simultaneously positive control (1) of at least 3 mm. © G. Tjalvin

12.3.6 Quality check

Potential error sources that might influence the results of a skin prick test:

- Tests that are placed too close together (< 2 cm) might cause overlapping reactions
- Insufficient penetration of the skin, leading to false negative results
- Spreading of allergen when excess solution is wiped away (cross-contamination between drops of different allergens)
- Induction of bleeding might lead to false positive results (- and increased risk of a systemic reaction)
- Interfering medications

12.3.7 Interpretation of results

The positive and negative controls should be measured first to make sure that the results can be relied upon.

The positive control should be positive (≥ 3mm) to verify that the test extracts are applied correctly and to exclude a negative result due to interfering medications.

The negative control should be negative to verify that there is no dermographism.

For clinical purposes a positive test can be defined as a wheal that is ≥ 3mm. (Figure 12.4).

A test is negative if there is no wheal or the wheal is < 3 mm with a simultaneously positive control of at least 3 mm.

The most common cause of a false negative test is that the patient has used a drug that inhibits the effects of histamine (e.g., antihistamines).

A positive SPT by itself, is not sufficient to make an allergy diagnosis as it only indicates the presence of IgE specific to that allergen (i.e., sensitization). Positive skin tests must be supported by an appropriate clinical history of reactivity and, in some cases, an allergen challenge, to confirm that the suspected allergen causes symptoms.

12.4 Criteria for the dermatitis diagnosis

Tests like the ones described in this chapter can be a good support to set a diagnosis. However, test results are not sufficient for a diagnosis, and different criteria have been developed for this purpose. Here is one example, the Mathias Criteria, developed by the dermatologist Toby Mathias in Spain, 1989 (Tab. 12.1). Four of these criteria must be positive for the diagnosis of occupational dermatitis.

Table 12.1. The Mathias Criteria for dermatitis diagnosis

Question	**Possible answers**
1. Is the clinical appearance consistent with contact dermatitis?	Yes: Identification of clinical features of eczema (pruritus, erythema, vesicles, exudation, crusting, signs of lichenification). No: Clinical appearance is not eczematous. Don't know: Seborrheic dermatitis, dyshidrotic eczema, nummular eczema, atopic eczema, and neurodermatitis all have clinical patterns that resemble an eczematous reaction.
2. Are there workplace exposures to potential cutaneous irritants or allergens?	Yes: The physician should inquire about all sources of workplace exposure, including personal protective equipment, creams, and soaps. It is important to be familiar with the toxicological data on these products. No: Toxicological data and/or clinical experience indicate that there is no irritant or allergic exposure at the workplace. Don't know: If the physician is unable to determine whether there is workplace exposure to irritants or allergens, this criterion should not be assessed.
3. Is the anatomic distribution of dermatitis consistent with cutaneous exposure in relation to the job task?	Yes: Contact dermatitis is usually more severe on surfaces that are exposed at work. No: Dermatitis spares skin surfaces with the greatest exposure but affects others. Don't know: There are exceptions to the above statement, for example, more permeable areas such as the eyelids, the face, and the genitals.
4. Is the temporal relationship between exposure and onset consistent with contact dermatitis?	Yes: The exposure preceded the onset of the symptoms. In the case of allergic contact dermatitis, the expected latent period can be as long as 6 months. No: Most of the symptoms occurred before exposure at the workplace. Don't know: If the latent period is more than 6 months, it will be difficult to establish a causal relationship. Workers aged between 50 and 60 years may have greater skin sensitivity due to age.

5. Are nonoccupational exposures excluded as probable causes?	Yes: Other irritants such as cosmetics and glues must be excluded by a thorough nonoccupational history and on occasions patch testing. No: Nonoccupational exposures may be the cause of dermatitis. Don't know: Without a thorough exposure history, the physician cannot confidently exclude a nonoccupational cause.
6. Does dermatitis improve away from work exposure to the suspected irritant or allergen?	Yes: There is improvement during leave, weekends, holidays, etc. No: The dermatitis does not improve after the removal of the workers from the workplace. Improvement may not be seen for up to 3 or 4 weeks in the case of chronic dermatitis. Don't know: Improvement off work or with workplace modifications are sometimes due to medical treatment.
7. Do patch or prick tests implicate a specific workplace exposure?	Yes: A positive patch test supports a causal relationship only when the exposure occurs at the workplace; it does not indicate the source of exposure. A provocation test can be useful for confirming a probable source of exposure to an allergen identified by the patch test. No: A causal relationship is not likely if the results are negative. Don't know: Incomplete studies, false positive or false negative results.

12.5 References

Aalto-Korte K, Suuronen K, Frosch PJ. Patch testing with the patients' own products. Contact dermatitis, 2020: 551-569.

Ansotegui IJ, Melioli G, Canonica GW, Caraballo L, Villa E, Ebisawa M, et al. IgE allergy diagnostics and other relevant tests in allergy, a World Allergy Organization position paper. World Allergy Organ J. 2020;12(2):100080.

Antonov D, Schliemann S, and Elsner P. Contact dermatitis due to irritation. Kanerva's Occupational Dermatology 2020: 1-20.

Bains S. N., Nash, P. & Fonacier L. Irritant contact dermatitis. Clin Rev Allergy Immunol 2019; 56: 99–109.

Heinzerling L, Mari A, Bergmann KC, Bresciani M, Burbach G, Darsow U, et al. The skin prick test - European standards. Clinical and translational allergy. 2012;3(1):3.

Inger A, Merims S. The validity of the Mathias criteria for establishing occupational causation and aggravation of contact dermatitis. Contact Dermatitis 2004;51, 3 August.

Kowal K, DuBuske L. Overview of skin testing for IgE-mediated allergic disease. UpToDate. Available from: https://www.uptodate.com/contents/5541 (2022)

Menné T, Johansen JD, Sommerlund M, Veien NK; Danish Contact Dermatitis Group. Hand eczema guidelines based on

the Danish guidelines for the diagnosis and treatment of hand eczema. Contact Dermatitis 2011 Jul;65(1):3-12.

Patel K, Nixon R. Irritant Contact Dermatitis - a Review. Curr Dermatol Rep 2022;11(2):41-51.

Uter W, Wilkinson SM, Aerts O, Bauer A, Borrego L, Brans R, Buhl T, Dickel H, Dugonik A, Filon FL, Garcìa PM, Giménez-Arnau A, Patruno C, Pesonen M, Pónyai G, Rustemeyer T, Schubert S, Schuttelaar MA, Simon D, Stingeni L, Valiukevičienė S, Weisshaar E, Werfel T, Gonçalo M; ESSCA and EBS ESCD working groups, and the GEIDAC. Patch test results with the European baseline series, 2019/20-Joint European results of the ESSCA and the EBS working groups of the ESCD, and the GEIDAC. Contact Dermatitis. 2022 Oct;87(4):343-355.

van Kampen V, de Blay F, Folletti I, Kobierski P, Moscato G, Olivieri M, et al. EAACI position paper: skin prick testing in the diagnosis of occupational type I allergies. Allergy. 2012;68(5):580-4.

Chapter 13. Vibration Related Disorders

Bente E. Moen

13.1 General concepts

Exposure to vibration at work may cause health problems. These are often described as two types: Hand-arm-vibration syndrome caused by local vibration exposure to the hands of the worker, and low-back pain related to vibration exposure to the whole body. Some of the diagnostic examinations mentioned here require special competence and equipment and need to be done by medical specialists. This scientific area is of interest for research in occupational health, as many issues related to the health effects from vibration are not well-known.

13.2 Hand-arm vibration syndrome

Hand-arm-vibration syndrome (HAVS) is an expression of dysfunction of vessels, nerves and the musculoskeletal system in the hand and arm, caused by exposure to vibration from hand-held tools. How long the exposure may take place before the symptoms start is not clear. Workers seem to develop symptoms at quite a young age if the exposure is high. HAVS has been seen after 1-2 years of exposure.

HAVS occurs among workers who operate hand-held vibrating tools. Examples of such tools are drills, chain saws and grinders. Workplaces where this exposure occurs include agriculture, mining, construction, and forestry. The prevalence of HAVS might be high at such workplaces but the prevalence varies a lot in the different studies. Studies from cold countries like Sweden and Canada report high prevalence of HAVS, while in other countries the prevalence is unknown. The first HAVS patients in South Africa were diagnosed in 2003, in a group of gold miners, and the disease seemed not to be well known in that country.

13.2.1 Symptoms of HAVS

HAVS may appear as attacks of vasospasm of the fingers, causing white, numb fingers (also called Raynaud's phenomena). The attacks are often very painful and lasts 5-15 minutes. Workers who develop such problems may also develop a diffuse peripheral neuropathy, giving tingling and numbness in the fingers and hands. Musculoskeletal symptoms may also develop, such as pain, reduced strength and stiffness in the hands and wrists. Pain may also develop in the elbow and shoulder.

13.2.2 Health examinations

It is difficult to find objective signs of HAVS, as the disease appears by attacks related to vibration exposure. Between the attacks, the worker might have "normal hands". Therefore, the interview is very important. The workers need to tell their story and describe the symptoms.

These examinations are suggested to disclose the problems:

-Interview: Exposure to vibration, development of symptoms.

-Clinical examinations: Observation of skin and function of hands and arms. Neurological examination, focusing on testing sensitivity, vibration, grip strength, temperature sensitivity, two-point discrimination.

For those who want to learn about neurological examinations, there is a free online book here: Neurology in Africa by William Howlett: https://www.uib.no/en/cih/72120/book-neurology-africa Chapter 11 is about Disorders of peripheral nerves, which is relevant for studies of the effect of vibration on the workers.

-Cold provocation test: Exposing the hands of the workers to ice-cold water may provoke the vasospasm. This test has low sensitivity, a large part of patients with HAVS may not respond to this test. However, it is used a lot in cold countries to verify the existence of the disease.

-Pegboard test: This test is a psychomotor test which may help to detect the overall dexterity and hand function. This test might be performed by any physician/ nurse, and only a wooden or metal peg board is needed. The pegboard consists of a board with five parallel rows with 5 holes in each row into which cylindrical metal pegs are placed by the person examined. The test involves a total of four trials. To begin, there is a brief practice. The subsets for preferred, non-preferred, and both hands require the patient to place the pins in the holes as quickly as possible, with the score being the number of pins placed in 30 seconds

In addition, blood tests are recommended to rule out other diseases causing the symptom: A complete blood count, erythrocyte sedimentation rate, measurement of antinuclear antibody, rheumatoid factor, cryoglobulin, cold agglutinin, glucose, thyroid-stimulating hormone, vitamin B12, and red blood cell folate levels.

Sometimes, X-rays of hands and arms also might be useful.

Some specialists in occupational medicine or neurology have access to and are competent to perform other examinations:

Vibrameters can be used to detect a reduced threshold for vibration. The nerve conduction velocity can be measured by specific instruments to detect sensory and motor disturbances. -Doppler ultrasound and digital plethysmography (often used after cold water stress) can be used to show reduced blood flow.

These examinations may help in evaluation of the seriousness of the disease, and also help to find differential diagnoses.

13.2.3 Diagnosis and grading of HAVS

In many countries HAVS is defined as an occupational disease, and the workers with this disease might be compensated by their authorities. This makes it important to make the correct diagnosis and to grade the function level of the worker. For classification of HAVS, Stockholm Workshop Scale, (Table 13.1) is often used. This scale describes the seriousness of HAVS and is also useful in evaluation of the progress of the disease. In addition, many physicians use drawings of the hands to register which hand, and which fingers are affected and how much.

In many countries, four diagnostic criteria must be present for the diagnosis of HAVS:

1. Sufficient vibration exposure by hand-held equipment must have occurred.
2. Typical symptoms and development of these.
3. A relation between vibration exposure and development of symptoms.
4. No other disease can explain the symptoms.

Table 13.1. Stockholm Workshop Scale; each hand should be graded separately.

A) Classification of cold-induced Raynaud's phenomenon in HAVS
B) Sensorineural stage in HAVS

A)		
Stage	**Grade**	**Description**
0	None	No attacks
1	Mild	Occasional attacks affecting the tips of ≥1 finger
2	Moderate	Occasional attacks affecting distal and middle phalanges of ≥1 finger
3	Severe	Frequent attacks affecting all phalanges of most fingers
4	Very severe	As stage 3, with trophic changes of the fingertips
B)		
Stage	**Description**	
0SN	Exposed to vibration but no symptoms	
1SN	Intermittent numbness with or without tingling	
2SN	Intermittent or persistent numbness, reduced sensory perception	
3SN	Intermittent or persistent numbness, reduced tactile discrimination or manipulative dexterity	

13.3 Whole body vibration and low back pain

Whole body vibration at workplaces occurs for instance during driving vehicles. Drivers of tractors, trucks and different kinds of lorries may cause high exposure to the whole body of the driver. The exposure levels depend on several factors, for instance the vehicle, how it is designed, the surface it drives on and the speed. Whole body vibration exposure may also occur among seamen of fast-going vessels and helicopter pilots.

13.3.1 Symptoms

There are several studies of workers who have been exposed to whole body vibration and possible health effects. The results differ, but several studies suggest a relationship between the vibration and development of low back pain. However, the different studies are inconsistent and not conclusive, and the mechanism behind the vibration and the low back pain is not clear. One theory is that the vibration causes increased frequency of lumbar prolapse, intervertebral disc damage and spinal degeneration. Low back pain is the health effect examined most, other symptoms mentioned in the studies are for instance headache, sleep, and visual disturbances.

13.3.2 Examinations

There is no specific test for the diagnosis of low back pain due to vibration, the story told by the patient is therefore very important. The following factors are of importance in the examination:

-Interview: Exposure description, which vehicles, how long exposed daily and how many years. Development of pain in the lower back and influence of daily functioning.

-Clinical examination: General clinical status, neurological status.

-X-ray of the spine might be useful, to describe the objective findings, and also for differential diagnoses. However, these may not be present, and the worker may still have major pain.

-Magnetic resonance imaging can be of help where this method is available.

13.3.3 Diagnosis and compensation

Several countries with compensation systems for occupational diseases do not include low back pain due to whole body vibration exposure. This is due to the lack of good research in the area and of the differing results from the studies. However, in the countries that accept this disease as an occupational disease, it is required to document the exposure, the pain and dysfunction due to the disease and that no other diseases or explanations cause the low back pain.

13.4 References

-Burström L, Järvholm B, Nilsson T, Wahlström J. White fingers, cold environment, and vibration—exposure among Swedish construction workers. *Scand J Work Environ Health* 2010;36(6):509-13.

-Burström L, Nilsson T, Wahlström J. Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis. Int Arch Occup Environ Health 2015 May;88(4):403-18.

-Gemne G, et al. Stockholm Workshop scale for the classification of cold-induced Raynaud's phenomenon in the hand-arm vibration syndrome (revision of the Taylor-Pelmear scale). Scand J Work Environ Health 1987; 13: 275-8.

-Lichty PD. Injuries Caused by Physical Hazards. In: Ladou J, Harrison R (eds) Current Occupational and Environmental Medicine, McGraw Hill, 5th Edition, San Francisco, 2014:193-195.

-Nilsson T, et al. Hand-arm vibration and the risk of vascular and neurological diseases - A systematic review and meta-analysis. PLoS One 2017; 12: e0180795.

-Rehn B, Nilsson T, Olofsson B, Lundström R. Whole-body vibration exposure and non-neutral neck postures during occupational use of all-terrain vehicles. Ann Occup Hyg 2005;49(3):267-275.

-Qamruddin AA, Nik Husain NR, Sidek MY, Hanafi MH, Ripin ZM, Ali N.Prevalence of hand-arm vibration syndrome among tyre shop workers in Kelantan, Malaysia. J Occup Health 2019 Nov;61(6):498-507.

Chapter 9.4 Vibration. In: Gardiner K, Rees D, Adisesh A, Zalk D, Harrington M. Pocket consultant Occupational Health, 6th Edition. Wiley Blackwell, 2021; pages 195-205.

Chapter 14. Visual Fitness Assessment

Vilhelm Koefoed and Ole Jacob T. Møllerløkken

Vision is vital, and several occupations have special requirements for visual fitness. Such occupations include drivers (buses, trucks, and trains), pilots, sailors, and crane operators. Assessment systems must detect reduced visual performance in professions that rely on good visual fitness to avoid occupational hazards.
The visual fitness assessment typically includes visual acuity, colour vision, field of view, eye motion and need for refractive correction, and may include additional tests for contrast sensitivity, stereo vision, and dark vision adaptation. In occupational medicine, this type of testing is most often performed as a part of a health examination needed for the worker to achieve a health certificate.

14.1 General concepts

The visual system comprises multiple optical and neural structures and pathways. All these are specialised and follow a hierarchical organisation from the tear film to the brain's visual cortex. Each part of the visual system may cause reduced visual performance. This chapter does not aim to describe the function of the visual system in detail. Still, understanding the visual function is essential for understanding the results of visual fitness assessment. Assessment testing should always be done by or supervised by a medical doctor who understands the visual system as part of their education.

14.2 Indications and contraindications for examination of visual fitness

Indications for visual fitness assessment vary with the purpose of the test. A visual evaluation is often performed on a clinical suspicion from a doctor or as part of a general health check-up organised by the authorities. Most countries also have legal visual requirements for getting a licence or authorisation to perform an occupation or activity.
In addition, some employers have visual fitness standards and will require an assessment of visual function.
Generally, there exist no contraindications to do the tests. Still, the tests depend on active participation and cooperation from the tested person. The fitness assessment may be challenging for children and persons with limited ability due to psychic or mental disorders.

Visual acuity (**VA**) commonly refers to the clarity of vision. Still, it technically rates a person's ability to recognise small details precisely.

Visual acuity is tested by reading charts at near or far distances. Visual acuity depends on optical and neural factors. Common causes for reduced VA are refractive errors or opacities of the optic pathway. Refractive error is the most common cause for reduced VA.

Light is refracted mainly by the cornea and the eye's lens. When this refraction is misaligned with the size of the eye, the result is a refractive error. The result of which is blurred vision either of objects close to the eye (hyperopia), blurred vision of distant objects (myopia), distorted image due to an irregularly curved cornea (astigmatism) or difficulty reading or seeing at arm's length from the eye (presbyopia). Refractive errors can be congenital, due to injuries or diseases, or caused by ageing.

Refractive errors are essential to diagnose since they cause poor visual development in childhood and poor visual performance in all ages. Often refractive errors can be challenging to diagnose. When they are congenital or in early childhood, parents often notice that their child seems to have poorer vision or a squint, but this is not always easy. Usually, refractive error is diagnosed by regular childhood health check-ups. In adults, the onset of refractive error is often not noticed. The person might complain of headaches, tiredness, or dizziness. These symptoms may be due to the eyes working hard to compensate for the refractive error. After assessment and later correction with glasses, these symptoms tend to disappear.
Refractive errors can mostly be corrected by optical means (such as eyeglasses, contact lenses, and refractive surgery).

Colour vision is the ability to perceive differences between light composed of different frequencies independently of light intensity. Colour perception is a part of the neurological visual system. It is mediated by a complex process between neurons that begins with the differential stimulation of different photoreceptors by light entering the eye.

Colour vision deficiency (**CVD**) is the decreased ability to see colour or differences in colour. The most common cause is a genetic inhered variation. Ishihara figures test colour vision.

14.3 Equipment for testing vision

An ophthalmoscope, Snellen or EDTRS chart and Ishihara test figures are frequently used equipment. The instruments must be functional and clean, and the room's light conditions must be appropriate.

When using the ophthalmoscope, the doctor/tester is seated directly in front of the test person; often, it is functional to have the test person on a fixed seat while the tester has a movable seat.

When using the Snellen chart, the test person must be at a fixed distance from the board, most often 6 meters (20 feet). The board must be illuminated, and the light conditions in the room used must be comfortable. The test requires much concentration and is best performed in a room without distractions.

The Ishihara test is done with the doctor displaying test figures to the test person sitting at a table. The room needs comfortable light conditions and be without distractions. The best is to use a "daylight" bulb giving 6000 – 7000 colour temperature.

14.4 Patient preparation

The patient must be awake, concentrated and not influenced by drugs that enhance or decrease visual function and ability. The

tests can be done with or without corrective measures (glasses and contact lenses), and often it is required to do both.
The tests all demand cooperation from the test person and often verbal responses. It is important to use techniques adapted to different cultures and abilities. For instance, Snellen's cart for visual acuity has been developed differently for children and adults in various languages and using signs—the same for Ishihara colour test. The light conditions are essential, as is the technique the tester uses for increasing repeatability and confidence in the tests.

14.5 Inspection, motion, visual field, and stereo vision

Sitting comfortably opposite one another, the test of visual function starts with a visual inspection of the eyes.
A likeness of the two eyes, do they fixate when looking at a point, and are there any problems related to the eyelids or eyes inspected?
The ophthalmoscope can be used to inspect how light is refracted and the light reflex. The pupil should contract when exposed to light and retract when light is removed.

The red reflex can also be inspected. When the test person looks beyond you, the eyes should display a red reflex when light reaches the pupils. The reflex relies on the transparency of optical media. The red reflex is considered abnormal if there is an asymmetry between the eyes, dark spots, or a white reflex. More advanced inspection can also be done, but it is beyond the scope of this chapter.

The motion of the eyes is inspected by making the test person keep their head still and focus on a finger/pointer, which you move in different directions, making the eyes move to both sides, up and down and across. The eyes should move synchronised, and the person should not observe double vision.

Also, by focusing on the pointer or a finger, you can test the eyes' accommodation by moving the finger close to the eyes and further away. You should then see the lens contraction, which is done when the pointer moves close, and the person must contract the lens to see the pointer sharply. The lens will retract when the pointer moves away from the eye.

The visual field is inspected by sitting opposite the test person with the eyes in the same plane, approximately one meter apart. The tester and the test person must mask the same side (for instance, the tester's left eye and the test person's right eye). Both look directly at each other and keep their eyes fixated. The tester places his hand between them and moves it in the different visual field quartiles. By moving the hand in and out of the visual field in all directions, the tester can map how the visual field is. Given the tester has a normal visual field, the test person should be able to see the hand/fingers simultaneously as the tester.

Lastly, the tester can also test the depth vision of the test person. By holding a pointer/finger in front of the test person, the test person should be able to point at and touch the pointer without hesitation. To increase test difficulty, the pointer can be moved in different positions and distances from the test person, always making the

test person point at and touch the finger at each position.

14.6 Test of visual acuity

Figure 14.1. Snellen's chart. ©Colourbox

Snellen's chart is commonly used to test visual acuity. The test has objects or letters of black contrast on a white background, and the test person has a given distance from the board. One eye at a time is tested by asking the person to tell what object/letter the tester is pointing at, starting with the top letter and moving as far down the chart as possible. After testing each eye, the person should be tested using both eyes simultaneously. The test depends on cooperation between the tester and the tested person.
The test can also be done with correction (glasses/lenses) to investigate how the vision is with refractive correction.
However, the test may need to be revised by the possibility that the test person could both mask a good vision by responding deliberately wrong and hiding a poor vision by having trained and memorised the sequence of letters.

14.7 Colour Test

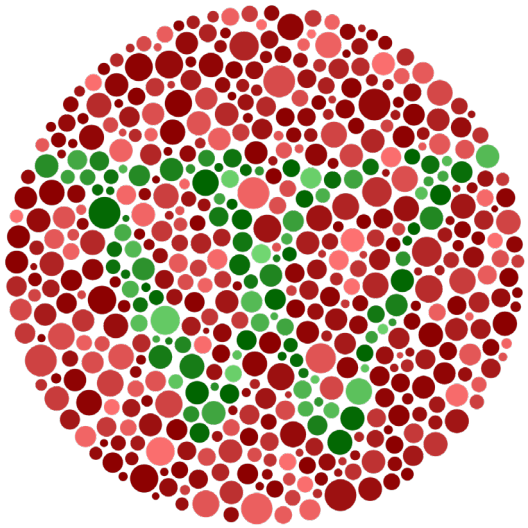


Figure 14.2. Ishihara colour test. ©Wikimedia Commons

The Ishihara colour test uses different plates of colours, which investigates the ability to distinguish colours from each other. The test comprises 10 – 38 different figures with different colours and numbers. It is recommended to only give the test person three seconds per figure for an answer, and it is best to present the figures in a random order. The test is excellent for detecting colour vision deficiencies but does not grade the degree of reduced colour vision function.

14.8 Interpretation of results

Since the tests depend on cooperation and many conditions, it is good practice to interpret the results cautiously. Typically, findings on these screening tests should lead to a referral to more accurate testing by ophthalmologists or optician specialists.

14.9 Other visual assessment techniques

There are several other and more advanced assessment techniques. New technologies have also improved the possibility of investigating the visual function. Contrast sensitivity function, advanced visual field, and fundus assessment can be done.

In the occupational setting, advanced technology, for instance, virtual reality, may be used to investigate the actual visual function when the test person performs the tasks in their occupation. Though, the evidence of such tests in visual fitness assessment is still low.

14.10 References

Cassel GH. The Eye Book: A complete guide to eye disorders and health. A John Hopkins Press Health Book 2021

Flach AJ. Test of visual acuity. In: Ladou J, Harrison R (eds). Current diagnosis and treatment. Occupational & Environmental Medicine, 5th Edition. McGraw Hill, 2014, pages 137-140.

Chapter 15. Heat-related symptoms and illnesses

Abera Kumie and Bente E. Moen

15.1 General aspects and definitions

As the temperature on our planet is increasing, the number of workers in hot climate areas is increasing as well. High temperatures at work can be a challenge for many workers outdoors, especially in agriculture, but also for instance in surface mining, quarry work, and building sites. Indoor working places can also be related to very high temperatures, such as work in smelteries, bakeries, and laundries. In addition, we have firefighters, with episodic exposure to high temperatures, when putting out fires.

The human body has a core temperature of 37°C. To maintain this temperature the body has several mechanisms. In the brain, heat sensors are in the hypothalamus. When temperatures exceed 37°C they send out warning signals which causes:

- Increased blood flow in the skin to increase heat loss (vasodilatation)
- Sweating (evaporation)

This way, the body copes with high temperature levels. Body heat balance is simply a balance between the body's heat gain and heat loss.

The heat load of a worker is a combination of factors:

- Air temperature
- Wind (air movement)
- Humidity
- Radiation (sun, machines, processes)
- Muscular work

Different important core temperatures for human beings are described in Table 15.1.

Table 15.1. Important core temperatures of humans

Temperature (degrees Celsius)	**Description**
46.5	Highest recorded survival temperature
43	Tissue damage (brain, liver)
41	Cessation of sweating
39	Threshold of hyperthermia
37	Normal temperature
35	Hypothermia

15.2 Heat illnesses

Very hot work conditions may cause serious health problems. Heat stress is the overall heat load on the body, in its mild form it is uncomfortable and may affect performance, but when it is more extreme the heat can be very dangerous and lead to heat stroke.

All workers and leaders should be aware of signs of heat stress to prevent the serious health effects from occurring. Signs of heat

stress are often treated simply by moving the worker to a cool place to relax and by giving him/her water and salt.

Working during hot temperatures will cause:

- Sweating
- Redness of face/skin (vasodilatation)
- Increasing heart rate (pulse)
- Electrolyte changes and dehydration.

The sweating, redness of the skin, and high pulse are easily recognized.

15.2.1 Dehydration

Dehydration can lead to the following consequences:

- Reduced blood volume
- Impaired cardiovascular stability
- Reduced physical and cognitive performance
- Reduced muscle and general endurance
- Elevated thermal strain at any given thermal stress
- Reduced heat tolerance
- Reduction in the benefits of heat adaption

A simple method to detect dehydration is to look at the urine of the worker. Dark colour is a sign of dehydration, as the urine becomes concentrated (Figure 15.1).

	Extremely dehydration
	Clearly dehydration
	Mildly dehydration
	Suspected dehydration
	Not dehydration

Figure 15.1. Urine colour chart suggesting dehydration or not. ©University of Bergen

Table 15.2. Critical thresholds for dehydration as % reduction in body weight (Taylor, 2005).

Percent reduction of body weight	**Body change**
3	Physical and cognitive performance starts to deteriorate. Occurs in about 45 minutes during heavy work without fluid replacement.
5	Severe degradation in physical and cognitive performance. Occurs in about 75 minutes during heavy work if fluids are not replaced.
10-15	Serious and dangerous dehydration approaching circulatory collapse. Occurs in about 150 minutes during heavy work if fluids are not replaced.
20	Potentially lethal dehydration associated with uncontrolled fluid loss, usually diarrhoea.

15.2.2 Heat stress and heat stroke

Heat stroke is a form of hyperthermia, an abnormally elevated body temperature with accompanying physical symptoms. Heat stroke is also sometimes referred to as heatstroke or sun stroke. Severe hyperthermia is defined as a body temperature of 40ºC or higher.
Heat stress or heat exhaustion is a less severe illness than heat stroke, but this can be the start of a heat stroke. Signs of heat stress are:

- Fainting (heat syncope)
- Heat rash (prickly heat)
- Nausea, vomiting
- Fatigue, weakness
- Headache, dizziness
- Muscle cramps and aches

Heat stroke, which is a state of thermoregulatory failure, is the most serious of the heat illnesses. Heat stroke is usually considered to be characterized by:

- High body temperature
- No sweating
- Red, hot skin with rash (tiny red spots)
- Difficulty breathing
- Strange behaviour, confusion
- Cramps
- Coma, death

These symptoms of heat stress should be known to workers and leaders, to prevent more serious health effects from occurring. Signs of dehydration and heat stress should lead to immediate action; by moving the worker to a cool place and by giving him/her water and salt.

15.2.3 Predisposing factors for heat illnesses

The effects and severity of heat on individuals depend on several factors, including age, gender, general health (including medical conditions, alcohol, caffeine and diet, nicotine use, and medication.

Age: Age as such is not the most important feature when assessing the susceptibility to heat strain. The physical condition of a person is more significant. As people get older, the personal factors of general good health, presence of diseases, and level of physical fitness are more important than simply the age itself.

Illnesses: Some physical disabilities, such as cardiovascular diseases can reduce the response to heat stress. Also, other chronic illnesses (e.g. diabetes mellitus) that reduce cardiac output or reduce circulating blood volume may reduce the coping ability of heat stress. Skin conditions such as sunburn and psoriasis can inhibit the body's ability to cool itself by sweating.

Gender: There is no difference in the tolerance levels of males and females.

Alcohol and diet: The consumption of alcohol prior to or even the night before undertaking
hot work should be discouraged. Drinks containing > 4% alcohol by
volume act as a diuretic and increase fluid loss. This may contribute to dehydration.

The consumption of a high- protein meal can place high demands on the water reserves of the body, as some water will be lost in excreting nitrogenous waste. High-fat foods take longer to digest, diverting blood supply from the skin to the gut, thus reducing cooling potential.

Caffeine: Caffeine is present in a range of beverages and is readily absorbed by
the body, with blood levels peaking within 20 minutes of ingestion. One
of the effects of caffeinated beverages is that they may have a diuretic
effect which may contribute to dehydration.

Nicotine use: Using nicotine tightens your blood vessels so the blood vessels in the skin cannot widen to let heated blood reach the surface to release heat. This might

make you more susceptible to heat-related illnesses.

Medications: Some medications can influence the hydration of the body and/or the cardiovascular system (e.g. blood pressure). This can make the worker more prone to develop dehydration and heat-related illnesses.

15.3 Guidelines from ACGIH

The American Conference of Governmental Industrial Hygienists (ACGIH) has provided guidelines relating to heat exposure. They suggest that exposure to heat stress should be discontinued when any of the following occurs:

-Sustained (several minutes) heart rate of more than 180 beats per minute (bpm) minus the individual's age in years (180 – age), for individuals with assessed normal cardiac performance; or
-Body core temperature greater than 38.5°C for medically selected and acclimatized personnel; or greater than 38°C in unselected, unacclimatised workers; or
-Recovery heart rate at one minute after a peak work effort is greater than 120 bpm: or
-There are symptoms of sudden and severe fatigue, nausea, dizziness, or light-headedness.

15.4 Heat stress index (HSI) - prevention

A heat stress index is a measure combining air temperature and relative humidity to determine how hot the temperature is experienced by the human body. It is a comparison of evaporation required to maintain heat balance with the maximum evaporation that could be achieved in that environment. This is a tool for combining the effects of temperature, humidity, and other environmental factors on the human body. However, although the HSI considers all these environmental factors and work rate, it is not completely satisfactory for determining an individual worker's heat stress and is quite difficult to use.
Another heat stress index, for threshold limit values, is made by ACGIH. The values are based on wet-bulb temperature (WBGT), and are based on a formula that includes the wet-bulb temperature T_{nwb}, the shielded dry-bulb temperature T_{db}, and black-globe temperature $T_{g,}$ which are measurements that account for effects caused by solar radiant heat, air velocity, relative humidity and ambient temperature. With direct exposure to sunlight, the formula is: $WBGT= 0.7T_{nwb} + 0.2T_g + 0.1T_{db}$. There are instruments that can calculate WBGT automatically for you.
We also have the heat index (HI), which is also called the apparent temperature or comfort index.
It is important to keep in mind that there are various heat stress indexes, and they have different definitions and applications. Many of them have been used in different types of research on health and safety in hot environments.
Normally, the measured temperature values needed for the calculation of these heat stress indexes are not available. A simpler method for evaluation of the risk of heat disorders is to use a chart to evaluate the working situation, based on temperature and humidity (Figure 15.2). When you use this chart, you should look for the temperature across the top, and then find the relative humidity on the left. The point where they intersect on the chart tells you the Heat Index, color-coded by the likelihood of a heat disorder. For example,

look at an air temperature of 37°C and Relative Humidity of 40%. The chart shows the Heat Index - how hot it feels - is 43°C, which is in the orange range for DANGER.

Be aware that these values are in the SHADE. You can add up to 8°C to these values if you are in direct sunlight.

		Temperature (°C)															
%		27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
REL. HUMIDITY	40	27	27	29	30	31	32	34	36	38	41	43	46	48	51	54	58
	45	27	28	29	31	32	34	36	38	40	43	46	48	51	54	58	
	50	27	28	29	31	33	35	37	39	42	45	48	51	55	58		
	55	27	29	30	32	34	36	38	41	44	47	51	55	58			
	60	28	29	31	33	35	38	40	43	47	51	54	58				
	65	28	30	31	34	36	39	42	46	49	53	58					
	70	28	30	32	35	38	41	44	48	52	57						
	75	29	31	33	36	39	43	47	51	56							
	80	29	31	34	38	41	45	49	54								
	85	29	32	36	39	43	47	52									
	90	30	33	37	41	45	49	55									
	95	30	34	38	42	47	53										
	100	31	35	39	44	49	56										

☐ Caution ☐ Extreme caution ☐ Danger ☐ Extreme danger

Figure 15.2. Heat Index Chart, developed by the U.S. National Oceanic and Atmospheric Administration (NOAA). It shows the likelihood of heat disorders with prolonged exposure and/or strenuous activity. ©Bente E. Moen

15.5 References

American Conference of Governmental Industrial Hygienists (ACGIH). TLVs and BEIs. Threshold limit values, 2017.

Gardiner K, Rees D et al. 9.2. Heat. In: Pocket consultant. Occupational health. Wiley Blackwell, 2022, pp 172-185.

Health and Safety Executive (HSE): Heat stress in the workplace A brief guide, 06/13. https://www.hse.gov.uk/pubns/indg451.pdf

Lichty PD. Disorders caused by heat. In: Injuries caused by physical hazards. In: Ladous J, Harrison R (eds). Current diagnosis & treatment. Occupational & Environmental Medicine. McGraw Hill, 2014, pp174-180

National Oceanic and Atmospheric Administration (NOAA). Heat Index, updated September 20, 2023. https://www.noaa.gov/jetstream/synoptic/heat-index

OSHA-NIOSH INFOSHEET: Protecting workers from heat illness. https://www.cdc.gov/niosh/docs/2011-174/pdfs/2011-174.pdf?id=10.26616/NIOSHPUB2011174 (retrieved 06.08.2024)

Contributors

Editorial team

Dr **Alexander M. Tungu** is a Senior Lecturer and researcher in the Department of Physiology, Muhimbili University of Health and Allied Sciences (MUHAS) in Tanzania. He has interest in Occupational Epidemiology and Respiratory Physiology. He has been a member of the Taskforce for Development of the Guidelines for Impairment and Disability Assessment and the Guidance Notes for Diagnosis of Occupational Diseases at the Workers Compensation Fund from 2016 to 2020. Dr Tungu has also been a member of the Medical Advisory Panel to the Workers Compensation Fund and the Occupational Safety and Health Authority in Tanzania since 2019. He has also worked as a Medical Officer at Morogoro Referral Regional Hospital from 2013 to 2015.

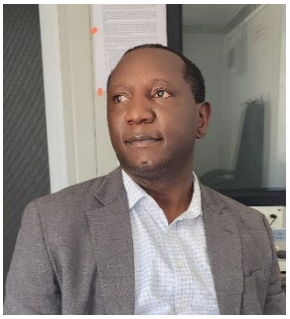


Photo: Private

Dr **Israel P. Nyarubeli** is an experienced Environmental and Occupational health specialist and Lecturer at the School of Public Health and Social Sciences, Muhimbili University of Health and Allied Sciences (MUHAS) in Tanzania. He has been engaged and leading several projects on occupational exposures to hazards and related health outcomes in different sectors since 2014 and a leader in government positions as Council head of department from 2012.

Photo: E. Bartle

Professor **Bente E. Moen** is a Professor in Occupational Medicine and Global Health at the Centre for International Health, University of Bergen in Norway. She has been a physician since 1982. She is working mainly in occupational epidemiology and with occupational exposure studies. She has established education in occupational health for medical students in Bergen and in an international Master's in Global Health. She is involved in research and training collaboration with universities in Eastern Africa and has been editor of several books in Occupational Health.

Photo: E. Senneset

Ms **Gunhild Kolda**l is a Senior Executive Officer in the administrative staff at the Centre for International Health (CIH), Department of Global Public and Primary Health Care, University of Bergen in Norway. She has been working at CIH since 2016 and associated with the Research Group of Occupational Medicine since 2012. She works with project administration for research projects, online courses, web editing and general centre administration.

Photo: Private

Professor **Magne Bråtveit** is a Professor at the Department of Global Public and Primary Health Care, University of Bergen in Norway. He has long experience in teaching and research in occupational health. He has specialised in occupational exposure assessments and has led several research projects in different industries. Since 1999 he has been responsible for an international master program in occupational hygiene where students from several countries in East Africa have completed the master's degree. The last 25 years he has been involved in occupational health research in various manufacturing industries in East African countries. He has supervised several PhD-candidates from collaborating universities in these countries.

Photo: Private

Dr **Samson Wakuma Abaya** (PhD), is an Environmental and Occupational Health Specialist and an Associate Professor at the School of Public Health, Addis Ababa University. He has served as a principal investigator for numerous national and international projects in the areas of environmental and occupational health and has over fifteen years of experience in this field.

Photo: Private

Co-authors

Professor **Simon HD Mamuya** is an Associate Professor and former Head of Department of Environmental and Occupational Health at Muhimbili University of Health and Allied Sciences (MUHAS). He has served as principal investigators for environmental research working with Stanford University on water quality and child health, NUFU project coordinator in Tanzania on work and health in dusty industries, Edulink as Train of trainer on Health of displaced population course, World bank on WASH and determinants in

Tanzania, World health organization as a lead consultant in writing Country workers' health profile. Currently, he is the coordinator of multi-countries research on assessing injuries and diseases affecting workers in developing countries. Also, he is currently a Norhed II coordinator for SAFERWORK project in collaboration with University of Bergen and Addis Ababa University.

Photo: Private

Dr **Bjørg Eli Hollund** works as an occupational hygienist at Haukeland University Hospital, department for Occupational Medicine. In nearly 40 years she has been engaged in Occupational Hygiene, in labour inspection, laboratory of occupational hygiene, University of Bergen and as a consultant in occupational health service, and different industries.

Photo: Private

Dr **Meaza Gezu Shentema** is a professional in the fields of Epidemiology, Environmental Health, and Occupational Health. She is an Assistant Professor of Public Health at the School of Public Health, Addis Ababa University. Currently, she serves as the Head of the Department of Preventive Medicine at the same institution. With a decade of experience in academia, Meaza has mentored many master's students and has co-led several research projects focused on environmental and occupational health.

Photo: Private

Dr **Ole Jacob Møllerløkken,** Associate professor, is Head of Public Health, Occupational- and Environmental Medicine, University of Bergen, Norway and Head of Section for Occupational- and Environmental Medicine, Helse Bergen HF, Norway. He is working mainly in occupational epidemiology and occupational exposure studies. He is currently responsible for the education in public health and occupational medicine at the University of Bergen, in addition to being a specialist in occupational medicine at the University hospital, Haukeland, in Bergen, Norway."

Photo: Private

Professor **Abera Kumie** is a national environmental Health Specialist who has served the Ministry of Health of Ethiopia for over 15 years. He joined Addis Ababa University in 2000 and completed his PhD in 2009. He is currently a professor of Environmental Health and has over 80 publications in areas of environmental health. He advised over 70 master's and 20 PhD students. His primary research area is on air pollution and environmental exposure assessment.

Photo: Private

Dr **Hussein Mwanga** is a Consultant Occupational Medicine Physician and a Senior Lecturer at Muhimbili University of Health and Allied Sciences. He holds a PhD in Public Health and a Master of Medicine (MMed) degree in Occupational Medicine from University of Cape Town. Dr Mwanga is also a Fellow of the College of Public Health Medicine of South Africa – Occupational Medicine [FCPHM (SA) Occ. Med]. Dr Mwanga's main research interests are in respiratory diseases, occupational allergies and exposure assessment for chemical agents.

Photo: Private

Dr **Gro Tjalvin** is an experienced senior consultant in Occupational Medicine and associate professor at the University of Bergen, Norway. At Haukeland University Hospital in Bergen, she specialises in evaluating patients with suspected work-related conditions, focusing on the respiratory system, allergies, and the nervous system. She is also dedicated to education, teaching master and medical students in Occupational and Environmental Medicine and leading a national course for physicians specialising in Occupational Medicine. Her research primarily centres on occupational epidemiology and exposure studies.

Photo: Private

Dr **Kaja Irgens-Hansen** is a specialist in occupational medicine and works as a senior physician at the Department of Occupational Medicine, Haukeland University Hospital in Bergen. She has a 50% position as an associate professor at the research group for Occupational and Environmental medicine, University of Bergen. She is an experienced researcher and physician and has specialised in noise-induced hearing loss as well as allergy and work-related skin diseases.

Photo: Private

Dr **Vilhelm F. Koefoed,** is a specialist in public health with expertise in contrast sensitivity and colour vision in occupational settings. He is a retired Surgeon Captain from the Royal Norwegian Navy, where he served as Head of Medical Services, he is currently a senior consultant at Haukeland University Hospital's Department of Occupational Medicine.

Photo: Private

Dr **Teferi Abegaz Shifaw** is an Occupational and Environmental Health Specialist and an Associate Professor at the School of Public Health, Addis Ababa University. Teferi has served for more than twenty years in the field of occupational health and safety. He led several nationally and internationally funded Road Safety and Occupational Health and Safety projects. Teferi has served in leadership and management positions at different levels, as a dean of the College of Health Sciences at Jijiga University. He is a member of the Technical Working Group on Occupational Health and Safety at the Ministry of Health and MoLS.

Photo: Private

Dr **Dorothy Ngajilo** is a board-certified Occupational Medicine Physician in Tanzania. She holds a Doctor of Medicine Degree from MUHAS, with Occupational Medicine specialty training from the University of Cape Town, South Africa. She is also a Fellow of the College of Public Health Medicine (Occupational Medicine) of South Africa. Dr Ngajilo has special interest in occupational health, safety and well-being of health workers and has worked with WHO in developing the global guide for the development and implementation of occupational health and safety programmes for health workers and providing technical support on occupational health for health workers to different countries.

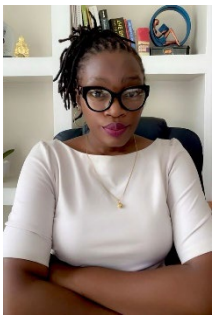


Photo: Private


አዲስ አበባ ዩኒቨርሲቲ
ADDIS ABABA UNIVERSITY


UNIVERSITAS
BERGENSIS


MUHIMBILI UNIVERSITY OF HEALTH AND ALLIED SCIENCES
ELIMU
TIBA
UTAFITI
MUHAS