RRC INTERNATIONAL

RRC Study Text

NEBOSH

International Diploma for Occupational Health and Safety Management Professionals

Unit ID2 - Part 2
Do - Controlling Workplace Health Issues (INT)

June 2021

nebosh

LEARNING PARTNER

GOLD 335

NEBOSH INTERNATIONAL DIPLOMA FOR OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT PROFESSIONALS

UNIT ID2 - PART 2

ID2 Learning Outcome 9.9

ID2 Learning Outcome 9.10

ID2 Learning Outcome 9.11

ID2 Learning Outcome 9.12

ID2 Learning Outcome 9.13

ID2 Learning Outcome 9.14

ID2 Learning Outcome 9.15

CONTRIBUTORS

Kevin Coley, MSc, BA, CMIOSH

For information on all RRC publications and training courses, visit: www.rrc.co.uk

RRC: ID2 - Part 2

ISBN for this volume: 978-1-912652-43-3
First edition June 2021

ACKNOWLEDGMENTS

RRC International would like to thank the National Examination Board in Occupational Safety and Health (NEBOSH) for their co-operation in allowing us to reproduce extracts from their syllabus guides.

This publication contains public sector information published by the Health and Safety Executive and licensed under the Open Government Licence v.3 (www.nationalarchives.gov.uk/doc/open-government-licence/version/3).

Every effort has been made to trace copyright material and obtain permission to reproduce it. If there are any errors or omissions, RRC would welcome notification so that corrections may be incorporated in future reprints or editions of this material.

Whilst the information in this book is believed to be true and accurate at the date of going to press, neither the author nor the publisher can accept any legal responsibility or liability for any errors or omissions that may be made.

ID2 Learning Outcome 9.9

ID2 Learning Outcome 9.10

ID2 Learning Outcome 9.11

Contents

ID2 Learning Outcome 9.12

ID2 Learning Outcome 9.13

ID2 Learning Outcome 9.14

ID2 Learning Outcome 9.15

Suggested Answers to Study Questions - Part 2

Learning Outcome 9.9

NEBOSH International Diploma for Occupational Health and Safety Management Professionals

ASSESSMENT CRITERIA

- Recognise when workplace monitoring for hazardous substances must take place.

LEARNING OBJECTIVES

Once you've studied this Learning Outcome, you should be able to:

- Explain how occupational exposure limits are used in the workplace.
- Outline the methods for the sampling of airborne contaminants.

Contents

Workplace Monitoring for Hazardous Substances

IN THIS SECTION...

- Occupational Exposure Limits (OELs) are standards for exposure to particular health hazards above which workers should not be exposed.
- Two OELs can be set for a chemical - a Long-Term Exposure Limit (LTEL) based on an 8-hour Time-Weighted Average (TWA) exposure; and a Short-Term Exposure Limit (STEL) based on a 15-minute TWA exposure.
- The concept of exposure standards.
- The meaning of Exposure Limits for airborne harmful substances.
- LTELs are used to control long-term exposure and the chronic ill-health effects that might result, whereas STELs are used to control short-term exposure that might create acute effects.
- The ILO Code of Practice - *Safety in the Use of Chemicals at Work* states that, "employers should monitor and record exposure of workers to hazardous chemicals to ensure their health and safety". In the UK the Control of Substances Hazardous to Health Regulations identify the legal requirement for monitoring.
- Selecting the right people to take part in personal monitoring/sampling. The use of a competent person to carry out monitoring. Gaining cooperation from workers when monitoring.
- The identification, measurement and evaluation of health hazards, and the subsequent design and testing of control measures is often the work of the occupational hygienist.
- The involvement of competent occupational hygienists, the role of the hygienist and the role of the health and safety professional involved in the management and monitoring of hazardous substances.
- If quantitative monitoring is to be carried out, then an approved method (such as one from the UK's HSE MDHS guidance series) must be used to ensure the validity of results obtained.
- Direct reading instruments can be used to measure airborne concentrations of contaminants.
- Stain tube detectors provide a way of spot-sampling concentrations of gases and vapours in air. They are simple to use but do have limitations.
- Dust concentrations in air can be monitored using an air pump and sampler containing a filter. Different types of sampler allow for inhalable or respirable dust to be collected. The amount of dust collected is quantified by weighing.
- Asbestos concentrations in air can be measured using similar equipment with a cowled sampler head. The amount of asbestos collected is quantified by counting fibres by Phase Contrast Microscopy (PCM).
- Gas and vapour concentration can be measured using various passive and active devices.
- In Britain, the HSE guidance HSG173 indicates that an effective strategy for monitoring hazardous substances calls for a three-stage approach: an initial appraisal, a basic survey and a detailed survey, if needed.
- The interpretation of the occupational hygienists' reports will be important.

The Concept of Exposure Standards

Occupational Exposure Limits (OELs) are developed by professional organisations as guidelines and the values given are often prescribed into national laws to make them enforceable.

Occupational exposure standards are Regulations that have been mandated by national laws to set the exposure limits of a substance that may become airborne in the workplace. The occupational exposure standards would ideally be based on a complete understanding of the toxicology of the substance but in reality, are often based on experience and judgement. The standard will usually limit the airborne concentration of the substance to which a worker can be exposed without causing harm to health. Exposure values are often set for a reference time period where exposure can occur without the consequent ill-health effects of exposure.

Many thousands of chemicals in substantial quantities are used in almost all work activities. The framework of effective control of chemical risks at work begins with information from the manufacturer, or importer, to the users of the chemicals, who can then identify potential hazards arising from the chemical, and take adequate safety precautions.

The Meaning of OELs

The use of OELs is important for the protection of people at work from a wide variety of health hazards. For example, OELs are used to control personal exposure to hazardous substances, noise, vibration, and radiation. This section focuses on OELs for hazardous chemicals. Those applicable to other health hazards will be dealt with later in the unit.

Protection from airborne hazardous substances

The ILO defines "exposure limit to airborne harmful substances at the workplace" as follows:

"...concentration in the air of a harmful substance which does not, it is believed in the light of present scientific knowledge, cause adverse health effects - including long-term effects and effects on future generations - in workers exposed for eight to ten hours per day and 40 hours per week; such exposure is considered acceptable by the competent authority which establishes the values, although concentrations below the exposure limit may not completely guarantee protection of the health of all workers; the exposure limit therefore does not constitute an absolute dividing line between harmless and harmful concentrations but merely serves as a guide for the prevention of hazards."

Source: ILO Code of Practice - *Occupational Exposure to Airborne Substances Harmful to Health*, Copyright © International Labour Organization, 1980

It is worth noting some of the subtleties in this definition:

- The substance must be airborne.
- It is established on the basis of current scientific knowledge, which is naturally subject to change.
- The limit might not completely guarantee the safety of all workers and is a guide.

Likewise the ILO Code of Practice - *Ambient Factors in the Workplace* has the following definition of an exposure limit:

> *"...a level of exposure which is specified by a competent authority, or some other authoritative organization such as a professional body, as an indicator of the level to which workers can be exposed without serious injury."*

Source: ILO Code of Practice - *Ambient Factors in the Workplace*, Copyright © International Labour Organization, 2001

Worker being exposed to airborne contaminant

OELs can be defined specifically for airborne contaminants, giving maximum concentrations (normally measured across a particular reference period of time) to which employees may be exposed. The intention of OELs is to put a ceiling in place so that workers will not be exposed to high concentrations of airborne substances (either for short durations of time or for long periods of the working day) where scientific evidence suggests that there is risk to health.

We will use the term 'occupational exposure limits' throughout this Learniong Outcome. However, different countries have applied different names and limits through national legislation. Examples will be given later in this section.

How OELs are Established

The ILO Code of Practice - *Occupational Exposure to Airborne Substances Harmful to Health* (CoP) (Section 3) establishes principles to be followed when setting exposure limits. It recognises that limits may be established through national legislation or through collective agreement with employers or workers, such as worker representative groups, and that such limits should be able to be modified in light of scientific knowledge.

The CoP also states that exposure limits should be established based on a study of the dose-effect and dose/response relationship in the context of the:

- Physical and chemical properties of the substances (including nature and quantity of contaminants).
- Way in which the substance will be used, and hence the way in which workers will be exposed to it.
- Results of laboratory tests (including animal testing) which will establish the acute and chronic health effects.
- Results of health surveillance of workers, including epidemiological studies.

Data should be submitted to a competent authority, so that suitable exposure limits can be established. These limits will apply to airborne exposure, but where there is potential for substances to be absorbed also through the skin, this should be emphasised.

Once the data on the properties of the substances and the tests, epidemiological data, etc., have been gathered, the results can be extrapolated in order to establish an exposure limit. The ILO recognises that this should, however, incorporate a safety factor established by experts to take into account the following factors:

- Although animals are used in toxicological testing, there are metabolic and functional differences between man and animals.
- There may be differences between experimental conditions and occupational exposure conditions.
- There may also be an effect due to the selection of workers (as the working population may differ between regions/countries).

Exposure Limits and Time-Weighted Average Values

Exposure limits are in place to control the effect of a substance.

Both long-term and short-term exposure limits are expressed as **Time-Weighted Average (TWA)** concentrations. This means that measurements are taken and the airborne concentrations are averaged out over a given period of time.

Long-Term Exposure Limits (LTELs)

Long-term exposure limits (LTELs) are designed to control the **chronic** ill-health effects of long-term exposure to harmful substances - the sort of exposures that might occur routinely on a daily basis over a period of weeks, months or years in a workplace.

The long-term exposure limit is based on an 8-hour TWA. If an 8-hour TWA exposure can be calculated, then it can be compared to the LTEL.

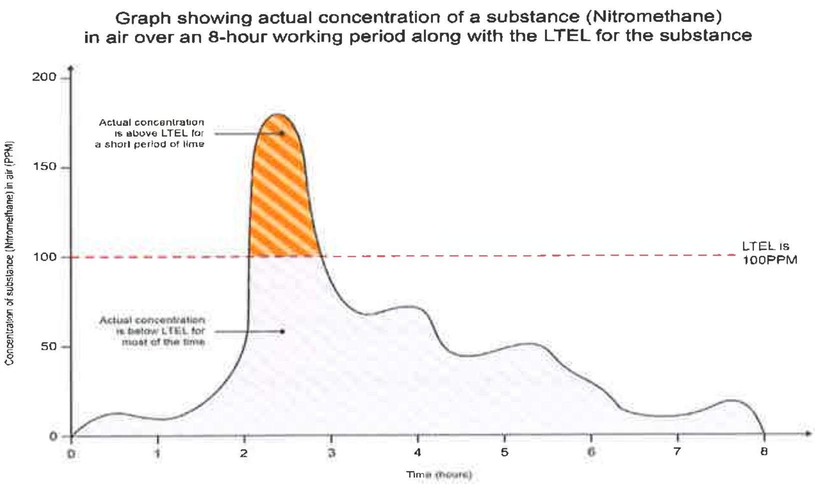
The general formula for calculating an 8-hour TWA exposure is:

$$\text{8 hour TWA exposure} = \frac{C_1T_1 + C_2T_2 + \ldots C_nT_n}{8}$$

Where C_1 is the concentration for time T_1, C_2 is the concentration for T_2 and so on. The concentrations (C_1, C_2, etc.) are measured in units of parts per million (ppm) or milligrammes per cubic metre ($mg.m^{-3}$). The times (T_1, T_2, etc.) are in hours.

The concept of a TWA allows excursion **above** the LTEL, provided there are equivalent excursions **below** the limit to compensate for the excess exposure.

The following figure illustrates a variable exposure over an eight-hour period.



Graph showing actual concentration of a substance (nitromethane) in air over an eight-hour working period along with the LTEL for the substance

From the graph, we can see that the actual concentration of the substance fluctuates over the eight-hour work period; from zero at the start, then rising above the LTEL (100ppm) for about an hour, reaching a peak of 180ppm, then falling rapidly below the LTEL and gradually reducing to zero by the end of the sampling period.

From the graph, the TWA exposure can be estimated (by imagining the area under the line spread out evenly over the entire eight hours) at approximately 60ppm. This is below the LTEL of 100ppm. So, even though there has been an excursion above the LTEL, this **excursion** was not significant enough to take the TWA concentration above the LTEL; the LTEL has not been exceeded.

Short-Term Exposure Limits (STELs)

MORE...

The UK Guidance Note EH40: *Workplace exposure limits*, which contains details of the UK limits and the means by which they are established, is available from:

www.hse.gov.uk/pubns/priced/eh40.pdf

The list of PELs in the USA is available from the OSHA website at:

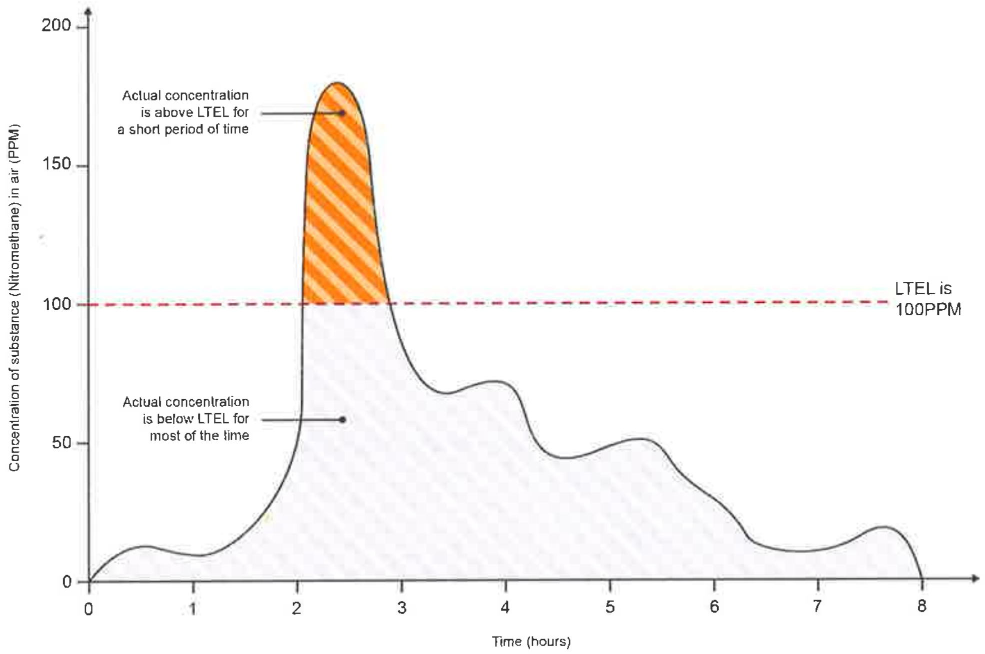
www.osha.gov/dsg/annotated-pels/index.html

Short-Term Exposure Limits (STELs) are designed to control the **acute** ill health effects that might result from exposure to a high concentration of a contaminant over a short period of time. The short-term exposure limit is based on a 15-minute TWA. If the 15-minute TWA exposure can be calculated, then it can be compared to the STEL.

15-minute TWA exposures have to be calculated by measuring airborne concentrations across the 15-minute reference period.

The practical effect of a STEL is that it imposes a ceiling on the peaks in airborne concentration (the excursions) that are permissible in the workplace.

The following graph shows the same variable exposure over an eight-hour period as before, only this time the STEL of 150ppm has been added.



Graph showing actual concentration of a substance (nitromethane) in air over an eight-hour working period along with the LTEL for the substance

From the graph, we can see that the actual concentration of the substance rises above the STEL (150ppm) for about an hour reaching a peak of 180ppm, then falling rapidly below the STEL and gradually reducing to zero by the end of the sampling period.

From the graph, it can be seen that this excursion above the STEL has lasted for well over 15 minutes. Therefore, the TWA concentration during the excursion must be above the STEL; the STEL **has** been exceeded.

So, even though the LTEL was not exceeded during the working period (see first graph), the STEL was exceeded. This means that the peak in concentration of the substance is too pronounced and must be reduced to below 150ppm so that the STEL is not exceeded.

Not all substances are assigned STELs. Where a STEL has not been assigned, the UK guidance note EH40 suggests that a value of **three times** the LTEL, averaged over 15 minutes, should be used to control short-term excursions.

International Examples of Occupational Exposure Limits

There are no internationally recognised global standard exposure limits at present - different countries have implemented their own limits based on the interpretation of the dose-response data obtained. The names, definitions, and methods for calculating exposures and the legal status of the limits vary between these countries. It is, therefore, important to select the correct OEL for the country in question and use the correct codes of practice in interpretation.

Some of the different occupational exposure limits are outlined below as examples:

- In the UK, the Health and Safety Executive (HSE) has established a series of **Workplace Exposure Limits (WELs)** which have legal status. Limits have been established for many substances, including lead and asbestos.
- In the USA, the Occupational Safety and Health Administration (OSHA) have established **Permissible Exposure Limits (PELs)**, which are also enforceable limits. Additional controls, known as **Threshold Limit Values (TLVs)**, have been established by the American Conference of Governmental Industrial Hygienists (ACGIH); these are not enforceable, but in many cases establish a more stringent limit than the PEL established in law.
- There are numerous other national limits - in France these are known as the VME (Valeur Moyenne d'Exposition), whilst in Germany they are called MAK values (Maximale Arbeitsplatz-Konzentration). In the EU, **Indicative Limit Values** (published by the EU Commission) are used as the basis for many countries' limits.

As an example, the following table lists UK WELs for a range of substances.

Substance	CAS number	Workplace exposure limit				Comments
		Long-term exposure limit (8-hr TWA reference period)		Short-term exposure limit (15-minute reference period)		The Carc, Sen and Sk notations are not exhaustive.
		ppm	$mg.m^{-3}$	ppm	$mg.m^{-3}$	
Arsenic and arsenic compounds except arsine (as As)		-	0.1	-	-	Carc
Arsine	7784-42-1	0.05	0.16	-	-	
Asphalt, petroleum fumes	8052-42-4	-	5	-	10	
Azodicarbonamide	123-77-3	-	1.0	-	3.0	Sen
Barium compounds, soluble (as Ba)		-	0.5	-	-	
Barium sulphate inhalable dust respirable dust	7727-43-7	 - -	 10 4	 - -	 - -	
Benzene	71-43-2	1	3.25	-	-	Carc, Sk
Benzyl butyl phthalate	85-68-7	-	5	-	-	
Benzyl chloride	100-44-7	0.5	2.6	1.5	7.9	Carc
Beryllium and beryllium compounds (as Be)		-	0.002	-	-	Carc

Extract from Table 1 of EH40/2005 Workplace exposure limits (4th ed.), HSE, 2020

(www.hse.gov.uk/pubns/priced/eh40.pdf)

Notes relating to the table:

- **CAS number** = Chemical Abstracts Service number, which provides a way of uniquely identifying a chemical compound. This is useful because the same compound may be known under different names.
- **LTELs** are listed for all substances, but **STELs** are only assigned for three.
- **ppm** = parts per million.
- **mg.m-3** = milligrams per cubic metre of air.
- In the comments column:
  - **Sk** denotes skin absorption.
  - **Sen** indicates a respiratory sensitiser.
  - **Carc** indicates a carcinogen or mutagen.

We will now look at how exposure limits for two specific hazardous substances - lead and asbestos - have been implemented in different countries.

Lead

In the UK, the occupational exposure limits for lead are set out not in the WELs but in the **Control of Lead at Work Regulations 2002 (CLAW)**.

The limits are 8-hour TWA concentrations as follows:

- For **lead** other than lead-alkyls, a concentration of lead in the atmosphere to which any employee is exposed, of **$0.15mg.m^{-3}$**.
- For **lead-alkyls**, a concentration of lead in the atmosphere to which any employee is exposed, of **$0.10mg.m^{-3}$**.

These OELs are ceiling limits which must not be exceeded when calculated as time-weighted averages over 8 hours.

Actual exposures must be measured and calculated in accordance with the methods referenced in **CLAW**, but the general principles for use are the same as for WELs.

As far as exposure by inhalation is concerned, control is considered adequate when exposure does not exceed the relevant OEL. This is not sufficient to ensure absence of health risk, however, because other routes of exposure to lead are also important, such as ingestion and contact with the skin (for lead-alkyls).

Because these other routes of exposure can contribute to the amount of lead that a worker might absorb, workers must be subjected to **biological monitoring**. This involves taking blood and urine samples and then analysing those samples to estimate the amount of lead in the worker's body. The results of this monitoring are then compared to the **biological limit values** contained in **CLAW**.

In the USA, there are PEL limits established for lead. These are lower than the UK limits and are set as an action limit of **$30\mu g/m^3$** as an 8-hour TWA, with no person to be exposed to a concentration greater than **$50\mu g/m^3$** as an 8-hour TWA.

Asbestos

In the UK, the occupational exposure limit for asbestos is set out in the **Control of Asbestos Regulations 2012 (CAR)**, where it is referred to as the control limit.

The control limit is **0.1 fibres per cubic centimetre** of air averaged over a continuous period of **four hours**.

Note that the general principles applied here are the same as those for WELs - the limit is a time-weighted average.

There are some differences though:

- The units of measurement for asbestos in air are fibres per cubic centimetre (**f/cm^3**) or fibres per millilitre (**f/ml**).
- The reference period is four hours (not eight as for WELs).

In the USA, there is also a PEL for asbestos, which again illustrates the differences between the two countries. The PEL is established as $0.1f/cm^3$ averaged over a continuous period of 8 hours, with an excursion limit of $1f/cm^3$ averaged over 30 minutes.

The method by which the number of fibres is calculated involves light microscopy and will be outlined later in this Learning Outcome.

Exposure Monitoring

Exposure monitoring means using suitable techniques to establish how much a person(s) has been exposed to a substance through inhalation, ingestion and/or absorption. The information from the monitoring can then be used to assess if exposure is adequately controlled.

The ILO Code of Practice - *Safety in the Use of Chemicals at Work* (Section 12) states that, "employers should monitor and record exposure of workers to hazardous chemicals to ensure their health and safety".

In the UK, the legal requirements for monitoring are covered by Regulation 6(1) and 7(1) of the **Control of Substances Hazardous to Health Regulations (COSHH)**. These two Regulations say that the employer must carry out a suitable and sufficient assessment of the risk to employees and other persons, if they are exposed to hazardous substances. The employer should also prevent exposure, or where this is not reasonably practicable, ensure exposure is properly controlled.

The **Approved Code of Practice** to Regulation 10 of **COSHH** clarifies the requirements for monitoring to ensure exposure is controlled:

- If the risk assessment shows it to be necessary, or investigative monitoring is necessary to make an informed judgement.
- If the failure or deterioration of control measures (e.g. LEV failure) could result in a serious health effect.
- Where measurement is required to ensure an exposure limit or any self-imposed (set by the organisation) working standard is not exceeded.
- When results are used as an additional check on the effectiveness of any control measures.
- If the substance or processes is specified in Schedule 5 to the **COSHH** Regulations.
- Following any process or condition change (e.g. change of substances used) that affects workers, where adequate controls must be re-established.
- If the risk assessment identifies the possibility of biological agents outside of the primary containment.

Selecting the Right People

To comply with local or national legislation, employers may have to carry out a programme of monitoring exposure. Monitoring can be carried out in a variety of ways but most commonly the air in the employees' breathing zone is monitored. The person carrying out the exposure monitoring must have the skill, knowledge and ability to do so. A competent person, with the necessary experience, will apply a strategy aimed at the actual circumstances found in the workplace. They will also use the knowledge and experience of management and workers.

Monitoring will always require cooperation and that the workers are doing their job as normally as possible. Where PPE is involved, the worker must wear the PPE and replicate the conditions as close as possible to those experienced whilst doing the normal job.

Workers should not interfere with the sampling equipment or create abnormal circumstances to result in false high results.

The person selected for the monitoring analysis must have the same shared attitude as the analyst in getting the best from the monitoring exercise.

Role of the Health and Safety Professional

The organisations' health and safety professional will:

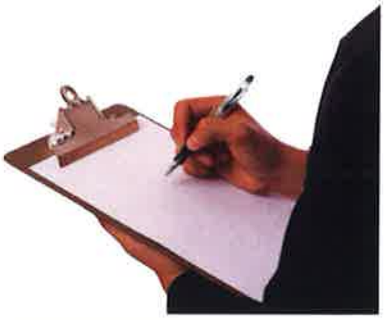
- Ensure that sampling is aligned to real workplace conditions and not to occasions when there is likely to be limited exposure.
- Support decisions on personal monitoring or static monitoring strategies.
- Have access to historical sampling data and knowledge of the health hazards that can be used for monitoring strategies.
- Have knowledge of the number and types of people exposed.
- Understand if exposure is through inhalation, absorption or ingestion, which will impact on the monitoring methodology.
- Gather information on the substances that people are exposed to, and undertake some simple qualitative tests: such as noting smells, visible fumes, and accumulations of dust; and use dust lamps to identify sources of dust, that can be used to identify monitoring equipment.
- Read and understand documentation on the hazards present and make recommendations on the type of sampling required.
- Be able to identify if the monitoring required is routine, and the frequency of the monitoring required to meet legal requirements.

The health and safety professional would also be able to provide information on shift patterns and hours of exposure. They can also give information and supervision for the workers involved in monitoring, so that they understand the importance of what is being done.

Role of the Occupational Hygienist

The work of the occupational hygienist generally involves:

- Identification of health hazards (such as toxic chemicals, heat or noise).
- Measurement of the hazard by data collection (e.g. personal dosimetry).
- Evaluation of the risk by comparing estimated exposures to legal standards (e.g. use of OELs).
- Identification of control measures and their implementation, use, testing and maintenance.


Occupational hygienists must be trained and competent

Occupational hygienists often specialise in one topic area, such as noise or asbestos. A wide range of monitoring techniques are available, making use of special equipment and instruments. The occupational hygienist must be trained and competent in the selection of technique, use and, importantly, the interpretation and evaluation of the results.

Another of their areas of involvement is the monitoring of control measures, to ensure they are working effectively. Consequently, they may be skilled in carrying out measurements on ventilation systems and other environmental control devices, to ensure they operate at optimum performance.

Selecting a Competent Occupational Hygienist

MORE...

For more information on the British Occupational Hygiene Society, visit:

www.bohs.org

For more information about the American Board of Industrial Hygiene, visit:

www.abih.org

It is important that, before an employer retains the services of an occupational hygienist, their competence is checked. The level of competence needed will depend on the service required. The employer must make an informed choice based on:

- Training and qualification.
- Experience in the field in question.
- Background knowledge and education.
- Certification or accreditation to relevant standards.
- Membership of professional organisations. For example:
  - The British Occupational Hygiene Society (BOHS) is the leading professional organisation for hygienists, which operates a membership system (similar to IOSH) and examination/qualification scheme in various hazard areas. Care must be taken, since some membership grades can be achieved without qualification. Higher membership grades do require qualifications.
  - Likewise, in the USA, the American Board of Industrial Hygiene (ABIH) is the certifying body for Certified Industrial Hygienists (CIHs). Earning the CIH certification requires candidates to meet rigorous education and experience requirements.

In many instances, there is no one standard of qualification or certification required and the employer must make a judgment. In a few instances, such as when sampling asbestos, there is a clear certification scheme that can be checked.

The Methods for the Determination of Hazardous Substances (MDHS) Series

If the monitoring strategy calls for the use of quantitative analysis of the concentration of airborne substances, then it is essential to use the relevant standard method. This ensures scientific validity. The UK's HSE publication series *Methods for the Determination of Hazardous Substances (MDHS) Guidance on Analysis* is a set of detailed descriptions of approved sampling and analytical methods. MDHS methods exist for most chemical agents likely to be encountered in the workplace. They provide reliable and consistent methods to ensure that accurate measurements can be made.

The use of these approved methods allows the results obtained to be meaningfully compared to the relevant standards (such as WELs). If sampling or analysis is not carried out in accordance with the relevant MDHS method, then the quality and validity of the results obtained are questionable and would not be legally admissible as evidence of compliance.

A good example of a widely used and important **MDHS** Guidance Note is the approved method for carrying out dust sampling as given in the MDHS Guidance Note 14, *General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols*. Note that this guidance note uses the broad term 'aerosol' which applies to any solid or liquid suspended in air, rather than 'dust'.

MORE...

MDHS14/4 General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols is available as a free download from the HSE website at:

www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf

The NIOSH Manual of Analytical Methods Series

In the USA, the National Institute for Occupational Safety and Health (NIOSH) have also published standard analytical methods for the analysis of airborne contaminants. This is a collection of analytical methods for the sampling of air, but also biological sampling of blood and urine of exposed workers.

ISO Standards

The International Organization for Standardization (ISO) have also published analytical methods which can be employed when determining the content of samples taken in the workplace.

MORE...

The NIOSH Manual of Analytical Methods can be found at:

www.cdc.gov/niosh/docs/2003-154/method-l.html

The ISO catalogue of standards is available at:

www.iso.org/standards-catalogue/browse-by-ics.html

Methods and Equipment

Direct Reading Instruments

Direct reading instruments can be used to measure the concentration of various chemicals in air. These instruments rely on a variety of techniques, such as:

- **Chemical** reactions designed to produce a colour change, which enables a qualitative analysis to be made (often referred to as 'colorimetric').
- **Electrical** detection, in conjunction with chemical or electro-chemical processes.
- **Physical** methods based on the absorption of ultraviolet or infrared radiation in proportion to the concentration of the contaminant.

They can be used in a variety of different ways, for example, to give:

- Simple quantification of concentration of a contaminant at one moment in time.
- Continuous monitoring of concentration of a contaminant with data-logging, so that concentration profiles can be plotted over time.
- Continuous monitoring of concentrations so that alarms can be activated if levels rise or fall above or below pre-set values.

A typical example of a direct reading instrument is the **photoionisation detector** (PID) where the contaminant is drawn into a cell and is ionised by ultraviolet (UV) radiation, which generates a current proportional to the concentration of contaminant present. They are useful in measuring concentrations of airborne contaminants and can be used for continuous monitoring or general screening in a workplace.

Advantages of Direct Reading Instruments

Direct reading instruments have many advantages, such as:

- Some may be used to continuously monitor the air for the given substance.
- Some are specific to a given substance.
- They give an immediate (or nearly immediate) reading of a contaminant concentration.
- They are very useful for identifying periods of peak concentrations during a working shift.
- Many instruments can be connected to a chart recorder, data logger or a warning device so do not need constant attention.

Disadvantages of Direct Reading Instruments

They can also be disadvantageous in that they:

- Can be expensive.
- Need a competent technician.
- Need to be calibrated to ensure accurate measurement.
- Can be influenced by mixtures.

Stain Tube Detectors

Stain tube detectors are a type of colorimetric direct reading instrument. They provide a convenient method of analysing gas and vapour contamination in air.

The principle of operation is very simple: a known volume of air is drawn over a chemical reagent in a glass tube. The contaminant reacts with the reagent and a coloured product, a **stain**, is produced.

Stain tube detectors are made to allow grab sampling (a crude point-in-time measurement at one location) or long-term sampling, operated by hand bellows, hand pistons or motorised pumps.

The Drager stain tube detector is a typical example of the instrument. It consists of two main parts, the **bellows hand pump** and the **stain tube** (shown in the following figure), selected to suit the particular contaminant and measurement to be carried out.

The bellows pump is designed to draw in 100cm3 of air with one stroke. To achieve this, the bellows must be fully compressed before being opened to its maximum volume. The time taken for the bellows to open fully from the closed position gives one pump stroke. The stroke time will depend upon the type of Drager tube being used and can vary from three seconds to 40 seconds.

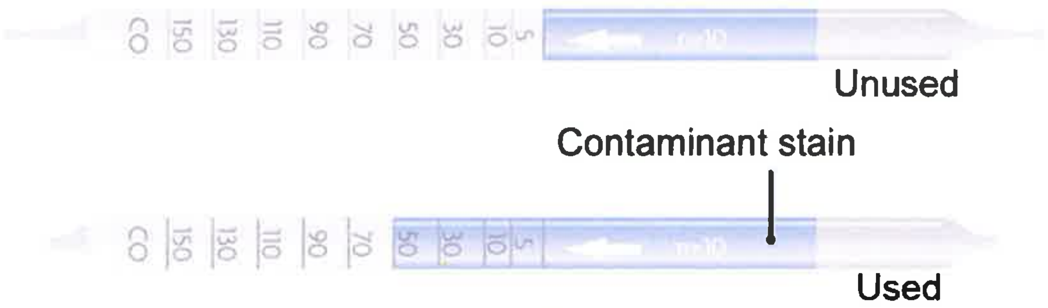
Owing to the time involved and the number of strokes required for a particular measurement, it is important to have a stroke-counter fitted to the unit.

The detector tubes contain a reagent which reacts with the contaminant in the airflow passing through it to cause a coloured reaction.

The method of controlling the colour developed is either by drawing a fixed volume of air through the tube, using a specified number of strokes, or by counting the strokes required to produce a colour change.

In the first method, the tubes are marked with a graduated scale; the longer the stain produced, the higher the concentration of contaminant. This is the most commonly used system. Unused and used tubes are illustrated below.

In the second method, used less frequently, the greater the number of strokes taken, i.e. the greater the volume of air sampled, the smaller the concentration of the contaminant.



Stain tube before and after use

Note the closed and open ends of the tube. Arrows show direction of air flow.
n=10 indicates that 10 strokes on the hand-bellows are required.
These tubes are sensitive to carbon monoxide (CO). Final concentration is given as 50 parts per million (ppm)

TOPIC FOCUS

General Method of Operation of Stain Tube Detectors

The general method of operation of stain tube detectors is as follows:

- Select the appropriate tube for the measurement being made, taking note of any possible cross-sensitivity.
- Break the end off the tube to be inserted into the pump. (Use the tube end-breaker provided.)
- Insert the tube into the pump and exhaust the bellows, by fully depressing the front plate.
- Allow the system to remain in this state for a few seconds and check for possible leaks.
- If there are no leaks, break off the remaining tip in an uncontaminated atmosphere. Cover the end with the rubber cap provided.
- Select the sampling position, remove the rubber cap and proceed to carry out the sampling procedure, e.g. the given number of strokes for a scale tube and the time allowed for the colour to develop fully.
- Note the reading and record the result and sample position.
- Remove the stain tube, cover both ends with a rubber cap and dispose of it according to the manufacturer's instructions.

Limitations of Stain Tube Detectors

Whilst there are various advantages to stain tube detectors (relatively cheap, easy to use, give quick results, etc.), there are also limitations that have to be recognised:

- The rate of flow of air is important, so stain tubes with incorrectly broken ends may not give the correct flow rate.
- The accuracy of the sampled volume is critical, therefore the bellows action must be fully operated for every stroke. The number of strokes must be recorded accurately, hence the need for an effective counter. Leaks must be eliminated.
- There may be the possibility of cross-sensitivity of tube reagents to other substances than the one being analysed. This will be indicated on the data sheet accompanying the particular stain tube.
- There may be problems caused by variations in temperature and pressure. Stain tubes are designed to operate at about 20°C and one atmosphere pressure. Variation in atmospheric pressure will probably be within the limits of accuracy of the system, although changes in altitude could cause problems. Normal variations in temperature will be problematic; a change of 10°C can cause a reaction rate to be doubled or halved. With ambient temperature ranging between 0°C and 30°C, the potential for error is considerable.
- Because of the complexity of the indicating reagent, tubes have a shelf life, so care must be taken to turn over stock and only use tubes that are currently operative.
- Reagent complexity also causes a variation between each tube; hence, judgments cannot be made on one grab sample.
- Hand-operated stain tube systems are capable of only a point-in-time (or 'grab') sample.

Personal Sampling for Solid Particulates

The sampling equipment (sometimes referred to as a 'sampling train') consists of an air pump, connecting hose, sampler (sampling head containing a filter) and flow meter:

- **Air pump** - must meet certain minimum standards, and is usually a unit that can be worn by a worker on a belt or in a pocket, and is capable of drawing air at a steady fixed rate for 4-8 hours.
- **Hose** - simply a clear plastic tube for connecting the air pump to the sampler.
- **Sampler** - a small filter holder that can be attached to the worker close to their breathing zone; usually clipped to clothing at the collar bone.
- **Flow meter** - used to check the flow rate of the sampler train before and after use.

There are a number of different types of sampler used for gravimetric analysis of dust. They fall into two main categories: inhalable samplers and respirable cyclones.

General Method for Sampling and Gravimetric Analysis of Dusts

In Great Britain, the HSE's MDHS Guidance Note 14 explains the general methods to be used when sampling and analysing both respirable and inhalable dust:

- **Inhalable** dust is dust where the particles are suspended in air and so can be inhaled through the nose or mouth into the respiratory tract.
- **Respirable** dust is that fraction of inhalable dust that is small enough to pass through the upper respiratory tract, lower down into the lungs, to the region of gas exchange.

The most recent version of Guidance Note 14 (MDHS14/4) gives guidance on collecting the **thoracic** aerosol fraction in air for the purpose of monitoring workplace exposure. This is the fraction of inhaled airborne material that penetrates beyond the larynx.

The general principle is simple:

- Contaminated air is drawn through a **filter** held inside a **sampler** (sampling head) for a period of time.
- The filter is **weighed** both before and after sampling, to give the weight of dust that has collected (hence *gravimetric* analysis).
- The weight of dust collected is used to calculate the dust concentration in air (mg.m^{-3}).

(The dust collected might also be analysed by other methods to reveal its chemical composition).

The type of sampling head used depends on the nature of the particulates being measured (e.g. inhalable vs. respirable dusts). A similar method is used for the analysis of asbestos fibres, but makes use of slightly different sampling equipment and a very different analysis method.


HSE

General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols

MDHS14/4

Introduction

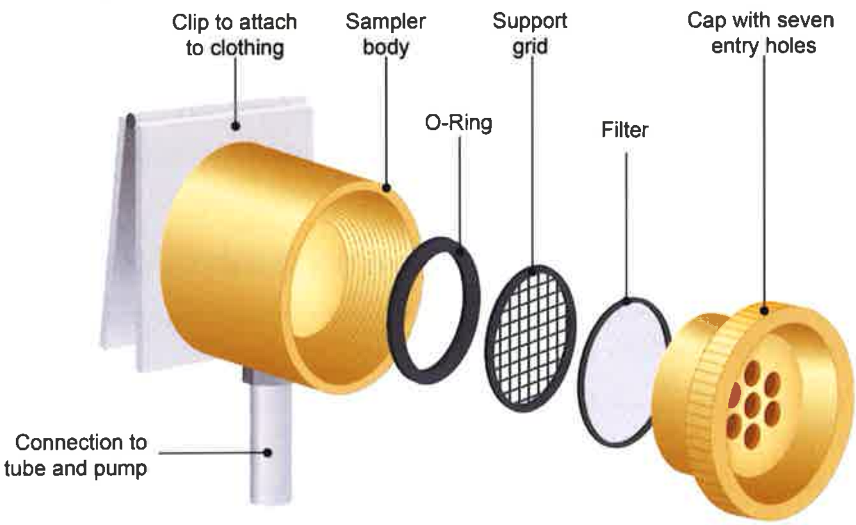
Scope

MDHS Guidance Note 14
(Source: www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf)

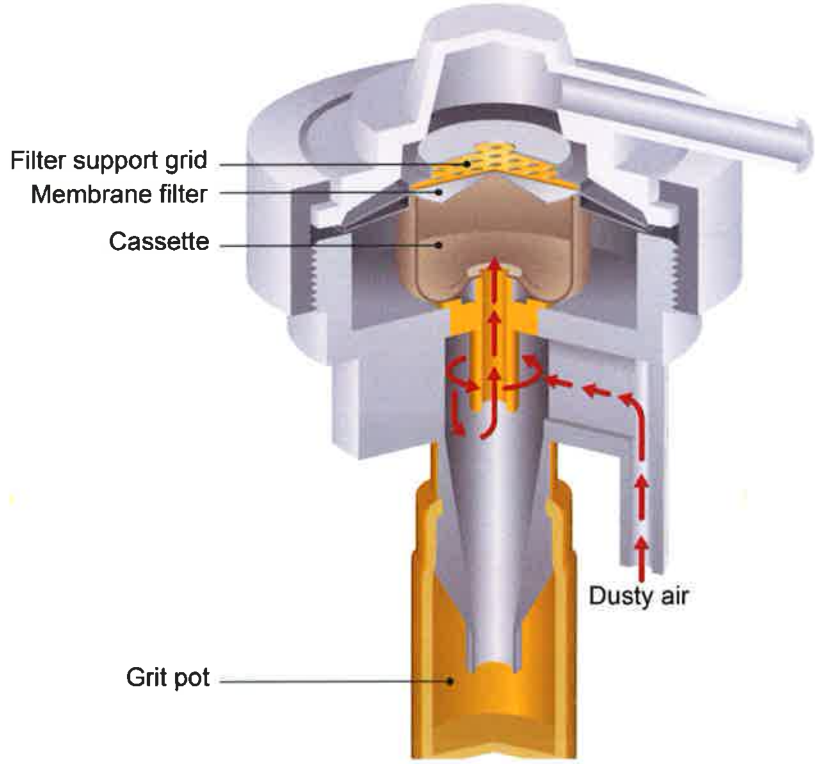
The MDHS Guidance Note 14 method of sampling can be used for both **background** (fixed point or static) sampling in the workplace environment (where the sampler is fixed at a set location in the workplace) and for **personal sampling** or dosimetry (where the sampler is attached to a worker). Personal sampling is always more indicative of real worker exposure levels.

The multi-orifice sampling head shown below has to be fitted to an air pump unit capable of maintaining a smooth flow rate of 2.0l/min. Different types of sampling head can be used. The multi-orifice type shown has to be loaded with a pre-weighed filter before use. Other types, such as the UK Institute of Occupational Medicine (IOM) sampling heads, are loaded with a cassette that contains the filter. This eliminates the need for the end user to directly handle the filter, and reduces the potential for handling errors.

The cyclone sampler works on a similar principle to the inhalable sampler, except that larger particles of dust are excluded from the sample by using a small cyclone (same principle as a Dyson vacuum cleaner). Only smaller, respirable particles are permitted to enter the cassette in the middle of the sampler, where they are then collected on a membrane filter. The cyclone sampler shown in the second image below, requires a pump air-flow rate of 2.2 l/min.



Multi-orifice inhalable sampling head - just one of the many types available
(Based on MDHS 14/4 *General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols*, HSE, 2014 (www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf))

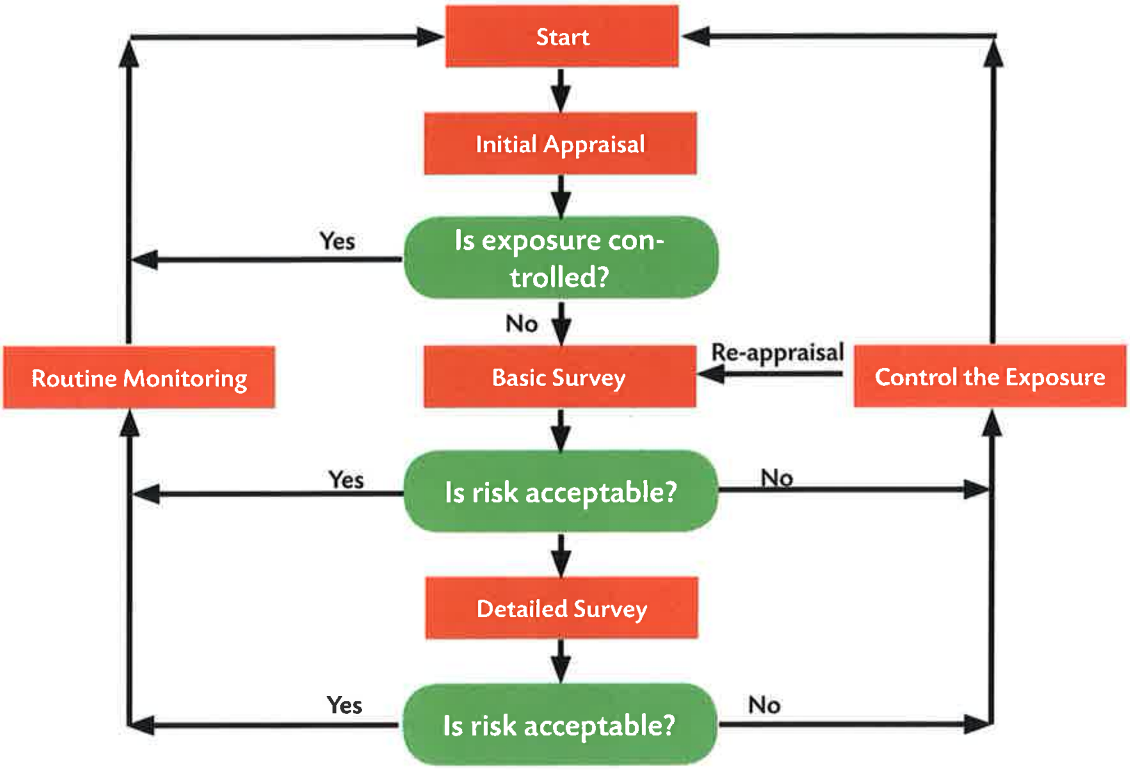


Cyclone respirable sampler
(Based on MDHS 14/4 *General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols*, HSE, 2014 (www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf))

Monitoring Strategy

In Britain, the HSE has published the Health and Safety Guidance Booklet - HSG173: *Monitoring Strategies for Toxic Substances* giving advice on the principles of monitoring of hazardous substances. The basic philosophy is "do not measure unless you know what you are measuring and what you will do with the results". The basic strategy is shown in the following flow diagram.

9.9 Workplace Monitoring for Hazardous Substances



Monitoring of hazardous substances

Initial Appraisal

This helps establish the need for, and extent of, exposure monitoring. It helps you decide if you need more information - like actual monitoring data.

Stage 1: Gather information about:

- The substances to which employees are exposed:
  - Identity.
  - Hazardous and physical properties.
  - Airborne forms, e.g. dust, mist, fume, aerosol, vapour.
  - Any applicable OELs or in-house limits.
- The possibility of exposure by inhalation, ingestion or skin absorption.
- Processes or operations where exposure is likely to occur.
- The number, type and position of emission sources.
- The groups or individuals most likely to be exposed.
- The likely pattern and duration of exposure.
- Any existing control measures in place - LEV, RPE (and effectiveness), etc.

Stage 2: Conduct some simple **qualitative** tests:

This helps establish if there is a risk to health, for example:

- Smoke tubes - show air movements.
- Dust lamp - makes fine dust visible and helps identify emission sources.
- Smell - can be unreliable.

Now conclude (based on gathered information and qualitative tests): is the level of exposure by inhalation acceptable?

- If **YES** - you may not need to carry out exposure monitoring at all (remember - exposure patterns can change - so keep it under review).
- If **NO** (or uncertain) - complete a basic survey.

Basic Survey

This estimates employees' personal exposure and the effectiveness of controls.

It is best to look at worst-case situations first. If exposure is found to present insignificant health risks when compared with current standards, then lesser-exposed staff need not be assessed in detail. So, first identify those groups of staff most likely to be significantly exposed to a hazardous substance and also the conditions and factors giving rise to exposure. You can then use **semi-quantitative** methods to **estimate** personal exposure (to give a rough numerical estimate). Methods range from stain tubes ('Drager tubes') to the more complex, such as photoionisation detectors (which can be worn by individuals to analyse exposure to organic vapours). Alternatively, fully **quantitative**, validated laboratory-based sampling and analysis can be used (as discussed later) or a mixture of methods. Anemometers and other such devices can be used to measure the performance of LEV systems.

Personal sampling can be used at peak periods and static sampling used to verify the existence, sources and spread of contaminant release.

Finally, conclude whether the risk is acceptable. If not, or uncertain, either take direct control action or conduct a detailed survey.

Detailed Survey

This is used, for example, when:

- Dealing with carcinogens, mutagens and respiratory sensitisers.
- Exposure is highly variable between employees doing similar tasks.
- The initial appraisal and basic survey indicate:
  - TWA concentrations are very close to the OEL; and
  - The cost of additional controls needs to be justified with more detailed evidence of the exposure profile.

Detailed surveys may be used for complex processes

Therefore, these surveys would tend to be used for complex processes. They involve techniques similar to those already used for the initial appraisal and basic survey, but more detailed monitoring and analysis would be used to identify exposure patterns and the degree of control.

Re-Appraisal

The monitoring conducted during basic and detailed surveys may indicate some problems with controls. Once remedial action has been taken, you need to see if the changes have had the desired effect. So, a brief re-appraisal of the situation is usually all that is needed. Additional exposure monitoring may also be necessary (high-risk cases like carcinogens or very variable exposure patterns).

Routine Monitoring

Once you have implemented effective controls, you may decide to use routine monitoring to ensure that controls stay effective. The frequency and type of routine monitoring required will vary, depending on:

- **Legal standards** - some substances must be routinely monitored, e.g. in the UK continuous monitoring for vinyl chloride monomer (as specified in **Regulation 10** and **Schedule 5** of **COSHH**).
- The **degree of confidence** that the controls are adequately controlling risks. For example, if the measured exposure is close to the OEL (rather than well below it), then monitoring is needed to ensure compliance.

It may be more cost-effective in the long term to invest in better controls that always ensure that control is below the OEL - thus reducing the need for routine monitoring. Routine monitoring can be expensive in the long term and complicated, but it doesn't always have to be, e.g. use of smoke tubes, dust lamps and pressure sensors on LEV.

Personal and Static Monitoring

OELs relate to personal exposure to the hazardous substance. So, in many instances, it is necessary to carry out personal monitoring (or personal dosimetry) to determine what an individual worker's exposure to the airborne contaminant might be. It is not the concentration of the substance at one fixed point that has to be compared to the OEL, but the concentration of the substance that the worker might inhale. This is estimated by fitting them with personal monitoring equipment.

However, there are circumstances where fixed place or static monitoring are appropriate. This involves collecting a sample of the atmosphere (and the contaminant that it contains) at a fixed location, rather than securing the sampling equipment to a worker.

Method of Use

MDHS Guidance Note 14 describes the sampling procedure in practical detail. Key points to observe are:

- Clean and load the sampler with a pre-weighed filter or cassette.
- Fit the sampler to the pump. Run the pump to stabilise airflow and then check and adjust flow rate using the flow meter.
- Attach the sampling train to the operator, not more than 30cm away from the nose-mouth region.
- Record the time at the start of the sampling period and check, record and readjust the flow rate as necessary at the end of each hour.
- At the end of the sampling period, note the time and remove the filter for re-weighing.
- Re-check the flow-rate using the flow meter.

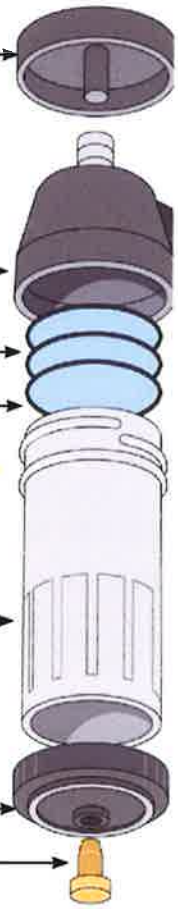
Filters have to be weighed accurately using laboratory scales. The accuracy of the scales and weighing method usually means this should be carried out at an accredited laboratory.

Sampling and Analysis for Asbestos

Sampling and analysis of asbestos fibres in the air should be carried out using the approved method (Appendix 1 of Great Britain's HSE guidance note HSG248).

The method of sampling is similar to that for dust. A sample is collected by drawing a measured volume of air through a membrane filter held in a cowled sampler by means of an air pump.

The method of analysis is rather different. The filter is mounted on a microscope slide and rendered transparent ('cleared'). Fibres of appropriate dimensions ('countable fibres') on a measured area of filter are counted visually using Phase Contrast Microscopy (PCM) (described in further detail below) and the number of fibres in the air calculated.



Sampling head with cowl, for collection of asbestos fibres
Source: Figure A1.1 Exploded view of a personal sampling head from HSG248: *Asbestos: The analysts' guide for sampling, analysis and clearance procedures*, HSE, 2006 (www.hse.gov.uk/pubns/priced/hsg248.pdf)

Cowled Sampler

A cowl is a hood that is attached to the sampling head. Cowls can be bought in a variety of shapes and sizes, e.g. conical. The size of the cowl will affect the size of the surface area over which air is drawn. For the collection of asbestos fibres, an open-faced filter holder and a cylindrical cowl are used, as illustrated.

The cowl is made of an electrically conducting material to ensure that static build-up does not affect the collection of fibres. The membrane filters used are of cellulose or nitrocellulose.

Fibres are collected using a very similar technique as for dusts. Fixed point and personal sampling can be conducted using a calibrated air pump, flexible tube and sampler. Different air pump flow rates and sampling durations are used depending on the purpose of the measurement.

Analysis - Phase Contrast Microscopy (PCM)

Phase Contrast Microscopy (PCM) is used to count the number of asbestos fibres collected on the filter. Before the fibres can be visualised by microscope, the filter has to be made transparent **(cleared)**. This is done by mounting the filter on a microscope slide and then spraying it with **acetone vapour**. The filter is then dried and covered with a coverslip.

The filter is then examined on a phase contrast light microscope. This type of microscope allows asbestos fibres to be distinguished from the background of the filter.

A known proportion of the filter is visually scanned and the number of fibres counted. Only those fibres with a length in excess of 5µm, a width less than 3µm and a length to width ratio of more than 3:1 are defined as **countable fibres**. Measuring the length of a fibre requires a microscope eyepiece with a calibrated scale (called a graticule). By calculating the number of fibres in a known proportion of the sample collected, the number in the whole sample and the airborne concentration can be calculated.

The above is a simplification of the analysis method, which is necessarily complex. Counting has to be done to strict rules to avoid subjective errors in what constitutes a countable fibre.

Personal Sampling for Vapours

DEFINITIONS

ABSORB

Any material is drawn into another material and held throughout its bulk, e.g. water into cotton wool. Note: no chemical binding takes place.

ADSORB

A process in which any material is attracted by and adhered to the surface of the 'sorbent'.

SORBTION

Encompassing both **absorption** and **adsorption**: a physical and chemical process by which one substance becomes attached to another.

SORBENT

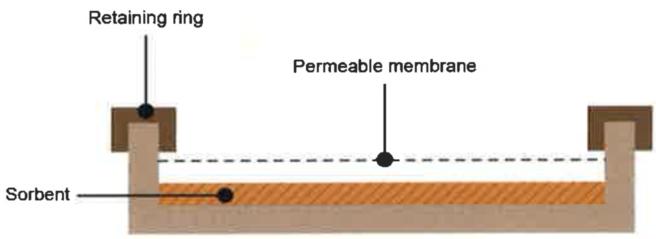
A solid or liquid material that is capable of adsorbing a gas or vapour sample (e.g. activated charcoal).

There are two main ways in which these airborne contaminants can be sampled: diffusion sampling and mechanical sampling. In **diffusion sampling** (or **passive sampling**), the contaminant passes over the sampling system in natural air currents, and diffuses into a chamber containing a sorbent material for later analysis. The **mechanical sampling** (or **active sampling**) system uses a pump to provide airflow through the sampling device or analysing instrument. These techniques are described in the following section.

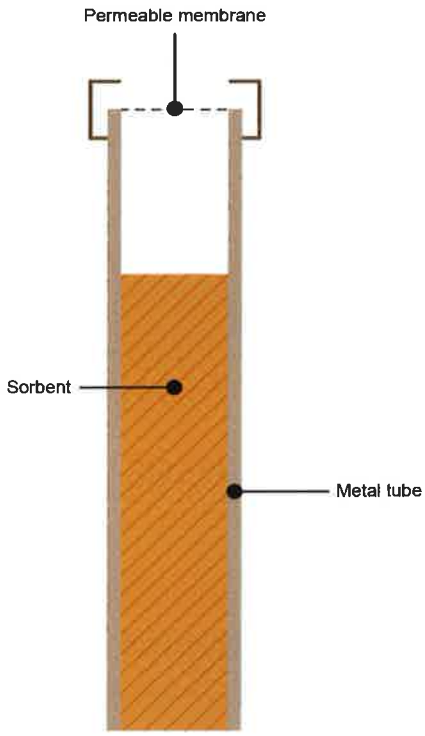
Passive Devices

Passive devices employ sorbent material to sample concentrations of airborne contaminants without using a pump to draw air through the collector. The sorbent material is contained in a holder designed to allow the gases to diffuse and/or permeate to the sorbent surface. These holders are small enough to be worn like a lapel badge and are free of any pump or tubing. At the end of the sampling period, the holder is returned to the laboratory, where the sorbent material is removed and the amount of gas or vapour collected can be analysed.

In practice, there are two main types of design. The badge-type sampler has a flat, permeable membrane supported over a shallow layer of sorbent (see below). The tube-type sampler has a smaller, permeable membrane supported over a deep metal tube filled with sorbent (see below).



Badge sampler



Diffusing sampler

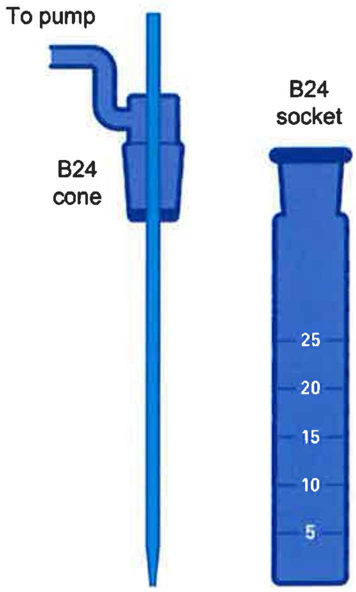
Active Devices

These largely involve contaminated air being drawn through some sorbent material (solid or liquid).

- **Liquid Sorbents - The Midget Impinger**

  A common example is a midget impinger (commonly called a 'bubbler').

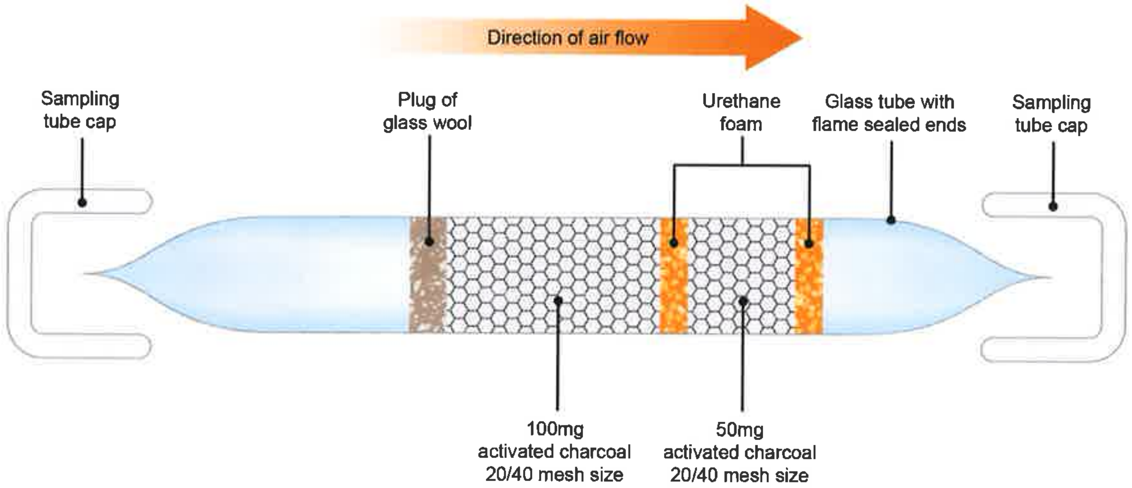
  Here, the bottle is partially filled with 10-20ml of a liquid sorbent (which could be something as simple as water), in which the vapour gas will readily dissolve (or react). The cone is inserted into the socket (see diagram), the outlet tube then being connected to the pump. This then 'bubbles' contaminated air through the sorbent. The impinger is attached to the worker's clothing.



Midget impinger for vapours

- **Solid Sorbents - Sorbent Tubes and Pumps**

  Certain gases and vapours are readily sorbed by solid materials such as silica gel, activated charcoal and various types of porous resin. When a continuous stream of air is pumped through a tube containing activated charcoal, any gases or vapours will be sorbed. The amount of contaminant collected can then be determined back in the laboratory. The pumps used in this technique are small and can be attached to the worker in the same way as a passive device. An activated charcoal sample tube is shown in the following figure.



Activated charcoal sampling tube

Analysis of Vapours

Vapours collected on sorbents within samplers can be desorbed in a laboratory and chemically analysed using a variety of techniques, e.g. Gas Chromatography (GC), or infrared spectroscopy. In this way, it is possible to identify the actual chemical collected and calculate its concentration (by calibration of the instrument for a given chemical and knowledge of the collection parameters - flow rate and collection time).

Calculating Exposures

General Method for Calculating 8-Hour TWA Exposures

The 8-hour TWA exposure for a work activity where the exposures have been measured can be calculated using the following formula:

$$\text{8 hour TWA exposure} = \frac{C_1T_1 + C_2T_2 + \ldots C_nT_n}{8}$$

The simplest way of using the formula is:

1. For each partial exposure period, multiply the concentration by the duration of exposure (in hours).
2. Add all of these partial exposures together.
3. Divide the sum by 8 (to give an 8-hour average).
4. Express the answer in the same units as the concentrations were first measured in.

Example:

Steps 1 and 2:

Concentration of Contaminant in PPM	Exposure Time in Hours	Product
60	0.5	60 × 0.5 = 30
40	1.5	40 × 1.5 = 60
50	2.0	50 × 2 = 100
60	3.0	60 × 3 = 180
80	1.0	80 × 1 = 80
		sum 450

Table showing measured exposures (concentration and duration of exposure) along with the partial exposures (concentration × time in hours) and the sum of the partial exposures (Steps 1 and 2).

Steps 3 and 4:

$$\text{8 hour TWA} = \frac{450}{8} = \mathbf{56.25ppm}$$

If the Work Exposure Limit (WEL) listed in Great Britain's HSE's publication EH40 for the substance in question was:

- 30ppm, then the WEL would have been exceeded.
- 60ppm, then the limit would not have been exceeded, but the 8-hour TWA would be unacceptably close to the WEL.
- 200ppm, then the exposure would be acceptable in relation to the WEL.

Note that even if the total duration of the working period is less than, or more than, eight hours, the total exposure is **always** divided by 8 to give the 8-hour TWA.

Example Calculation Using Sampling and Gravimetric Analysis of Dust Method

When a dust sampling train is used to collect a dust sample from the atmosphere, then calculating the dust concentration in $mg.m^{-3}$ is relatively simple:

(a) First calculate the volume of air (in m^3) drawn through the sampler:

(i) Multiply the pump flow rate (l/min) by the sampling time (in minutes).

(ii) Convert this from litres to cubic metres by dividing by 1,000.

(b) Second calculate the weight of dust (in mg) on the filter by:

(i) Weight of the filter after use - weight of the filter before use.

(c) Third calculate the weight of dust per cubic metre of air ($mg.m^{-3}$) by dividing b with a.

So, for example, if the following sampling data is obtained:

- pump flow rate = 2.0l/min
- sample duration = 6 hours
- pre-use filter weight = 2,123mg
- post-use filter weight = 2,136mg

then using the steps above would give:

(a) Total volume of air drawn through sampler = 2.0 × (6 × 60) = 2.0 × 360 = 720 litres
720/1,000 = **0.72m³**

(b) Weight of dust on filter = 2,136mg - 2,123 mg = **13mg**

(c) 13/0.72 = **18.1mg.m⁻³**

Note that this exposure is for a 6-hour period of time.

Evaluation of the acceptability of this measurement would require that the result is first used to calculate the **8-hour TWA exposure**. Once this is done, the evaluation would then have to take account of the nature of the dust in question and the relevant standards that apply.

Calculation of the 8-hour TWA exposure is done using the method described above.

For the example given above, if we assume that no further dust exposure occurs during the working shift:

Concentration of Contaminant in $mg.m^{-3}$	Exposure Time in Hours	Product
18.1	6	18.1 × 6 = 108.6
Assumed 0	3	0 × 3 = 0
		sum 108.6

$$8 \text{ hour TWA} = \frac{108.6}{8} = \mathbf{13.6\ mg.m^{-3}}$$

MORE...

Further information on this topic is available in the following guidance documents, available as free downloads from the HSE website at:

www.hse.gov.uk/pubns

HSG173 *Monitoring strategies for toxic substances*

Appendix 1 of HSG248 Asbestos: *The analysts' guide for sampling, analysis and clearance procedures*

When evaluating whether this 8-hour TWA exposure is acceptable or not, reference would have to be made to national standards where they exist or in the UK to the standards set out in EH40 (or elsewhere). However, it is worth noting that, generally, the UK's WELs for dust are set at 10 $mg.m^{-3}$ or less and that for nuisance dust (dust of a general nature for which no specific WEL exists) a notional WEL of 10 $mg.m^{-3}$ should be used. Therefore, we can see that an 8-hour TWA dust exposure of 13.6 $mg.m^{-3}$ is unlikely to be acceptable. PELs may set different standards for respirable dust, such as 5 $mg.m^{-3}$ and for total dusts 15 $mg.m^{-3}$.

If multiple samples are taken during a work shift, then each partial exposure will have to be accounted for when calculating the 8-hour TWA exposure as already described.

Interpretation of Reports

Safety professionals may be involved in the management of occupational hygienists. A safety professional should, therefore, be able to read and understand a report produced by an occupational hygienist to verify that it is appropriate and valid. Not only does this ensure that the appropriate recommendations are acted on, it also provides a way of checking the hygienist's competence.

There are a number of general issues that should be checked:

- An appropriate strategy and method of sampling has been used. Standard strategies and methods are published by the HSE and other authorities (such as the World Health Organisation - (WHO)). Where these exist they must be adhered to, to ensure the scientific and legal validity of any result obtained.
- The equipment used was appropriately maintained, certificated and calibrated.
- The sampling was carried out at a place and time that would give results representative of real workplace conditions (this requires an understanding of the types and patterns of work that the hygienist may not have a full appreciation of).
- The results have been correctly evaluated against the correct legal standards/OELs.

TOPIC FOCUS

Issues to consider when assessing a report on a Local Exhaust Ventilation (LEV) examination conducted by an occupational hygienist:

- Identification of the relevant legal standards.
- Identification of the LEV plant, process and substance(s) being controlled.
- Date of last examination and test (reference to at least every 14 months in the UK).
- LEV intended (design) performance.
- Identification of the equipment used and its calibration and test certification.
- Assessment of whether any improvements/repairs are needed (which will depend on an analysis of current performance relative to design and legal standards).
- Date of examination/test.
- Name of person (and employer) doing the test.
- Credentials (qualifications, accreditation).
- Reference to record keeping (five years for LEV examination in the UK).

9.9 Summary

STUDY QUESTIONS

1. What specific form of hazardous substance are OELs intended to control?
2. Outline the difference between long-term and short-term exposure limits.
3. Outline the monitoring strategy described in HSG173.
4. Describe the gravimetric analysis of dust method for the analysis of inhalable dust.
5. State the limitations of stain tubes as a method of quantifying airborne contaminants.

(Suggested Answers are at the end.)

Summary

Occupational Exposure Limits (OELs)

We have described how:

- Occupational Exposure Limits (OELs) are standards for exposure to particular health hazards above which workers should not be exposed.
- Two OELs can be set for a chemical - a Long-Term Exposure Limit (LTEL) based on an 8-hour Time-Weighted Average (TWA) exposure; and a Short-Term Exposure Limit (STEL) based on a 15-minute TWA exposure.
- The concept of exposure standards.
- The meaning of Exposure Limits for airborne harmful substances.
- LTELs are used to control long-term exposure and the chronic ill-health effects that might result, whereas STELs are used to control short-term exposure that might create acute effects.
- Exposure monitornig requirements - using the UK's **COSHH** as an example to identify the legal requirement for monitoring and using the Approved Code of Practice to **COSHH** for additional requirements for monitoring.
- The right people must be selected to take part in personal monitoring/sampling. Employers should use a competent person to carry out monitoring and should gain co-operation from workers when monitoring.
- The identification, measurement and evaluation of health hazards, and the subsequent design and testing of control measures is often the work of the occupational hygienist.
- The involvement of competent occupational hygienists, the role of the hygienist and the role of the health and safety professional involved in the management and monitoring of hazardous substances.
- If quantitative monitoring is to be carried out, then an approved method (such as the UK HSE MDHS guidance series) must be used to ensure the validity of results obtained.
- Direct reading instruments can be used to measure airborne concentrations of contaminants.
- Stain tube detectors provide a way of spot-sampling concentrations of gases and vapours in air. They are simple to use but do have limitations.
- Dust concentrations in air can be monitored using an air pump and sampler containing a filter. Different types of sampler allow for inhalable or respirable dust to be collected. The amount of dust collected is quantified by weighing.
- Asbestos concentrations in air can be measured using similar equipment with a cowled sampler head. The amount of asbestos collected is quantified by counting fibres by Phase Contrast Microscopy (PCM).
- Gas and vapour concentration can be measured using various passive and active devices.
- The UK's HSE guidance HSG173 indicates that an effective strategy for monitoring hazardous substances calls for a three-stage approach: an initial appraisal, a basic survey and a detailed survey, if needed.
- The interpretation of the occupational hygienists' reports will be important.

Learning Outcome 9.10

NEBOSH International Diploma for Occupational Health and Safety Management Professionals

ASSESSMENT CRITERIA

- Outline where biological agents are likely to be encountered in the workplace and how these can be controlled.

LEARNING OBJECTIVES

Once you've studied this Learning Outcome, you should be able to:

- Explain the types and properties of biological agents found at work.
- Explain the assessment and control of risk from deliberate and non-deliberate exposure to biological agents at work.

Contents

Types and Properties of Biological Agents

IN THIS SECTION...

- Biological agents are micro-organisms, cell cultures, or human endoparasites which may cause infection, allergy, toxicity or a similar health hazard.
- The four types of biological agents of concern are: fungi, bacteria, viruses and protozoa. These are all microscopically small entities passed to humans from other humans, plants, animals or environmental sources.
- Many biological agents have special properties that complicate the risk that they present, namely a rapid mutation rate, an incubation period, infectiousness and the ability to multiply rapidly.
- Zoonoses are diseases that are passed to humans from vertebrate animals. Examples include: cryptosporidiosis, and psittacosis.
- Vector borne diseases are diseases that are transmitted to humans by insects or other small organisms. Malaria is a significant global vector-borne disease that can be a significant risk to workers travelling overseas to tropical countries where it is present.
- Biological agents of note that cause significant occupational diseases include: the blood-borne viruses hepatitis B, C, D and Human Immunodeficiency Virus (HIV), Legionella bacteria, Leptospira bacteria and norovirus.

Types of Biological Agent

Definitions

The International Labour Organization (ILO) defines a biological agent as:

> *"Any micro-organism, cell culture, or human endoparasite, which may cause any infection, allergy, toxicity or otherwise create a hazard to human health. These include viruses and bacteria which can cause infection and disease, dangerous plants and animals (for example parasites or insects), biologically contaminated dusts, or wastes from humans and animals."*

Source: Health, Safety and Environment: *A series of trade union education manuals for agricultural workers* (Manual 4, Fact Sheet 3), Copyright © International Labour Organization 2004

Bacteria, fungi and viruses are micro-organisms

And a **micro-organism** is defined as:

> *"A microbiological entity, cellular or non-cellular, which is capable of replication or of transferring genetic material."*

This definition of micro-organism includes **bacteria**, **fungi** and **viruses** as well as other microscopically small biological entities, such as protozoa and algae.

Human endoparasites are parasites that are capable of infecting and then living within the human body, e.g. malaria (caused by a single-celled organism that infects the blood) and tapeworms (large multicellular organisms that live in the gut).

The biological agents dealt with in this section of the course are all fungi, bacteria, viruses or protozoa. It is worth noting that the above definitions include a wider range of biological entities, such as algae and endoparasites and that therefore relevant legislation could be applied to these organisms if they presented an occupational health risk. The definitions do not include large multicellular organisms (other than endoparasites). So a dog is not a biological agent, but the rabies virus that the dog might be carrying is.

9.10 Types and Properties of Biological Agents

Though the definition of the term 'biological agent' is very broad and encompasses many different forms of entity, this Learning Outcome will focus on four principal types of biological agent: fungi, bacteria, viruses and protozoa.

- **Fungi**

  Fungi include moulds and yeasts. Some fungi are able to cause infection on, or inside, the human body (e.g. athlete's foot). Some fungi produce toxins (mycotoxins) that are harmful to humans. Fungi reproduce by forming spores that are released, dispersed and find a suitable environment to grow in. Inhalation of large numbers of these tiny spores of the aspergillus fungi can cause lung disease, such as Farmer's Lung.

- **Bacteria**

  Bacteria are simple single-celled organisms. They vary widely in shape and many have a tail (flagella) that allows them to move through liquid. Some form hardy spores that can survive adverse conditions, such as heat, cold and lack of water (e.g. *Bacillus anthracis*, the bacteria responsible for anthrax).

  Bacteria grow in virtually every environment on the planet, from water and soil to deep ocean and subterranean rock. There are approximately ten times as many bacteria growing in or on the typical human body as there are human cells. Most of these do not cause disease because of the immune system. Some (e.g. certain gut bacteria) are actually beneficial. Some bacteria can cause disease (e.g. **Legionnaires' disease** caused by the *Legionella* bacteria). Antibiotics, such as penicillin, can be used to treat most bacterial infections.

- **Viruses**

  Viruses are micro-organisms but are not strictly alive. They are self-replicating molecules (genetic material contained in a protein shell) that invade host cells, take control of the cell to produce more viruses, and then release these viruses to repeat the cycle. Virus particles are much smaller than fungal and bacterial cells. Hepatitis and Acquired Immune Deficiency Syndrome (AIDS) are two diseases of occupational significance that are caused by viruses present in human body fluids. Viral infections are usually prevented or halted by the body's immune system. This immune response takes time to come into effect, however, so there is often a period of illness before the body's defences become effective (an effect seen every time you catch a cold). Some viral infections are so severe that the immune system cannot respond effectively and serious disease or death results (e.g. smallpox). Some viral infections are not dealt with effectively by the body and so can persist (e.g. Human Immunodeficiency Virus (HIV), the causative agent of AIDS).

- **Protozoa**

  Protozoa are a very large and diverse group of single-celled organisms that all have a cell nucleus. They are therefore different to bacteria where no nucleus is present in the cell. Protozoa are often motile (able to move) and do not photosynthesise.

  Many diseases are caused by protozoans, perhaps the most notable being malaria. Sleeping sickness, giardia, amoebic dysentery and toxoplasmosis are all caused by different protozoans. Treatment often requires drugs (not antibiotics - which are only effective against bacteria). Diseases caused by protozoa do not usually self-resolve, i.e. the human immune system is incapable of dealing with the infection independently.

Sources of Biological Agent

Pathogenic (disease-causing) biological agents come from four main sources: humans, animals, plants and the environment.

- **Human sources** - many fungal, bacterial and viral infections are passed from person to person. This can happen by transfer of body fluids (e.g. **viral hepatitis** can be transferred by a needle-stick injury), by droplet infection (e.g. **tuberculosis** (TB) can be spread by coughing and sneezing) or by physical cross-contamination (e.g. 'flu virus spread by touching the nose and then touching a surface that others then come into contact with).

DEFINITION

PATHOGEN

A biological agent capable of causing disease.

- **Animal sources** - some serious fungal, bacterial and viral infections are passed from animals to humans. This can happen by the same general mechanisms as for person-to-person infection. For example, rabies is a viral disease that can be passed from infected animals to people, usually from a bite; leptospirosis is a bacterial disease spread by coming into contact with water or surfaces contaminated with an infected animal's urine (e.g. rat urine). A disease that can pass from vertebrate animals to humans is referred to as a 'zoonosis' (plural 'zoonoses') or 'zoonotic disease'.
- **Plant sources** - most plant diseases are caused by fungal or fungal-like organisms, though some are caused by viral and bacterial organisms. A sign of plant disease is physical evidence of the pathogen, e.g. leaf rust in corn crops. A symptom of plant disease is a visible effect of disease on the plant. Symptoms may include a change in colour, shape, or function of the plant, as it responds to the pathogen. The pathogen can be passed on to a human being through direct contact, or through pollen, or insects. An example is the bacterium *Pseudomonas aeruginosa*, which can cause a weak, soft rot of plants, such as lettuce. The effect on people, usually with compromised immune systems, is infections in the urinary tract, lungs, and blood.
- **Environmental sources** - some serious occupational diseases originate in the general environment, rather than coming from a human or animal source. A classic example of this is Legionnaires' disease (or legionellosis) caused by the *Legionella* bacteria. This bacteria is naturally occurring in damp soil and water courses.

Properties of Biological Agents

It is possible to think of biological agents as being simply another form of chemical agent. Indeed, national legislation often defines biological agents as a type of 'hazardous substance' (for example, the **Control of Substances Hazardous to Health Regulations** in Great Britain), in effect, putting biological agents in the same category as hazardous chemicals.

This simple approach can be a little misleading, however, because biological agents can have the following special properties:

- **Rapid mutation** - like all living organisms, biological agents are subject to mutation; their genetic code changes over time, so changing the characteristics of the organism. However, unlike many organisms, some biological agents have a very high mutation rate. This means that their genetic code and their characteristics change quickly, making it very difficult for the human body to effectively recognise and attack them. HIV, for example, the causative agent of AIDS, has a very high mutation rate.
- **Incubation period** - there is usually a time delay between infection (when a person catches a disease) and when the first signs and symptoms of the disease become apparent. This incubation period can range from 1-3 days (for 'flu) to many years (perhaps 30-50 years for Creutzfeldt-Jakob Disease (CJD)). This means that the presence of a biological agent may not be readily detectable, and that a link between the source of an infection and the symptoms of the disease may not be made.
- **Infectious** - it is often the case that a person (or animal) suffering from a disease is infectious, i.e. capable of spreading the agent to others. Many diseases spread by making the carrier infectious. When this is the case, an infected person poses a risk to their colleagues, others that they might come into direct contact with, and, in some cases, the community at large. Tuberculosis is an example of a highly infectious disease that can spread within the community. Some diseases are not infectious, e.g. Legionnaires' disease is not passed from one person to another. In some cases, a person may be infected with a disease and become infectious without showing any signs or symptoms of the disease (they are asymptomatic); they become a carrier, capable of spreading the disease, but will be unaware of their infectious state. Hepatitis C is an example of this type of disease.

- **Rapid multiplication** - micro-organisms can multiply very rapidly when environmental conditions are right. For example, the *E. coli* bacterium (a gut bacterium) is capable of multiplying at a rate greater than one cell division every 30 minutes. Though this may not sound impressive, it becomes more so when you consider that in a 24 hour period one bacterium can multiply to become over 200,000,000,000,000. It does not take long for a small number of agents (that might not present a risk of infection) to multiply to become large numbers that are capable of overcoming the body's defences to cause infection.

In general, with biological agents, there will not be a simple dose-response relationship of the kind that exists for chemical substances, and risk may be high even at small exposures.

Zoonotic/Vector-Borne Diseases

MORE...

Further information about zoonoses can be found at:

https://www.hse.gov.uk/biosafety/diseases/zoonoses.htm

www.who.int/zoonoses/en

As mentioned above, Zoonoses (singular, 'zoonosis'), or zoonotic diseases, are those that can be transferred to humans from vertebrate animals.

Vector-borne diseases can be transferred to humans by the bite of a carrier insect (or other small organism), such as a mosquito.

Occupations at risk from zoonoses will vary depending on the disease in question but, clearly, people whose work brings them intentionally or incidentally into close proximity with animals will be at risk from one or several zoonotic diseases, such as:

- Farm workers.
- Vets.
- Zoo workers.
- Pet shop workers.
- Sewage workers.
- Construction workers.

Though control measures will vary depending on circumstances, the general preventive measures described later for leptospirosis are relevant to all zoonoses.

Examples of occupational zoonoses include:

- **Cryptosporidiosis** - an infectious diarrhoeal disease. It is caused by a **protozoan** parasite and can be transmitted via contact with infected animals (mainly cattle and sheep). It can be caught by contact with faecal contaminated water or food (such as salad) and can also be spread from person to person where there is poor hygiene. Principal groups of workers at risk include: farm workers, construction workers where there is stagnant contaminated water, and healthcare workers dealing with infected people. There is no vaccine available and no treatment either (other than staying hydrated). Infected individuals usually recover within one month. The disease is best prevented through good personal hygiene measures, such as avoiding contact with potentially infected animals and contaminated water, use of gloves and hand washing.

- **Psittacosis** - also known as 'ornithosis' or 'parrot fever', is primarily an infection of birds. It can be transmitted to humans by breathing in infected material or occasionally by oral infection. The disease is caused by **bacteria**. Principal occupations at risk are poultry farmers, bird-keepers, cleaners and construction demolition workers working in bird-infested areas. The disease has a 1-4 week incubation period leading to 'flu-like symptoms, such as headache, fever, aching muscles with the possibility of pneumonia. The disease responds to antibiotic treatment.

Again, the disease is best prevented by isolating known infected birds, removing faecal material (before it has time to dry out and become airborne), preventing the creation of aerosols of faecal material during cleaning operations, use of protective clothing, particularly respiratory protective equipment and good personal hygiene.

- **Malaria** - is a **vector-borne disease** caused by a **protozoan** parasite of the Plasmodium classification, of which there are five species that cause malaria in humans. The WHO estimates there were 229 million cases of malaria worldwide and 409,000 deaths in 2019. In the UK, 1683 travellers were diagnosed with the disease in 2018 (after returning home) and six people died.

The parasite is spread by 'night-biting' mosquitoes (specifically the female Anopheles mosquito). As a consequence of a bite, the parasite passes into the bloodstream, where it breeds and multiplies. Symptoms usually appear between 7 and 18 days after becoming infected, but in some cases the symptoms can appear up to a year or more after. Symptoms include fever, sweats and chills, headache, vomiting, muscle pain and diarrhoea. It can prove fatal if not detected early and treated.

Malaria is found in more than 100 countries, mainly in tropical regions of the world, such as large areas of Africa and Asia, Central and South America, parts of the Middle East and some tropical island groups. Workers may be exposed to the risk of malaria as a result of living and working in an infected area or as a result of work-related travel to an infected area.

Control measures include:

- Obtaining travel advice before travelling to tropical areas to see if the area of travel is a malaria-infested area.
- Taking prophylactic anti-malarial drugs before, during and after visits.
- Preventing mosquito bites by using mosquito repellents, clothing and sleeping under mosquito nets at night.
- Early recognition of symptoms of the disease (which may occur weeks or months after infection) and referral to a medical doctor for proper diagnosis and treatment.
- Antimalarial drugs are also used for treatment of the disease which, if it is caught early, will usually be fully effective.

Control Measures

General Control Measures for Incidental Exposure to Biological Agents

This section considers a range of diseases caused by biological agents, together with the occupational contexts of exposure and the preventive measures commonly applied.

An infection is caused by harmful micro-organisms that produce disease; these are commonly referred to as pathogens or bacteria (for example gastroenteritis) and viruses (for example Influenza).

Infections, if not controlled, can spread rapidly, and may lead to people becoming unwell, and, in some cases, the infection can be fatal. Infection control involves taking positive action to prevent and control infections. The 'spread' of the infection (or more accurately the pathogen) is dependent on the existence of the pathogen, an environment that allows it to multiply, transportation (allowing the pathogen to move), a route of entry into a body (person or animal), and a route out of the body, entering another body.

General control measures for exposure to biological agents would include the following measures to prevent infection:

- Safe working environments, where workers comply with safe working practices:
  - Safe use, handling and transport of biological agents.
  - Safe handling and disposal of sharps (needles/scalpels).
  - Minimum numbers of people involved.
  - Minimise duration of exposure.
  - Disinfection and decontamination regimes.
  - Safe collection, storage and disposal of hazardous waste.
  - Display of appropriate biological hazard warning signs.
- Welfare facilities including hand washing facilities so that hygiene standards can be maintained.
- Immunisation programmes.
- Readily understandable information on good working practices and regular training on those practices.
- Reporting and recording outbreaks of infection.

Additional specific controls include:

- Avoid exposure where possible, e.g. by using remote cameras for sewer work or for monitoring animal behaviours.
- Appropriate training for relevant workers in the control measures being used and in methods of entry of biological agents.
- Implement suitable disinfection procedures, e.g. for workwear or work equipment that has become contaminated, consider the use of autoclaves for sterilisation.
- Arrangements for safe collection, storage, transport, and disposal of contaminated waste, e.g. using UN approved containers for the safe disposal of used syringes.
- Vaccinations for known biological agents that could cause zoonotic diseases, e.g. the rabies virus transferred from domestic or wild animals through scratches or bites. Rabies is a vaccine preventable zoonotic disease.
- Hygiene measures to prevent or reduce the accidental transfer of a biological agent, including:
  - Provision of appropriate and adequate washing and toilet facilities, e.g. use hands-free taps (sensor controlled).
  - Prohibition of eating, drinking, smoking and application of cosmetics in areas where biological agents are likely to be present.
  - Use of appropriate PPE.

General Controls for Exposure to Biological Agents when Working with Animals

Working with animals can result in physical contact infections (a scratch or bite resulting in the transfer of Leptospirosis from rats/mice) and behavioural related infections (newly acquired animals biting, for example Salmonellosis from Cats and Ferrets). Control measures can therefore be 'behavioural', assessing the animals behaviour and the likelihood of being bitten, etc. or avoiding direct 'physical' contact (e.g. barriers or cages). Physical control measures would also include, wearing appropriate protective clothing; or reducing aerosol exposure to urine by careful handling of wastes or the use of safety cabinets; and dust generation by vacuum or careful removal of animal bedding (straw). The use of suited systems for this type of work should be considered.

General Controls for Exposure to Biological Agents when Working with Infectious People

- Prohibition of eating, drinking, smoking and the application of cosmetics in working areas where there is a risk of contamination.
- Prevention of puncture wounds, cuts and abrasions, especially in the presence of blood and body fluids.
- Avoiding the use of, or exposure to, sharps, such as needles, glass, metal, etc. or, if unavoidable, take care in handling and disposal.
- Using devices incorporating safety features, such as safer needle devices and blunt-ended scissors.
- Covering all breaks in exposed skin by using waterproof dressings and suitable gloves.
- Protecting the eyes and mouth by using a visor/goggles/safety spectacles and a mask, where splashing is possible.
- Avoiding contamination by using water-resistant protective clothing.
- Wearing rubber boots or plastic disposable overshoes when the floor or ground is likely to be contaminated.
- Using good basic hygiene practices, such as hand washing.
- Using appropriate decontamination and waste disposal procedures.

Control Measures for Exposure to Biological Agents when Working with Hazardous Waste Contaminated with Micro-organisms

Workers involved in hazardous waste processing are exposed to bioaerosols (biological aerosols of fungi, bacteria and viruses that are introduced into the air via wind or other disturbances). Health effects could include 'Farmer's Lung', a chronic bronchitis condition.

Biological agents can also be associated with:

- Human waste (e.g. faeces present in nappies, incontinence pads and stoma bags).
- Food waste.
- Animal infestations (such as rodents).
- Animal waste (included in straw and hay) produced from domestic pet litter trays.
- Used needles/syringes and drugs.

Control measures:

- Employers should always try to prevent exposure at source. For example, consider working with other agencies to reduce the risk at source by promoting/ providing needle return schemes.
- Appropriate protective clothing, e.g. gloves, safety boots and cut-resistant trousers.
- Adequate hand-washing facilities (including warm running water, and soap towels) at fixed sites or collection vehicles.
- Emergency decontamination procedures and arrangements.
- Use of the appropriate equipment for the task, e.g. litter-picking tongs.
- Covering all new and existing cuts and grazes with waterproof dressings.
- Health surveillance allows early identification of ill health.

Routes of entry can be through inhalation or cuts and abrasions.

Control Measures for Exposure to Biological Agents when Working in Sewers

Raw sewage is mainly water containing excrement, industrial effluent, and debris. Excrement is the major source of harmful micro-organisms, including bacteria, viruses, and parasites. Treatment of the sewage reduces the water content and removes debris, but does not kill or remove micro-organisms.

Exposure to the micro-organisms is usually through hand-to-mouth contact during eating, drinking, or smoking; or touching exposed skin, i.e. the face, with contaminated gloves. Exposure can also occur through skin cuts and abrasions or from penetration wounds from discarded hypodermic needles. Some organisms can enter the body through the eyes, nose, or mouth.

As well as the general control measures already covered, additional measures include:

- Using robotic methods to eliminate exposure, e.g. robotic cameras for inspection of sewers.
- Drying slurry before disposal.
- Incineration of sludge.
- Injection of sewerage into land rather than spraying.

Blood-Borne Viruses

Hepatitis Viruses

There are at least five types of viral hepatitis, hepatitis A, B, C, D and E, each caused by a different virus named after the type of disease that it causes: hepatitis A virus (HAV), hepatitis B virus (HBV), hepatitis C virus (HCV), and so on.

Hepatitis A and E are usually contracted by the faecal-oral route; i.e. by eating or drinking water or food contaminated with faecal material from an infected person.

The other types, **B, C and D**, are of particular interest from an occupational health point of view because they are blood-borne viruses, transmitted by contact with contaminated body fluids. In recent years, infectious hepatitis has become the most common occupational disease amongst medical staff; those at risk include doctors, surgeons, nurses and ancillary staff, such as hospital porters.

Refuse disposal operatives form another group increasingly at risk from this severe form of jaundice. Infection amongst health workers is a result of contact with blood or excreta of patients suffering from viral hepatitis, or in whom the disease is still in its incubation stage. Hospital porters and refuse disposal operatives appear to be at risk from carelessly discarded syringes and other 'sharps' in disposable plastic sacks. The problem is becoming more severe with the increase in drug addiction and the use of shared needles (a practice that is also thought to be responsible for the spread of HIV-AIDS among drug users).

MORE...

The HSE guidance INDG342 - *Blood-borne viruses in the workplace* is available from:

www.hse.gov.uk/pubns

General information and advice regarding hepatitis is also available from the National Health Service (NHS) and the World Health Organization (WHO):

www.nhs.uk/conditions

www.who.int/health-topics/

The course of the disease is very much like that of leptospirosis (see later), but is usually much less severe and normally self-limiting with recovery in about six weeks. In about 5% of cases, chronic infectious hepatitis follows, leading to cirrhosis, liver cancer and possibly death. Some individuals infected with hepatitis (in particular, type C) do not show symptoms but still carry and transmit the disease.

Vaccinations are available for hepatitis types A and B (but not for C). Some antiviral drugs, such as interferon, are available for chronic cases.

Human Immunodeficiency Virus (HIV)

MORE...

General information and advice regarding HIV and AIDS is available from the NHS and the WHO from:

www.nhs.uk/conditions

www.who.int/health-topics/

Human Immunodeficiency Virus (HIV) is the virus responsible for **Acquired Immune Deficiency Syndrome (AIDS)**. HIV attacks the immune system by which the human body can resist infection. An infected individual may not show any signs of illness for several years. Once the HIV virus has weakened the immune system sufficiently, the person will then become prone to infection and disease (such as pneumonia and cancer). There is no vaccine or cure, though antiviral drugs are effective in combating the effects of the disease in many cases. The virus is found in most body fluids but is relatively delicate (compared to hepatitis B virus which is quite robust) and can be killed by heat and chemicals. It has a low infectivity and transmission is thought to be more likely with repeated exposure to infection rather than to a single contact.

Occupational risk comes from accidental inoculation or contamination of a cut or abrasion with the blood or body fluids of an infected person. Various studies of groups around the world who have been occupationally exposed to HIV-positive people, usually by accidental inoculation, have revealed only a handful of occupationally acquired infections. Doctors, nurses, dentists, laboratory and hospital support staff are identified as workers who can be at some risk, since they may come into close contact with body fluids and hence face the possibility of infection through an exposed cut or by accidental injection. Other workers possibly at risk might include community, welfare, custodial and emergency service workers. Thousands of healthcare workers have come into direct contact with HIV-infected blood and body fluids through needle-stick injuries and other accidents, but only a very small number of occupationally acquired infections have been reported.

Since HIV is a blood-borne pathogen, the **preventive measures** are similar to those for hepatitis listed previously.

Legionella Bacteria

The bacterium *Legionella pneumophila* is responsible for two important occupational diseases: Legionnaires' disease and pontiac fever. The disease Legionellosis is the generic term used to cover both Legionnaires' disease and pontiac fever.

Legionella bacteria are widespread in natural water sources and found in rivers, lakes, streams, mud and soil, as well as man-made water systems. To date, at least 34 different species of *Legionella* are recognised. *Legionella pneumophila* is the most pathogenic and is the species most commonly associated with disease outbreaks.

Infection is caused by inhaling airborne droplets or particles containing viable Legionella bacteria, which are small enough to pass deep into the lungs and be deposited in the alveoli.

Legionnaires' disease is a type of pneumonia. As well as affecting the lungs, it may also have serious effects on other organs of the body.

The first identified outbreak of Legionnaires' disease occurred among people who had attended a Pennsylvanian State Convention of the American Legion in 1976 (hence the name). Delegates subsequently suffered respiratory illness and the bacterium *Legionella pneumophila* was isolated from lung specimens.

The disease usually has an incubation period of three to six days. Males are more likely to be affected than females by a ratio of 3 to 1. Most reported cases occur in the 40-70 year age group. Although healthy individuals may develop Legionnaires' disease, people at greatest risk include smokers, alcoholics, and patients with cancer, chronic respiratory disease or kidney disease. The case-fatality rate is approximately 12%.

Initial symptoms include high fever, chills, headache and muscle pain. A dry cough soon develops and most patients suffer difficulty with breathing. About a third of patients also develop diarrhoea or vomiting and about half become confused or delirious.

Pontiac fever is a milder, non-fatal condition with an incubation period between five hours and three days. The illness usually lasts between two and three days. The symptoms of pontiac fever are similar to those of moderate to severe influenza, with headache, tiredness, fever and in a small proportion of cases nausea, vomiting and coughing.

MORE...

The UK's HSE website has a wealth of information and resources on this topic, including:

- L8 *Legionnaires' disease* - The control of legionella bacteria in water systems - Approved Code of Practice and guidance on Regulations (4th edition), available at:

  www.hse.gov.uk/pubns/priced/l8.pdf

- HSG274, which gives practical advice on the legal requirements concerning the risk from exposure to Legionella and is in three parts:
  - Part 1: *The control of legionella bacteria in evaporative cooling systems*

    www.hse.gov.uk/pubns/priced/hsg274part1.pdf
  - Part 2: *The control of legionella bacteria in hot and cold water systems*

    www.hse.gov.uk/pubns/priced/hsg274part2.pdf
  - Part 3: *The control of legionella bacteria in other risk systems*

    www.hse.gov.uk/pubns/priced/hsg274part3.pdf

- INDG458 *Legionnaires' disease* - A brief guide for dutyholders, available at:

  www.hse.gov.uk/pubns/indg458.pdf

- HSG282 *The control of legionella and other infectious agents in spa-pool systems*, which is primarily for those who manage or operate spa-pool systems and explains how to manage and control the risks from Legionella and other infectious agents, available at:

  www.hse.gov.uk/pubns/priced/hsg282.pdf

The following conditions have been found to affect the Legionella bacteria's rate of growth:

- Water temperatures in the range of 20-45°C favour growth. It is uncommon to find proliferation below 20°C and it does not survive above 60°C. Organisms may remain dormant in cool water, multiplying only when the temperature reaches a certain level.
- The presence of sediment, sludge, limescale and organic material can act as a source of nutrients.
- Commonly encountered organisms in water systems, such as algae, amoebae and other bacteria may serve as an additional nutrient source for Legionella. Algal slime may provide a stable habitat for multiplication and survival.

- Incorporation of *Legionella* in slime on surfaces in contact with water can protect it from concentrations of biocides which would otherwise kill it if it were freely suspended in water.
- *Legionella* can be identified in the laboratory from water samples but this can take at least seven days.

Man-made systems with a reasonably foreseeable risk of exposure to *Legionella* include:

- Water systems incorporating a cooling tower.
- Water systems incorporating an evaporative condenser.
- Hot and cold water systems.
- Other plant/systems containing water which is likely to exceed 20°C and which may release a spray or aerosol during operation or when being maintained (e.g. humidifiers, air washers, spa baths and pools).

Preventive measures for the control of *Legionella* include:

- The appointment of a competent person to take responsibility for managing the control scheme.
- Assessment of the risks inherent in the water system in the workplace (recorded if there are five or more employees).
- Preparation of a written scheme for the control of the *Legionella* risk, including information on the system, the responsible person, the operational parameters of the water system, the control methods and precautions and the checks to be carried out.
- The adoption of practical controls, such as:
  - Proper control of the release of water spray.
  - Management of water temperatures and conditions to avoid those that favour the growth of Legionella and other micro-organisms.
  - Preventing water from stagnating anywhere in the system by keeping pipe lengths as short as possible and by removing redundant pipework.
  - Avoiding materials that encourage the growth of *Legionella*.
  - Keeping the system and the water in it clean.
  - Treating water to kill or limit *Legionella* growth.
- Water treatment, such as:
  - Treatment of cooling towers/systems using biocides.
  - Ultraviolet (UV) irradiation, copper/silver ionisation and ozone.
  - Storing hot water above 60°C and distributing it at above 50°C - and keeping cold water below 20°C if possible.
  - Using chlorine dioxide (chlorination) for tap water.
- Water sampling to test for *Legionella*. Though a negative result does not prove that an entire system is Legionella-free, and a positive result may not mean that there is unacceptable risk.

Leptospira Bacteria

Leptospira bacteria are responsible for the disease **Leptospirosis** (also called **Weil's disease** in its severe form).

MORE...

Websites with useful information relating to biological agents:

www.hse.gov.uk

www.nhs.uk/

www.gov.uk/government/organisations/public-health-england

Dozens of websites also have background information on micro-organisms.

The *Leptospira* bacteria are found in the kidneys of infected rats (and other mammals, such as cattle) and are urinated out of the host animal; it is from this source that humans are infected. Infection usually occurs following contact with fresh rat urine or water that has been urinated into. The bacteria enter the body through damaged skin and through the mucous membranes of the mouth.

Occupational at-risk groups include anyone who is exposed to rats, rat or cattle urine or to foetal fluids from cattle. Farmers are now the main group at risk for both Weil's disease and cattle leptospirosis - the cattle form is a special risk for dairy farmers. Other occupational groups who have contracted leptospirosis in recent years include:

- Vets.
- Meat inspectors.
- Butchers.
- Abattoir and sewer workers.
- Workers in contact with canal and river water.

Symptoms of the disease can be divided into three stages:

Stages of leptospirosis infection

Stage I:	Fever with 'flu-like symptoms lasting for about a week. (It is for this reason that workers at risk should carry a card for presentation to their GP on the appearance of any 'flu-like symptoms, so that the possibility of the onset of Weil's Disease may be considered.)
Stage II:	By the start of the second week the fever has abated and jaundice becomes more obvious (sometimes making its appearance as early as the fourth day). This toxic stage is the result of the development of antibodies in the blood and the excretion of bacteria in the urine. About 5-10% may die at this stage.
Stage III:	The convalescent period. In severe cases the jaundice may be present for three or four weeks and a second fever usually occurs lasting for up to two weeks. Recovery can take many weeks or months, with patients remaining very tired and lethargic for a considerable time.

Preventive measures include:

- Good pest control, such as getting rid of rats and avoiding rat infestations through good housekeeping.
- Washing cuts and grazes immediately with soap and running water.

- Covering cuts and broken skin with waterproof plasters before and during work.
- Wearing protective clothing (and laundering it).
- Good hand-washing after handling animals or contaminated material.
- Good hand-washing before eating, drinking or smoking.
- Early reporting of symptoms to a doctor.
- Carrying an alert card to provide additional information to the doctor about the risk.

Norovirus

Norovirus is associated with 18% of global diarrheal disease and estimated deaths of 200,000 people worldwide. Norovirus is the most common cause of gastroenteritis in the UK. Each year, it's estimated that between 600,000 and 1 million people in the UK catch a norovirus infection.

The virus is highly contagious and easily spread. If an infected person doesn't wash their hands before handling food, they can pass the virus onto others. It is also possible to catch it by touching contaminated surfaces or objects. It can affect people of all ages and causes vomiting and diarrhoea. The incubation period is usually between 12 and 48 hours. Once sickness and diarrhoea start, the symptoms usually last for one to two days and then resolve naturally as the immune system rids the body of the virus. Sufferers are infectious to other people during this time. Although having a norovirus infection can be unpleasant, it's not usually dangerous and most people make a full recovery within a couple of days.

The following control measures can help prevent the virus spreading:

- Frequent hand washing.
- Avoiding the sharing of potentially contaminated articles, such as towels, clothing and PPE.
- Disinfecting potentially contaminated surfaces (that an infected person has touched).

Outbreaks of norovirus in public places, such as hospitals, nursing homes and schools, are common because the virus can survive for several days on surfaces or objects touched by an infected person.

In the UK, the general duties of the **Control of Substances Hazardous to Health Regulations** apply to incidental exposure to, and deliberate work with, biological agents. However, this legislation does not cover a situation where one employee may catch a respiratory infection from another. This is because the Regulation specifies that they apply when the exposure risk is work related, and not those where they have no direct connection with the work being done.

STUDY QUESTIONS

1. How does the ILO define a biological agent?
2. What are the four main categories of micro-organisms?
3. Explain the term 'zoonoses' and describe an occupational example.
4. Identify two occupational groups at risk from exposure to biological agents and, for one of these groups, summarise the ill health conditions that could arise.
5. What are the symptoms of Weil's disease (leptospirosis)?

(Suggested Answers are at the end.)

Summary

Types and Properties of Biological Agents

We have described how:

- Biological agents are micro-organisms, cell cultures, or human endoparasites which may cause infection, allergy, toxicity or a similar health hazard.
- The four types of biological agents of concern are: fungi, bacteria, viruses and protozoa. These are all microscopically small entities passed to humans from other humans, plants, animals or environmental sources.
- Many biological agents have special properties that complicate the risk that they present, namely a rapid mutation rate, an incubation period, infectiousness and the ability to multiply rapidly.
- Zoonoses are diseases that are passed to humans from vertebrate animals. Examples include: cryptosporidiosis, and psittacosis.
- Vector borne diseases are diseases that are transmitted to humans by insects or other small organisms. Malaria is a significant global vector-borne disease that can be a significant risk to workers travelling overseas to tropical countries where it is present.
- Biological agents of note that cause significant occupational diseases include: the blood-borne viruses hepatitis B, C, D and Human Immunodeficiency Virus (HIV), *Legionella* bacteria, *Leptospira* bacteria and norovirus.

Learning Outcome 9.11

NEBOSH International Diploma for Occupational Health and Safety Management Professionals

ASSESSMENT CRITERIA

- Recognise what noise is, what effects it can have on people, how it can be assessed, the control measures that can be used and the legal requirements to manage noise exposure in the workplace.

LEARNING OBJECTIVES

Once you've studied this Learning Outcome, you should be able to:

- Explain the basic physical concepts relevant to noise.
- Explain the effects of noise on the individual and the use of audiometry.
- Explain the measurement and assessment of noise exposure.
- Explain the principles and methods of controlling noise and noise exposure.

Contents

Basic Concepts of Noise

IN THIS SECTION...

- Noise is defined as *"all sound which can result in hearing impairment or be harmful to health or otherwise dangerous"*.
- A noise source generates pressure waves in air. Two characteristics of these pressure waves, their amplitude and frequency, are important in understanding their nature:
  - The amplitude determines the intensity of the noise - measured using the decibel scale (dB).
  - The frequency determines the pitch of the noise - measured in hertz (Hz).
- The decibel scale is a logarithmic scale. The addition of 3dB is a doubling of noise intensity.
- The human ear is not equally sensitive to all frequencies; consequently, the A-weighting matrix (represented by dB(A)) is used to correct for this frequency bias when calculating the amount of energy that has been delivered into the inner ear.
- The amount of damage done to the inner ear is determined by the dose of noise received. Dose is determined by two factors: the intensity of the noise (dB(A)) and the duration of exposure.
- The human ear detects noise by mechanically transmitting sound pressure waves from the outer ear through to the inner ear. There, fine sensory hairs respond to the pressure waves in fluid, sending nerve signals to the brain.
- Exposure to excessively loud noise can physically damage the transmission structures of the ear and can also cause deterioration of the sensory hairs in the inner ear.
- Tinnitus, Temporary Threshold Shift (TTS), Permanent Threshold Shift (PTS) and Noise-Induced Hearing Loss (NIHL) are all health effects associated with exposure to loud noise.
- Audiometry can be used as a form of health surveillance to determine the sensitivity of a person's hearing. The graphs produced (audiograms) can be used to differentiate between age-related hearing-loss (presbycusis) and NIHL.
- Noise surveys must be carefully planned to ensure that representative measurements are taken, to give a true reflection of real noise exposures occurring at work.
- Several different instruments are available for measuring noise; simple sound level meters, Integrating Sound Level Meters (ISLM), dosimeters and octave band analysers.
- ISLMs used for noise surveys must be calibrated before use and must be tested and certificated for results to be valid.
- Key information recorded during a survey is the equivalent continuous A-weighted sound pressure level (L_{Aeq}), maximum C-weighted peak sound pressure level (L_{CPeak}) and the duration of exposure.
- L_{Aeq}, in combination with duration of exposure, is then used to calculate a daily personal noise exposure ($L_{EP,d}$). This can be done using formulae, the UK's HSE web-based calculator, or the HSE ready reckoner.
- Calculated daily personal noise exposures ($L_{EP,d}$) can then be compared to the legal standards.
- Examples of national limits using the UK's **Control of Noise at Work Regulations 2005**:
  - The **Lower Exposure Action Value** (LEAV) for noise is 80dB(A) $L_{EP,d}/L_{EPw}$ and 135dB(C) L_{CPeak}.
  - The **Upper Exposure Action Value** (UEAV) is 85dB(A) $L_{EP,d}$ /L_{EPw} and 137dB(C) L_{CPeak}.
  - The **Exposure Limit Value** is 87dB(A) $L_{EP,d}/L_{EPw}$ and 140dB(C) L_{CPeak}.

- Noise control can be achieved by applying a hierarchy of controls:
  - Reduce noise at source by eliminating hazardous noise at source, changing the source, re-locating the source, re-designing the source (e.g. damping) and maintenance.
  - Attenuate noise transmission by isolating the source, using acoustic barriers or using an acoustic enclosure for the source.
  - Control noise exposure at the receiver using acoustic havens, hearing protection zones, and the use of passive and active hearing protection, limiting exposure time and health surveillance.
- Hearing protection must be carefully selected by reference to its attenuation data and the noise profile of the workplace. Three different methods exist to determine the attenuation achieved: octave band analysis, High, Medium, Low (HML) and Single Number Rating (SNR).

Definition of Noise

According to the ILO, noise is defined as:

> *"All sound which can result in hearing impairment or be harmful to health or otherwise dangerous."*

Source: C148 - Working Environment (Air Pollution, Noise and Vibration) Convention, 1977 Copyright © International Labour Organization, 1977

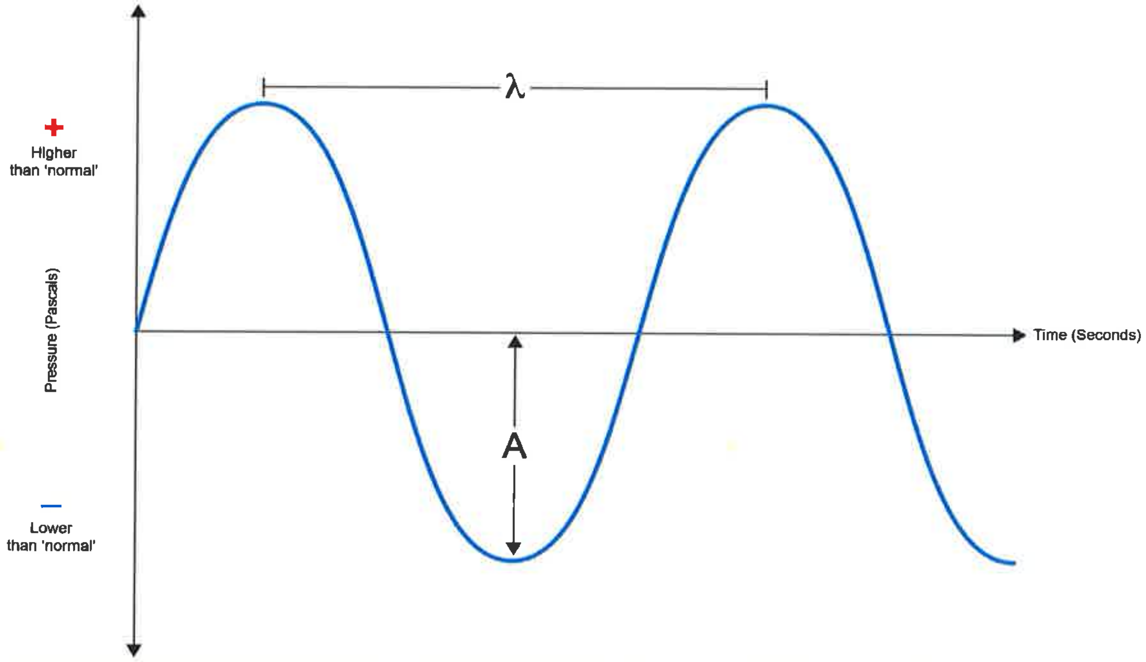
It is worth noting that noise is commonly defined as 'unwanted sound'. From a health and safety perspective, this definition is incorrect and misleading. It makes no difference whether a sound is wanted or unwanted; if exposure is significant then risk of hearing damage exists. The Regulations do not differentiate between wanted and unwanted sound; the risk to hearing created by the noise generated by an orchestra is considered in the same way as that generated by a diesel engine.

A significant occupational noise source - chainsaw use

Basic Concepts of Noise

A source of noise (e.g. chainsaw or hi-fi system) emits pressure waves into the air. These pressure waves are longitudinal waves, meaning that they exist as compression waves in the medium through which the sound is travelling. Sound will only travel through a medium (such as air or water). It cannot travel through a vacuum. Sound pressure waves move away from the noise source at the speed of sound (343 metres per second in air at sea level).

The characteristics of a sound pressure wave can be visualised by plotting a graph of pressure (measured in Pascals) against time, as in the following figure.



Graph of pressure against time for a sound of one single frequency, as might be generated by a tuning fork

There are several characteristics of this sound wave that are of interest:

- **Sound Pressure**

  Sound pressure is the average variation from the ambient atmospheric pressure caused by a sound wave. Sound pressure level (SPL), is a pressure measurement of sound in decibels (dB). SPL considers the whole increase in pressure levels - not only from a single noise source but also from reflections of noise from walls/ceiling and other sources. SPL is measured at the worker's ears.

- **Amplitude**

  This is the maximum displacement of pressure. In the graph above, it is represented by A and can be thought of as the height of the peak or depth of the trough of the sound wave. This equates to the 'loudness' or 'volume' of the noise; the bigger the amplitude, the greater the pressure difference and the louder the noise sounds.

- **Intensity**

  The intensity of sound is the power transmitted per unit area (measured in W/m^2); it is proportional to the square of the amplitude.

- **Frequency**

  This is the number of sound pressure waves generated per second (the unit of frequency is the hertz (Hz)). The frequency of a sound wave relates directly to its **pitch**. Sounds with a low frequency will sound very low-pitched, and sounds with a high frequency will sound high-pitched.

  Frequency is inversely proportional to the **wavelength** of the sound wave; the distance (in metres) between one peak and the next (shown in the graph above by the symbol λ). This means that as wavelength increases, frequency decreases.

Decibel Scale

Because sound intensity is proportional to the square of the amplitude, as amplitude increases, intensity increases exponentially. To explain; an increase in amplitude from 2 to 3 and then 4 is matched by an increase in intensity from 22 (4) to 32 (9) and then 42 (16).

The human ear can hear sounds across an enormous range of intensities; from the **threshold of hearing**, up to the **threshold of pain**. The intensity of the pressure wave at the threshold of pain is 10,000,000,000,000 times greater than the intensity of the pressure wave at the threshold of hearing.

To allow for easy measurement of sound intensity across such a huge range, the **decibel scale** is used, where 0 decibels (dB) is the threshold of hearing and 130dB is at the threshold of pain. The decibel scale is a logarithmic scale meaning that an increase in dB value of ten represents a ten-fold increase in intensity. So, 10dB is ten times the intensity of 0dB, 20dB is a hundred times the intensity of 0dB, 30dB is a thousand times the intensity of 0dB, and so on. See below for some typical decibel levels associated with different noise sources.

Examples of typical noise levels
Source: INDG362 (rev1) Noise at Work - Guidance for Employers on the Control of Noise at Work Regulations 2005, HSE, 2005

A-Weighting and C-Weighting

The human ear is not equally sensitive to sounds across all frequencies. Humans cannot hear very low- or very high-frequency sounds. The human hearing frequency range is from 20Hz to 20,000Hz (20KHz). Even within this frequency range, the human ear is more efficient at detecting the mid-range frequencies. Because the human ear is not equally sensitive to sounds at all frequencies, sound level meters have weighted scales to account for a variable sensitivity to frequency. The **A-weighted scale (dB(A))** electronically assimilates the sound pressure and mimics the human ear's response across the range of frequencies. The measurement of noise in dB(A) is a good indication of the physical harm caused to hearing.

Other weighting scales are also used, such as **C-weighting (dB(C))** for peak sound pressure.

Addition of Decibels

Because the decibel scale is a logarithmic scale, it is not possible simply to combine two separate sound levels together by adding them. For example, if you were to stand mid-way between two identical diesel engines, each of which individually produced a sound pressure level of 90dB(A), you would not be exposed to 90 + 90 = 180dB(A). Such a noise level would rupture your eardrums and cause instant deafness.

However, an estimate of the combined noise intensity can be made, provided the two noise sources are of equal value (i.e. same decibel value). In that case, a 3dB increase represents a doubling of sound intensity. In practice, the introduction of another source of equal value will double the sound intensity and hence increase the dB reading by 3. So, for the example above, two noise sources of 90dB(A) will give a total of 93dB(A).

So, 83dB + 83dB = 86dB

Noise Dose

MORE...

The British HSE website has a microsite dedicated to noise which has a range of publications, tools, etc. to use:

www.hse.gov.uk/noise

Other useful resources can be found on the EU OSHA website at:

https://osha.europa.eu/en

The damaging effects of noise are related to the total dose of energy that the ear receives. The dose is determined by two factors: the **level of noise** and the **duration of exposure**. A large dose of noise presents the same risk of hearing damage irrespective of how that large dose is achieved; so, a dose of noise achieved by exposure to a very loud noise for a short period of time presents the same risk of hearing damage as the same dose of noise achieved by exposure to a lower level of noise over a much longer period of time. The two doses of noise are said to be **equivalent**.

The concept of equivalent noise dose has been used in legislation. The ILO Convention C148 covering air pollution, noise, and vibration does not establish limits but determines that these should be established by the appropriate national competent authority. In the UK, the **Control of Noise at Work Regulations 2005 (CNAW)** refer to a worker's daily noise dose as the "**equivalent continuous daily personal noise exposure level**" or $L_{EP,d}$ and use the concept of noise dose to average out worker exposure over an 8 hour working shift.

For example, if a worker's noise exposure is calculated to be an 'equivalent continuous daily personal noise exposure level' ($L_{EP,d}$) of 85dB(A) then this is equivalent to exposure to a continuous noise, at an unvarying level of 85dB(A), occurring for eight hours. Exposures with different combinations of sound level and duration can produce a daily personal noise exposure ($L_{EP,d}$) of 85dB(A). This is illustrated in the following table:

Noise exposure

Sound Level dB(A)	Exposure Equivalent to 85dB(A) $L_{EP,d}$
85	8 hours
88	4 hours
91	2 hours
94	1 hour
97	30 mins
100	15 mins
103	7.5 mins

To explain; you will remember that a doubling of sound intensity is achieved by adding 3dB. Thus, the same dose of noise is achieved by doubling sound intensity but halving the time of exposure (85 + 3dB = 88dB(A); 8 hours/2 = 4 hours). So, what the table shows is that 85dB(A) for 8 hours is the same dose of noise as 88dB(A) for 4 hours, which is the same dose of noise as 103dB(A) for 7.5 minutes, etc. The above noise exposures are all equivalent to 85dB(A) $L_{EP,d}$. Each of these exposures will therefore deliver the same amount of energy into the ear, and so present the same degree of risk to hearing.

The following noise exposures will have to be directly measured or calculated during a noise assessment:

- **L_{Aeq}** - this represents the **equivalent continuous** A-weighted noise dose over the measurement period (alternatively written as L_{eqdB}(A)). L_{Aeq} is, in effect, a time-weighted average dose of noise over any time period chosen, e.g. 5 seconds, 7 minutes or 3 hours.
- **$L_{EP,d}$** - this represents the equivalent continuous **daily personal noise exposure** level. $L_{EP,d}$ is, in effect, the time-weighted average dose of noise calculated for a notional eight-hour day.
- **$L_{EP,w}$** - this represents the equivalent continuous **weekly personal noise exposure** level. Where very changeable exposures occur from day to day, the Regulations allow for a weekly personal noise exposure ($L_{EP,w}$) to be estimated and used for comparison to the standards.
- **L_{CPeak}** - maximum C-weighted peak sound pressure level(s) to which a person is exposed. This is the peak sound pressure level recorded during a noise survey using a sound level meter set to the C-weighted decibel scale. This is not a time-weighted average exposure (and so not a dose) but represents the 'spike' in sound pressure level achieved by exposure to a single **impulse** noise, such as a loud bang. A metal-cutting guillotine or a large metal object dropped on a concrete floor would produce such a pressure spike.

Physiology of the Ear

In order to explain how hearing is affected by exposure to noise, it is important to first consider the biology of our ears.

The main parts of the ear are shown in the following figure:

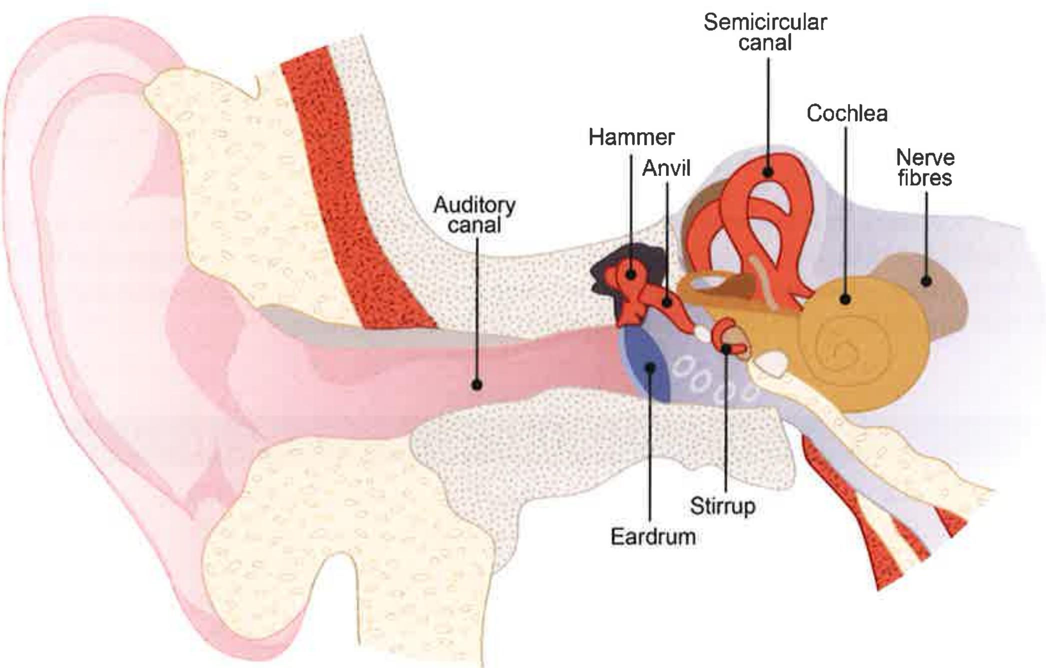


Diagram showing the internal parts of the ear

The three main parts of the ear are the:

- Outer ear with auditory canal.
- Middle ear.
- Inner ear.

The outer ear reflects and focuses incoming sound waves into the auditory canal. Sound waves then pass down the canal and set the eardrum vibrating. Between the eardrum and the fluid-filled inner ear are three small bones (ossicles) of the middle ear, known respectively as the hammer, the anvil and the stirrup. The hammer is attached to the eardrum and together with the anvil it forms a lever that acts on the stirrup. The stirrup is attached to the oval window in the wall separating the middle and inner ears. The middle ear transmits sound energy into the fluid of the inner ear.

The inner ear is made up of a complex set of small tubes and chambers embedded in solid bone. The part concerned with hearing is the **cochlea**, a spiral cavity that resembles a snail shell. The cochlea consists of about 30,000 highly sensitive hair cells. Pressure waves, transmitted into the fluid in the cochlea by the middle ear, bend the 'tufts' on top of these hair cells, stimulating the nerve endings at their base. Thus, sound energy is transmitted from the outer ear, through the middle, to the inner ear where it is converted to nerve impulses which are transmitted to the auditory centres of the brain.

Effects of Noise Exposure

Hearing Loss

Hearing loss (the process of losing auditory sensitivity) occurs, to a degree, naturally with age, but it may occur to a greater degree as the result of external causes. It can be classified under three broad headings:

- **Conductive hearing loss** occurs due to a physical breakdown of the conducting mechanism of the ear, resulting from an acute acoustic trauma, e.g. an explosion or gunfire. The eardrum, ossicles, or the cochlea, can be damaged, often beyond repair. There is no cure, although surgery may reduce the damage to the eardrum. This form of hearing loss will occur instantly upon exposure to the very loud noise and is therefore often referred to as **instantaneous** hearing loss. This form of hearing loss is not frequently caused by occupational noise exposures.
- **Sensorineural hearing loss** occurs when the hair cells in the cochlea are damaged. Harm may result from natural causes, such as infection, or by physical injury. In an occupational setting, sensorineural hearing loss occurs from long-term exposure to excessive noise, and so this is the type of hearing loss most commonly found by the safety practitioner.
- **Instantaneous hearing loss** or sudden deafness is also known as sudden sensorineural hearing loss (SSHL). SSHL occurs when there is something wrong with the sensory organs of the inner ear and it can affect one or both ears. It can happen instantly or over a span of several days. During this time, sound gradually becomes muffled or faint. A loss of 30 decibels in three connected frequencies is considered SSHL. This means that a hearing loss of 30 decibels would make normal speech sound like a whisper. Possible causes include very loud noise, neurological conditions, manière's disease, ototoxic drugs, tumours, and head injury.

Tinnitus

Tinnitus is a condition where the sufferer hears 'ringing in the ear' or other types of noise in their head without there being any external noise source. There are no observable external symptoms.

Tinnitus can occur after exposure to excessive noise levels as an acute condition which recedes with time (e.g. after attending a rock concert). The recovery period could be 12 or more hours where very high exposure levels occur.

People who have chronic noise-induced hearing impairment can suffer from chronic tinnitus. The symptoms of tinnitus suggest that damage to the nerve structure of the cochlea or the auditory nerve has occurred, or possibly both.

Threshold Shift

Threshold shift is a reduction in a person's ability to hear, i.e. they need more sound intensity to stimulate their hearing. The condition can be permanent or temporary:

- **Temporary Threshold Shift (TTS)**

  Temporary Threshold Shift (TTS) occurs after exposure to high noise levels where hearing acuity returns with time. The condition has been described as a fatigue of the hair cells in the cochlea. The level of threshold shift is expressed in terms of the raising of sound intensity required to hear a given sound level, e.g. a 20dB shift means the sound level has been increased by a value of 20dB before the individual concerned could detect the sound.

  If a person is subjected to a high noise level, say 90dB for a few hours, and then has a hearing test (audiometry), a loss of hearing acuity will be detected with the most pronounced dip occurring at a frequency of 4000Hz (4kHz).

  This is often described as the '4kHz dip' for acoustic trauma. The amount of dip from the 0dB average level is used to specify the amount of threshold shift. The development of a TTS is a function of time and noise level; the longer the exposure and the higher the noise, the greater the hearing loss.

  Recovery from TTS occurs over a period of several hours to several days and is first rapid and then proceeds at a reduced rate. The higher the noise exposure, the longer the recovery time.

- **Permanent Threshold Shift (PTS)**

  Permanent Threshold Shift (PTS) is the condition where there is a permanent reduction in hearing acuity, with the most pronounced reduction occurring at 4kHz. This reduction is irreversible, with no recovery of hearing acuity with time away from exposure. The condition follows from repeated TTS exposures, as might occur in a workplace where noise levels are high day after day and hearing protection is not worn (or not sufficient).

  When PTS first begins to occur, the dip may be detectable using a hearing test (audiometry) but may not interfere with the individual's ability to hear human speech. Unfortunately, if further high noise exposures take place, the shift worsens until the condition described as 'noise-induced hearing loss' occurs, where the ability to hear human speech is disrupted.

Noise-Induced Hearing Loss (NIHL)

Noise-Induced Hearing Loss (NIHL) is a permanent threshold shift caused by exposure to excessive noise. NIHL is a condition that results from failure of the hair cells in the cochlea to respond fully to sound intensities that have frequencies within the human speech range. The person does not necessarily lose the ability to hear all sounds, but is not able to distinguish the spoken word clearly, even if it is presented with a raised voice.

Presbycusis

Presbycusis is the term used to describe a reduction in hearing acuity that occurs naturally with age. This age-related hearing loss affects the individual's ability to hear, especially high frequency (high-pitched) noises. This type of hearing loss might start at the age of 30 and become more significant from the age of 60 onwards. Presbycusis accounts for the fact that young people may be sensitive to high frequency noise that an older person cannot hear. This has been put to use in 'youth repellent devices' to disperse teenagers.

A recent survey by the RNID has found that managers and workers can lack support for those with hearing loss, leading to exclusion from social conversations and increased isolation. These conditions then become stressful for the worker with hearing loss and they may be subject to workplace bullying. Almost half of workers with hearing loss do not tell their employer because of perceived attitudes towards them. People with hearing loss are more likely to experience social distress, loneliness, and depression.

Noise Risk Assessment and Planning for Control

The Principles of Noise Assessment

Workplace risk assessments should consider the risk of hearing impairment.

Risk assessments determine the daily personal noise exposure

Section 9.2 of the ILO Code of Practice - *Ambient Factors in the Workplace* (CoP) outlines the requirements for carrying out a workplace noise risk assessment.

The CoP states that the level of noise and/or duration of exposure should not exceed the limits established by the competent authority or other internationally recognised standards. The assessment should consider the:

- Risk of hearing impairment.
- Degree of interference with speech communications essential for safety purposes.
- Risk of nervous fatigue, with due consideration to the mental and physical workload and other, non-auditory hazards or effects.

The CoP requires that, for the prevention of adverse effects of noise on workers, employers should:

- Identify the sources of noise and the tasks that give rise to noise exposure.
- Seek the advice of the competent authority or occupational health service about exposure limits and other standards to be applied.
- Seek the advice of the suppliers of processes and equipment about the expected noise emission.
- If necessary, arrange for noise measurements to be taken by competent persons to nationally or internationally recognised standards.

In the UK the **Control of Noise at Work Regulations 2005 (CNAW)** require that where it is likely that a Lower Exposure Action Value may be exceeded, employers must carry out a suitable and sufficient risk assessment (the Regulations' action values will be described in more detail later). This section focuses on the requirement to undertake an assessment of noise exposure.

The purpose of the assessment is to:

- Identify people at risk of hearing damage.
- Determine the daily personal noise exposure ($L_{EP,d}$) of those who are likely to be exposed at, or above, the lower exposure action value.
- Identify additional information to comply with the Regulations, such as where noise control and hearing protection may be required.

The employer is therefore required to **reliably estimate** noise exposure in areas where a lower exposure action value might be exceeded. They are then required to establish daily personal noise exposures ($L_{EP,d}$) or, where exposures differ markedly from day to day, weekly personal noise exposures ($L_{EP,w}$), from the estimated values and the duration of exposure.

The employer might make use of an external consultant to undertake a noise assessment, or it might be undertaken by an internal person. In either case, the person must be competent. Qualifications, such as the Institute of Acoustics Certificate of Competence in Workplace Noise Risk Assessment, can be used as proof of competence, as can experience and membership of organisations, such as the Association of Noise Consultants (ANC), British Occupational Hygiene Society (BOHS), etc.

Note: there is often confusion between noise surveys and noise risk assessments. A **noise survey** is a measurement and record of noise levels in a noisy area. The data is used in **noise assessments**, which is far more than a noise survey.

DEFINITION

EXPOSURE ACTION VALUE

A noise exposure level at which employers are required to take certain steps to reduce the harmful effects of noise on hearing.

In UK legislation, for example:

- The lower exposure action value is a daily or weekly average noise exposure level of 80dB, at which the employer has to provide information and training, and make hearing protection available.
- The upper exposure action value is set at a daily or weekly average noise exposure of 85dB, above which the employer has to take measures to reduce noise exposure, and requires the use of hearing protection if the noise cannot be controlled by these measures.

A five-step approach to a noise risk assessment is described in the British HSE Guidance L108: *Controlling Noise at Work*, from which much of what follows is summarised.

- **Step 1: Is there a Risk Due to Noise?**

  This should be a relatively quick and uncomplicated decision. Noise data for equipment can be obtained from manufacturers/suppliers. Hearing checks can be used, e.g. if you need to shout to make yourself heard by a person only one metre away from you for more than about 30 minutes per day, then implied noise level exceeds around 90dB.

- **Step 2: Who Might be Harmed and How?**

  This involves identifying the people at risk. Don't just think about the operator of the noisy machine, but also other people working nearby. The Regulations require the protection of workers, rather than members of the public (on the basis that workers will be constantly present in the workplace but members of the public are likely to be transiently exposed).

- **Step 3: Evaluate the Risks and Develop a Plan to Control Them**

  To assess noise exposure properly, you need information on the average noise exposure levels, i.e. L_{Aeq} for your workers at risk, for various tasks done in a day and the time the worker spends on each of these tasks. It is worth saying that the law is not expecting precise measurements of noise. Rather, it is expecting a reliable estimate, so that you can assess whether any exposure action values are likely to be exceeded. This means that your data must be representative of employee exposure, taking account of all the different patterns of work, etc.

  Thus, L_{Aeq} may be calculated from actual noise measurements in your workplace, or noise level data from machinery manufacturers or suppliers. You may need to do a little of both, depending on the level of uncertainty.

  You also need to estimate the duration of exposure (easily done by observation and discussions).

From this data, you can then determine the daily personal noise exposure, using the formulae presented in **Schedule 1** to **CNAW** or the British HSE noise calculator spreadsheets and ready reckoner tools, described later.

You can then compare your calculated estimates to the lower and upper action values and the limit values contained in the Regulations. This determines any specific duties under the Regulations. Depending on the nature of your estimate, you may need to allow for some uncertainty in this comparison, i.e. treat an uncertain value close to an action value as if the action value is likely to have been exceeded.

You should then consider whether the risks have been reduced to the lowest level reasonably practicable, or if you need to do more to control noise risks. If you need to do more, develop an action plan. The plan would contain things such as, immediate actions taken to control the risks, e.g. personal hearing protection or longer-term actions (such as implementing a purchasing policy favouring less noisy machinery, plans for developing further noise reduction measures, training of personnel, health surveillance, etc.).

- **Step 4: Record the Findings**

  Record the major findings (risk assessment and action plan).

- **Step 5: Review the Risk Assessment**

  Review the assessment in all the usual circumstances, e.g. if there is reason to suspect it is no longer valid, when there is a change to equipment/methods of work, etc.

Planning the Survey

The noise survey forms an important part of the noise risk assessment and should cover the following points:

- **Who Should Be Assessed?**

  All workers likely to be exposed at or above a lower exposure action value, for example:

  - Workers who spend most of their day next to noisy machines.
  - Those who enter noisy areas for short periods.
  - Those whose exposure varies from day to day (i.e. maintenance, etc.).

- **Where?**

  At every location that the person works in, or walks through, during the day:

  - Note the time spent in each location.
  - It is not generally necessary to record exposures below 75dB(A) or so, because it is not significant in relation to the action value.

- **How?**

  - Take measurements at the position occupied by the operator's head and preferably with the person not present. If the operator needs to be present (e.g. to control the machine), then measure close enough to the head to get a reliable measurement, but far enough away to avoid sound reflections (>15cm).
  - In order to avoid taking lots of measurements, you can assume a worst case and measure the noisiest location (or during the loudest periods).
  - You can take more detailed measurements if this approach shows that the lower exposure action value is likely to be exceeded.
  - If using a dosimeter (described in more detail later), place the microphone on the person's shoulder (to prevent it touching the neck, etc.).

- **For How Long?**

  Measurements need to be sufficient to account for variations in the day. With integrating sound level meters, measurements should be long enough to obtain an indication of the average level of exposure. You may need to measure the A-weighted L_{eq} for the entire exposure period, but you can often do so for a shorter period if noise is steady or cyclic.

  Dosimeters are designed to operate for long periods (an entire shift) and for workers who have highly variable exposure.

- **Group Sampling**

  If several workers work in the same area, you may be able to assess the exposure for all by doing measurements in selected locations. Choose the locations and durations so as to determine the highest exposure someone is likely to receive.

- **Mobile Workers and Highly Variable Daily Exposures**

  This includes, for example, maintenance. There is no typical daily exposure here. Measure a range of different activities likely to be encountered - estimate the worst likely exposure from these.

- **Very Short Duration Noise**

  This includes, for example, gunfire, explosions, and cartridge-operated tools.

  This may already be included in the overall noise measurements of L_{Aeq} for the exposure period. There are methods to assess this separately if it has been excluded from other measurements, or if the meter does not have sufficient dynamic range.

- **Second, More Detailed, Noise Survey**

  This may be needed where exposure is at, or exceeds, an upper exposure action value. You may need to use frequency (octave band) analysis to enable proper selection of noise-attenuating materials and hearing protection.

Instrumentation for Taking Measurements

The sound level meter used must be a Class 2 integrating sound level meter (or better), with an in-date certificate of test and a suitably tested calibrator. Dosimeters might be used where workers move around in the workplace, preventing the measurement of exposure at static locations.

Several different categories of instrument are available:

- **Simple Sound Level Meter (SLM)**

  This gives a read-out of the sound level at that specific moment in time, usually with the facility to switch between A-weighting and C-weighting. These are basic meters that are suitable for the measurement of continuous or intermittent periods of steady noise. They can also be used where the noise fluctuates moderately. If the noise is non-impulsive and fluctuates through a range less than 5dB(A), the average reading of the meter can be estimated by eye if the response of the meter is set to 'slow'.

  Simple sound level meters are convenient for making routine spot checks, but are not considered adequate for establishing compliance with legal standards in most instances.

A simple Sound Level Meter (SLM)

- **Integrating Sound Level Meters (ISLM)**

  These are general-purpose meters that are capable of measuring the noise levels over a period of time and adding them together (integration), to give an average value for the measurement period. This value is called the Leq.

  For use in compliance with **CNAW**, such a meter must be a:

  - Class 2 instrument (**BS EN ISO 61672-1:2013**).
  - Equivalent, continuous A-weighted sound pressure level (L_{Aeq} or $L_{eqdB}(A)$), which is used to calculate the daily personal noise exposure ($L_{EP,d}$).
  - Maximum C-weighted peak sound pressure level (L_{CPeak}).

  An **octave band analyser** is a type of ISLM that allows frequency analysis of the noise to be carried out. Many ISLMs have a built-in octave band analysis function. Frequency analysis is the process of analysing noise by looking at the sound pressure level at different frequencies.

An Integrating Sound Level Meter (ISLM)

- **Personal Sound Exposure Meters (Dosimeters)**

  These devices are worn by the person whose exposure is being determined, to measure the total noise dose over the whole working period. The equipment consists of a small, portable amplification and recording unit that can be worn in a pocket or on a belt by the operative, and a flexible microphone unit that can be attached to a collar or supported from a helmet. The important point is to ensure that the microphone is positioned close enough to the operator's head to obtain a reliable assessment of the noise to which they are exposed. However, if the microphone is mounted too close to the person's body, reflections from the person will reduce the accuracy of the measurement. These meters are also susceptible to abuse by the wearer (e.g. tapping the microphone). For use in compliance with **national standards,** it must, at least, comply with **BS EN ISO 61252** or the International Electrotechnical Commission (IEC standard) of the same number.


Recommended position for a dosimeter microphone
Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

Importance of Calibration

The meter should be calibrated before and after use to ensure the noise measurements accurately reflect the actual noise intensities. A separate calibrator is used for this purpose; this produces a pure tone of a set intensity against which the meter can be adjusted.

For use in compliance with legal standards, calibrators should be at least Class 2, **BS EN ISO 60942**.

Both calibrator and sound level meter must be tested and certificated every two years to ensure scientific accuracy.

Measurements to be Taken

There are no established international limits for noise exposure, therefore we will use the limits and measurements established in the UK's **CNAW** Regulations as an example.

For each significant noise exposure (which might occur at different locations or for different tasks performed at the same location the following measurements should be taken):

- L_{Aeq} - equivalent continuous A-weighted sound pressure level.
- L_{CPeak} - maximum C-weighted peak sound pressure level(s) to which the person is exposed.
- Duration of exposure.

These will enable calculation of the daily (or weekly) noise exposure ($L_{EP,d}$).

Making measurements with a hand-held sound level meter
Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

Interpretation and Evaluation of Results

Calculating Noise Exposure

The British HSE's L108 document sets out the mathematical relationship between time averaged levels of noise and daily exposure and also provides a formula for combining mixed exposures of noise. A 'ready reckoner' is also provided by the HSE to simplify this process.

It is important to appreciate the two terms 'L_{Aeq}' and '$L_{EP,d}$' described earlier:

- L_{Aeq} represents the equivalent continuous A-weighted noise dose over the measurement period (alternatively written as 'L_{eqd}(A)'). L_{Aeq} is, in effect, a time-weighted average dose of noise over any time period chosen: 5 seconds, 7 minutes or 3 hours.
- $L_{EP,d}$ represents the equivalent daily (eight-hour) personal noise exposure. $L_{EP,d}$ is, in effect, the time-weighted average dose of noise calculated for a notional eight-hour day.

In the UK regime, the **Control of Noise at Work Regulations 2005** use $L_{EP,d}$ (daily dose) as one standard for noise exposure. Therefore, using an ISLM to measure L_{Aeq} does not allow direct comparison with the legal standards. First, the measurements must be used to calculate $L_{EP,d}$. If a single noise exposure occurs during the working day, and the working day lasts for exactly eight hours, then this is simple, since $L_{EP,d}$ will be the same as the measured L_{Aeq}.

But, where the duration of exposure is less, or greater than, exactly eight hours, or where multiple exposures occur, then $L_{EP,d}$ will have to be calculated.

MORE...

The useful daily and weekly spreadsheet calculators and ready reckoners are available from the HSE website at:

www.hse.gov.uk/noise/calculator.htm

Three different methods can be used to calculate $L_{EP,d}$:

- **Use the Equations**

  As presented in **Schedule 1** to **CNAW**.

  For multiple exposures:

$$L_{EP,d} = 10\log_{10}\left[\frac{1}{T_0}\sum_{i=1}^{n} T_i 10^{0.1(L_{Aeq,T})_i}\right]$$

MORE...

General information on noise and more specific information on measuring noise at work is available from the HSE website at:

www.hse.gov.uk/noise/index.htm

The **Control of Noise at Work Regulations 2005** are available to view in full from:

www.legislation.gov.uk

The ACoP and Guidance to **CNAW** will also be useful here. (See L108, as before.)

Where T_0 = 28,800 seconds (eight hours), T_i = duration of period i (in seconds), n = number of individual periods in the working day.

$(L_{Aeq,T})i$ = equivalent continuous A-weighted sound pressure level that represents the sound the person is exposed to during period i.

In simple cases of single exposures, this simplifies to:

$$L_{EP,d} = L_{Aeq,T_e} + 10\log_{10}\left(\frac{T_e}{T_0}\right)$$

Where T_e = duration of the person's working day, in seconds.

- **Use the HSE Calculator**

  A simple spreadsheet calculator is provided by the HSE on their noise website for this purpose. This allows for multiple exposures and exposure duration to be entered, and outputs a figure for $L_{EP,d}$.

- **Use the HSE Ready Reckoner**

  The revised version of L108 (the guidance to **CNAW**) contains a ready reckoner, which uses a points system to calculate the daily noise exposure. This ready reckoner is also available from the HSE website.

Comparison with Legal Limits

Once an individual worker's, or group of workers', daily personal noise exposure ($L_{EP,d}$) has been reliably estimated, it must then be compared to the limits contained in national and international legislation or standards.

Examples of national limits:

- The noise exposure limits in Europe were established from the **Physical Agents (Noise) Directive 2003/10/EC**. In the UK this was implemented as the **Control of Noise at Work Regulations 2005 (CNAW)**, which establish the following exposure limits:
  - Lower daily action limit of 80dB(A) $L_{EP,d}$ with a peak sound pressure limit of 135dB(C) L_{CPeak}.
  - Upper daily action limit of 85dB(A) $L_{EP,d}$ with a peak sound pressure limit of 137dB(C) L_{CPeak}.
  - In addition, no worker should be exposed to levels of noise exceeding 87dB(A) $L_{EP,d}$ or 140dB(C) L_{CPeak}. These are known as 'exposure limit values'.

MORE...

General information on noise and more specific information about measuring noise at work is available from the UK HSE website at:

www.hse.gov.uk/noise/index.htm

Information on the Australian limits can be found at:

www.safeworkaustralia.gov.au/doc/national-standard-occupational-noise

Information on the US OSHA standard can be found at:

www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=9735&p_table=standards

It should be noted that, where very changeable exposures occur from day to day, the Regulations allow for a weekly personal noise exposure ($L_{EP,w}$) to be estimated and used for comparison to the standards.

It should also be noted that, in many cases, measurements of L_{CPeak} taken from sound level metres during the survey can be directly compared to the L_{CPeak} values given in the Regulations.

Comparison of the measured $L_{EP,d}$, $L_{EP,w}$ and L_{CPeak} values in the workplace with the standards in **CNAW** will allow the correct actions to be identified to achieve legal compliance. These will be described in the next section.

- In Australia, similar limits have been established in the **National Standard for Occupational Noise (NOHSC: 1007(2000))**:
  - An eight-hour equivalent continuous A-weighted sound pressure level, L_{Aeq},8h, of 85dB(A).
  - Peak sound pressure level, L_{CPeak}, of 140dB(C).

These measurements are to be taken at the ear of the worker, and do not take into account the effect of any hearing protection which may be worn. Note also that the Australian standard uses the L rather than the $L_{EP,d}$ limit adopted by the UK $_{Aeq}$ measurement

- In the US there are similar legal limits published in **OSHA Standard 1910.95**, which stipulates:
  - "The employer shall implement a hearing protection programme when employee noise exposures equal or exceed an eight-hour TWA of 85dB(A) or equivalently a dose of 50%. This is without regard to any attenuation provided by hearing protection."

Hierarchy of Noise Control

Wherever noise is a problem, there are three orders of priority for dealing with it. Within each of these, there are various options available that form a simple hierarchy of control:

- **Reduce Noise at Source**

  Eliminate hazardous noise at source - remove the noise source entirely. Where this is not reasonably practicable, then:

  - Change the source to one that generates less noise.
  - Re-locate the noise source.
  - Re-design the source.
  - Carry out maintenance.
  - Implement a purchasing policy so that only low-noise equipment is purchased.

- **Control along Transmission**

  Reduce the transmission of noise before it reaches the worker, through:

  - Isolating the source to prevent transmission, e.g. using anti-vibration mounts.
  - Acoustic barriers that interrupt the movement of sound waves through the air.
  - Acoustic enclosure of the noise source.

- **Control Noise Exposure at the Receiver**

  This can be controlled by:

  - Acoustic havens.
  - Hearing protection zones and the use of passive and active hearing protection.
  - Limiting exposure time.
  - Health surveillance (audiometry).

Practical examples of the application of the noise control hierarchy are given in the next section.

Noise Control at Source

Noise exposure control is best done by elimination of the source of the noise problem. This might be done by avoiding noisy activities or avoiding plant and equipment that produce excessive noise. This can be done at the planning stage by adopting a noise-avoidance purchasing policy, where noise emissions are taken into consideration as a part of the purchasing process for plant and equipment.

Noise can often be reduced by **substituting** plant or equipment.

Suggested substitution of plant or equipment

Noisy Equipment or Process	Substituted By
Diesel/petrol engines	Electric motors
Pneumatic tools	Electric tools
Riveting	Welding
Solid wheels	Pneumatic rubber tyres
Metal gears and bearings	Plastic gears and fibre bearings
Metal chutes, buckets and boxes	Rubber or plastic ones

Alternatively, it may be possible to reduce the noise level within the workplace by **re-locating** the source of noise.

In 'open air' conditions, sound decreases by 6dB for every doubling of the distance away from the source:

Table showing reduction in dB level as a result of increasing distance from source to receiver

Distance	Noise Level
1m	112dB
2m	106dB
4m	100dB
8m	94dB

This is because noise (like many other forms of radiated energy) obeys the inverse square law: the energy intensity per unit area decreases inversely proportionally to the square of the distance from source to receiver.

A typical example is the use of compressor rooms where the compressor is removed from the main workplace and re-located in an isolated location. Whilst this does not reduce the noise being generated by the machine, it does reduce the noise exposure in the main workplace.

Rather than replace a complete machine or process, it may be possible to carry out a modification. For example, plastic or rubber-coated rollers and guides on a conveyor belt may be used for handling glass or metal components.

Many machines become noisy because of worn parts, poor maintenance, inadequate lubrication, or because they are 'out of balance'. **Planned preventive maintenance** or condition-based maintenance, involving the replacement of parts and lubrication, will reduce noise (and increase efficiency). Balancing rotating parts (to minimise vibration) can achieve significant noise reduction.

Control Transmission Pathways

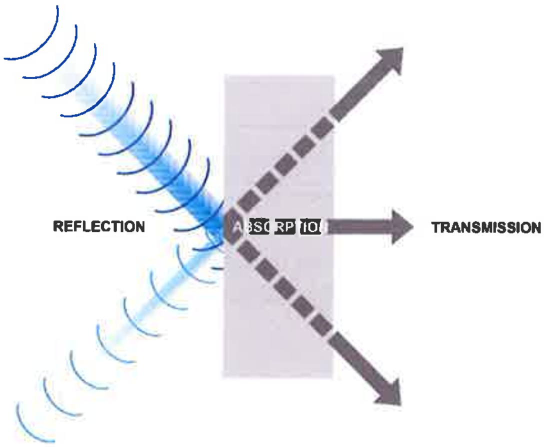
Noise Pathways

Before looking at practical examples of noise exposure control, it is perhaps useful to consider how noise travels from its source to an exposed individual in the workplace. A worker who is exposed to noise from a noise source will receive the noise from one or more different pathways:

- **Directly** - the noise moves directly from the source to the individual through the air.
- **Reflected** - some noise is reflected off surfaces before it hits the receiver, e.g. off hard surfaces, such as walls, ceilings or desktops.
- **Transmitted** - some of the noise from the source will move into the floor and other structures, will be transmitted through the structure in the form of mechanical vibration and will then be re-emitted into the air.

When sound strikes a surface (such as a wall), several things can happen. Depending on the properties of the material (the material of which the wall is made) and the characteristics of the noise, a proportion will be **reflected** from the surface, some will be **absorbed** by the surface and some **transmitted** through the surface.

The following figure illustrates the interaction of a sound wave front with a slab of material and its reflection, absorption and transmission.



Interaction of sound waves with a slab of material

Materials can be classified according to how well they reflect, absorb and transmit sound. These properties can be quantified under laboratory conditions in various different ways. Two particularly useful qualities of a building material are the **sound absorption coefficient and sound reduction index**.

- **Sound Absorption Coefficient**

  This is defined as:

$$\frac{\text{Intensity of sound absorbed by material}}{\text{Intensity of sound incident on same area of material}}$$

  This gives a measure of how well a material absorbs sound falling onto it, and can be derived for sounds of different frequencies. The higher the coefficient, the more sound is absorbed and the less is reflected or transmitted through. For example, glass fibre (75mm thick) has an absorption coefficient of 0.99 at 500Hz. In other words, 99% of sound falling onto the glass fibre is absorbed and only 1% is reflected back or transmitted through the material.

- **Sound Reduction Index (SRI)**

  This is the difference, in decibels (dB), between the sound level incident on a material and the sound level transmitted through the material, i.e. the level of attenuation (sound reduction) of noise. It is an idealised laboratory measurement of sound insulation (i.e. sound reduction) properties; real world measurements can differ (transmission through floor, etc.). SRI is also known as transmission loss.

  For example, a wall made of eight-inch hollow concrete blocks has a transmission loss of 58dB at 2kHz. In other words, the sound intensity at the 2kHz frequency is reduced by 58dB by passage through the wall. In general, the denser the barrier material, the higher the transmission loss.

Anti-vibration mounts isolate grinder from supporting surface
Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

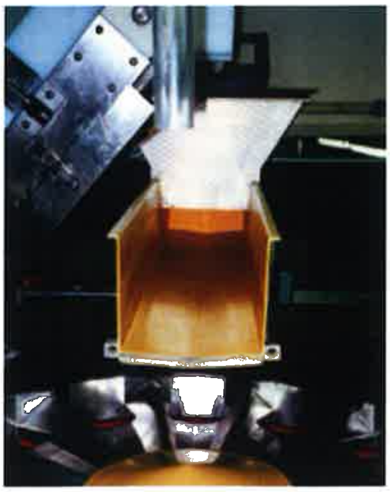
Isolation

Noise is not only transmitted from a source directly into air. It is also transmitted mechanically from the source to adjacent structures by direct physical transmission of vibration. This transmission route can be interrupted by isolating the noise source from adjacent structures. This is often achieved by mounting the whole machine on steel springs or high-density rubber matting. The principle here is that, though the machine itself vibrates, that mechanical vibration is absorbed by the isolating material and is not transmitted through.

Damping

Damping is one modification technique that can be very effective at reducing the noise radiated from steel panels and any structure that can 'ring' due to vibration. The principle is the same as for a musical cymbal that radiates sound when struck. If the instrumentalist touches the cymbal with their hand, then the sound is 'damped' and reduces immediately. In industry, damping may be achieved by:

- Using materials that have a higher damping capacity, e.g. cast iron causes less 'ring' than steel.
- Attaching stiffening ribs to the structure.
- Applying a commercial damping treatment, such as a plastic layer.
- Applying a sandwich layer between two vibrating structures.



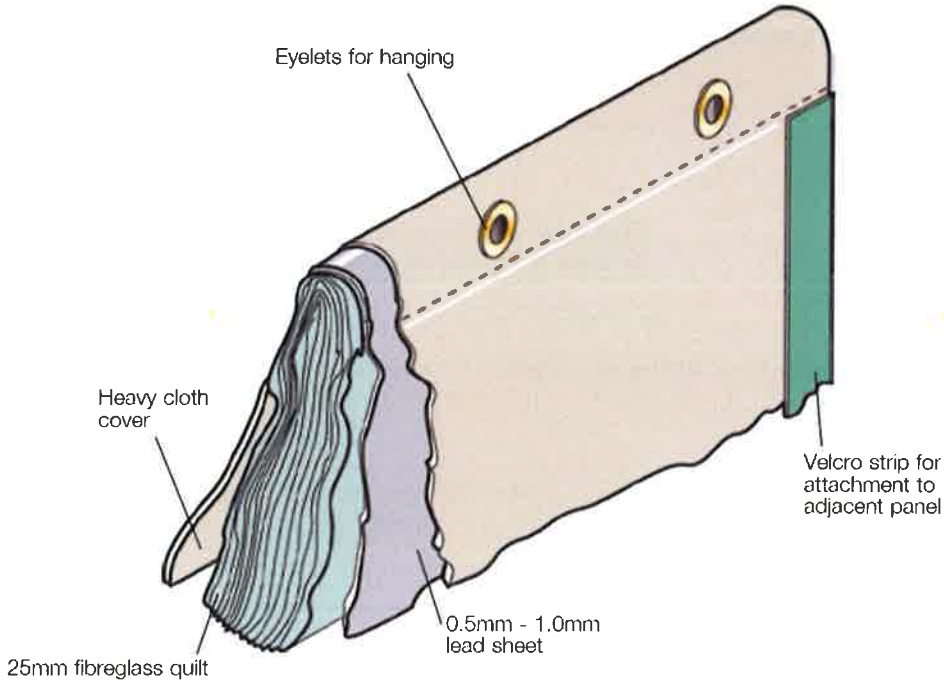
Damping material applied to transport chutes in the food industry
Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

Diffusion

Diffusion is the method of spreading out sound energy with a diffuser. The technique is often used in musical concert venues. The sound energy will be reflected from hard flat surfaces with almost the same sound energy. This means the receiver (the person) is not only receiving direct sound but also reflected sound. Because the reflected sound travels further, it often sounds like an echo or reverberating sound. Where acoustic absorption is the process of reducing sound energy, sound diffusion is the process of spreading the sound energy. Using cylindrical structural features will diffuse the sound energy, radiating the sound energy in multiple directions. This more evenly distributes sound energy and preserves the original sound.

Acoustic Barriers

This involves installing an acoustic screen between the noise source and the receiver. It therefore stops the direct noise but may allow reflective noise to reach the receiver. The screen is most effective against high frequencies and when close to the source. Barriers can be hard structures placed close to the noise source, or can be flexible, matting-type materials suspended in the workplace adjacent to the noise source.



Example of construction of a hanging, flexible acoustic barrier
Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

Distance

If the distance between the worker and the noise source is increased, then the noise intensity experienced by the worker will be reduced. Doubling the distance can reduce the effect of noise between 3 to 6dB. Noise follows the inverse square law, which states that the noise level is inversely proportional to the square of the distance from the source of noise. This is because the noise from (say) a routing machine is dispersed in a pattern that approximates to a sphere.

Acoustic Enclosure

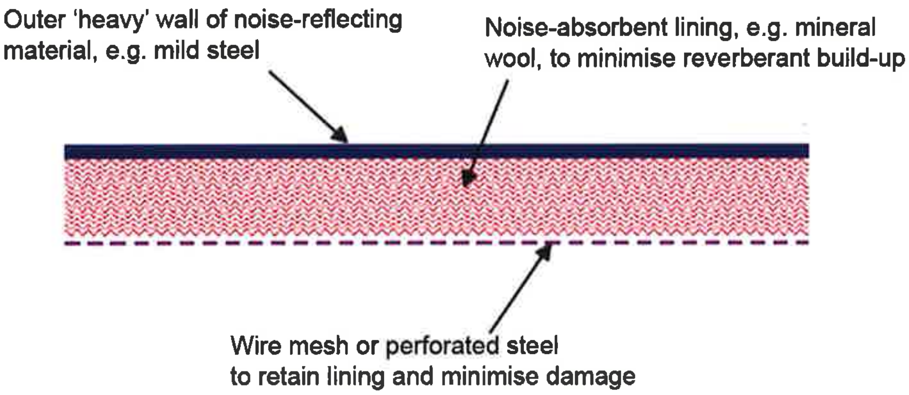
In many cases, the best method of noise control is to enclose the noise source.

To be effective, enclosures must be airtight; the smallest gap allows sound to escape and reduces the attenuation of the noise inside the enclosure. This is a particular problem with, for example, woodwork machines, such as saws and planes, where timber is fed in at one end and comes out at the other. However, such equipment can be fitted with noise-reducing feed, and delivery tunnels fitted with windows to allow clear viewing and also fitted with adequate lighting.

Machinery enclosures should be mounted so that they do not transmit noise and vibrations to the floor.

Dense high-mass materials are good sound insulators. They include brick, concrete, heavy-gauge steel and plaster. However, in order to absorb noise and reduce reflections from walls, low-density porous materials are required, such as mineral fibre and acoustic tiles.

Acoustic enclosures, therefore, have a heavy noise-reflecting outer skin and a noise-absorbent lining, such as mineral fibre. A typical enclosure wall is shown in the following figure:

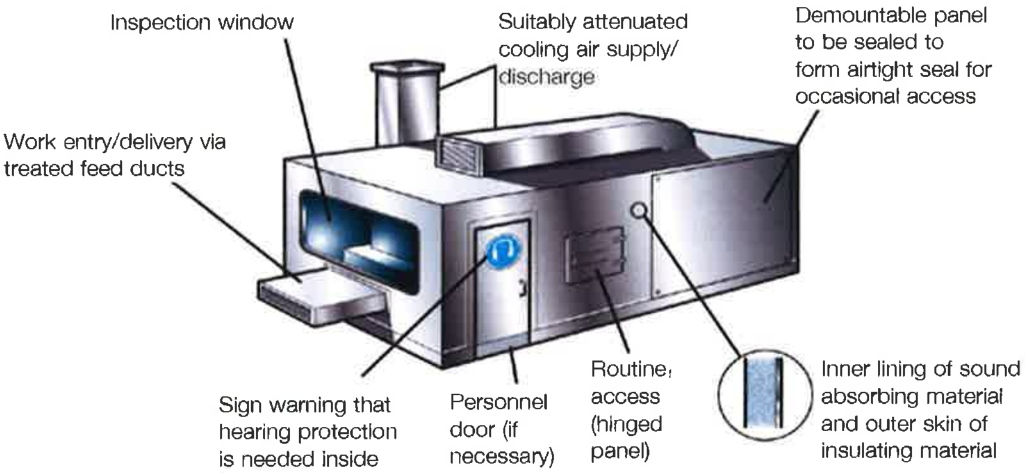


Structure of the wall of a noise enclosure

The amount of noise reduction or attenuation offered by the enclosure is measured by the difference in sound levels before and after the enclosure (or any other form of control) is fitted. A good enclosure will reduce noise levels by between 10dB(A) and 30dB(A).

There are also design and operational issues to consider. These include maintenance and access considerations which, if ignored, will result in doors being left open or panels permanently removed. Key design features include:

- Sound reduction index of the panelling of the enclosure.
- Protection of the internal absorbent lining.
- Robust construction.
- Sealing between panel and floor, and around penetrating ducts and pipes.
- Access for operation and maintenance.
- Robust locks to doors and hatches.
- Observation windows.
- Adequate internal space.
- Adequate lighting and ventilation.



Features required of a typical machine enclosure
Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

Active Noise Cancellation

Active noise cancellation, or Active Noise Reduction (ANR), is a method of reducing the noise emitted by a piece of equipment or machinery. The principle relies on electronic equipment detecting the sound pressure waves being created by the machine and then generating the exact opposite (180° out of phase) sound pressure waves so that the two pressure waves counteract or cancel one another. ANR equipment usually consists of one or several microphones mounted in or on the machinery, an electronic control unit and one or several speakers to generate the 'anti-noise'.

This technology is not generally widespread but is being used in car design (to reduce occupants' exposure to low-frequency engine noise) and some industrial machinery.

The one application where this technology is very widespread is in anti-noise/noise cancelling headphones and hearing protection, that will be outlined in the next section.

Control Exposure at the Receiver

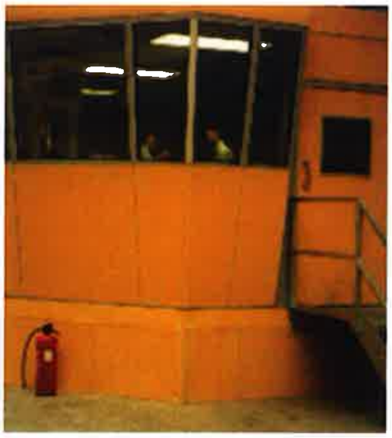
There are two main ways of controlling exposure by protecting the receiver. These are by the use of an acoustic haven (noise haven or refuge) and by the use of hearing protection. Hearing protection, in common with other types of PPE, should only be used when other methods are not reasonably practicable.

Acoustic Havens

An alternative to enclosing the machine is to enclose the worker. In facilities where a range of noisy plant is operated from a central control room, it is easier and cheaper to provide an acoustically insulated control room, or haven, than it is to enclose all the plant. Since the haven is a workplace for the operatives that use it, in addition to the acoustic performance of the enclosure, it is also necessary to consider environmental issues to ensure that workers are able to use the haven without risk or discomfort.

Key design considerations include:

- Noise reduction properties of the haven.
- Similar construction considerations as for the noise enclosure discussed earlier, except that the noise-absorbent lining is not required (since the purpose is now to keep the noise out rather than to keep the noise in).
- Observation windows.
- Adequate internal space.
- Adequate lighting and ventilation.
- Adequate seating.
- Inclusion of as many controls as possible to reduce the time needed to be spent wearing ear protection in the noisy environment outside the haven.



A noise refuge and control room
Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

Hearing Protection Zones

Areas in the workplace where noise levels are likely to give rise to exposures at or above the limits (as identified in the noise assessment) must be designated as mandatory hearing protection zones. Signs must be displayed. Workers entering such zones must be provided with suitable hearing protection. They must also be provided with information, instruction and training on the hazards and risks presented by noise; the control measures in place; and the correct fitting, maintenance and cleaning of the hearing protection. The employer must enforce the use of the hearing protection issued.

Hearing Protection

Hearing protection comes in a wide variety of types suitable for different applications. It is important that the correct type of hearing protection is selected and that it is used and maintained correctly. This section provides an overview of some of the different types of hearing protection available and the issues that must be considered in selection, care and use.

Earplugs with neck bands

Earplugs with neck cords

Custom moulded earplugs

Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

Earplugs and Earmuffs

Earplugs are small-shaped bungs that are inserted into the external auditory canal. Many are designed to be **disposable**, and some **re-usable**. The disposable types are usually made from polyurethane foam, and the re-usable type from flexible plastic or rubber. They often come with a cord or neck-band to prevent loss.

There are many **advantages** to earplugs, such as:

- Universal fit.
- They are relatively cheap.
- They require little or no maintenance.
- Minimal training is required for effective use.
- They are compatible with spectacles and any other items of PPE that have to be worn.
- There is generally good user acceptance.

Some of the **disadvantages** include:

- Supervision is more difficult (to ensure that plugs are being worn correctly, or at all) especially from a distance.
- They can be difficult to fit correctly*.
- They can work loose during use.
- They are not appropriate when hearing protection has to be removed and re-fitted frequently in an environment where contamination to the fingers is likely.
- They are not suitable for some individuals, due to medical conditions.
- They do not reduce sound transmission through bone to the inner ear.

* A note on fitting earplugs. Most earplugs have to be inserted into the ear canal to be effective. This cannot be achieved simply by pushing the plug into the ear canal, as the canal has a kink in it. To straighten this kink, the earlobe has to be pulled back as the earplug is fitted. This is best achieved by reaching around the back of the head with the opposite arm.

Custom moulded earplugs are another option. This type of earplug is custom-made to fit each ear of the individual and fits into the ear canal and the external folds of the outer ear. These are more expensive than other types of plug but share most of the benefits and disadvantages.

Earmuffs (ear defenders) are designed to cover the ears externally with large cups held in position by a headband. The cups are designed with an annular cushion made of a plastic material, filled with polyurethane foam, gel or liquid to provide a seal between the cups and the side of the head.

Some of the **advantages** of earmuffs are:

- They are easy to fit and use.
- Supervision of use is easy, even at a distance.
- They are more suitable for situations where they have to be frequently removed and re-fitted, and where there is risk of finger contamination.
- They are more effective at reducing bone transmission.

Some of the **disadvantages** include:

- They are more expensive than most earplugs.
- They may be incompatible with other items of PPE, such as hard hats, breathing apparatus, etc.
- Protection is reduced when worn by people with spectacles, earrings or a lot of hair around the ears.
- They require more training, cleaning and maintenance than most types of earplug.

Special Types of Protector

Several different types of special hearing protection are available for use in special circumstances. These include:

- **Level dependent protectors** - where the degree of attenuation increases as noise level increases, so allowing easy communication at low noise levels, but offering full protection at high noise levels.
- **Flat response protectors** - where the amount of noise attenuation is the same across all frequencies. This is unlike most ordinary hearing protectors where the degree of attenuation increases as frequency increases (i.e. they reduce the high-pitch noise more than low-pitch noise). This is of particular use to musicians who need to be able to hear the 'true' sound of their instrument but at reduced intensity.
- **Active noise-reduction protectors** - where electronic circuitry detects and then cancels out some of the background noise. This is done by generating the exact opposite sound pressure waves to the background sound pressure waves, so that the peaks and troughs of the pressure waves are out of phase and cancel each other out.

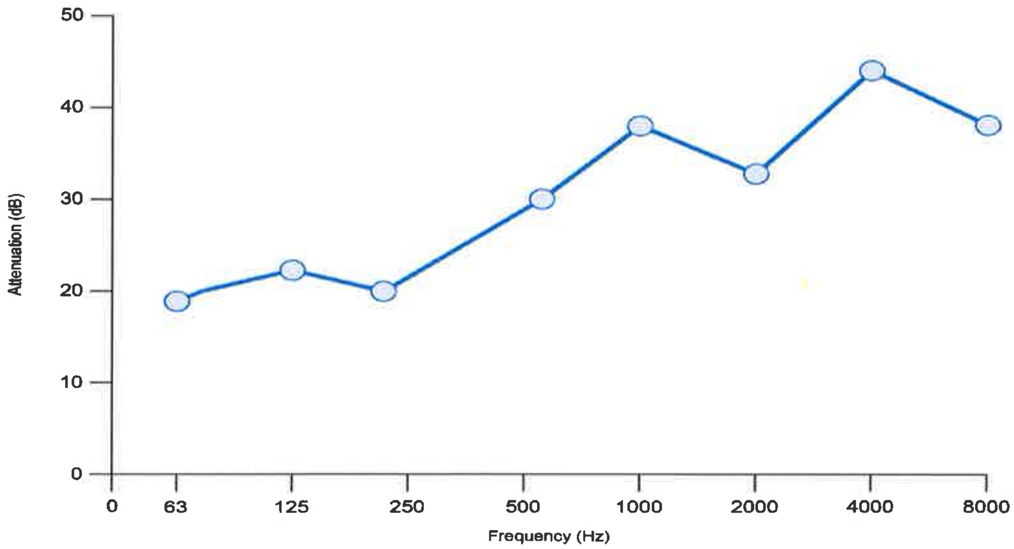
Types of earmuff
Source: L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

- **Communication protectors** - where the protectors have a speaker (and perhaps microphone) built in so that the wearer can hear (e.g. for entertainment) and perhaps talk (e.g. two-way radio).

Significance of Attenuation Data

Hearing protection should be chosen to reduce noise exposure at the user's ear to below the relevant action value. However, the degree to which a particular type of hearing protection reduces sound intensity varies with frequency.

The attenuation curve for one model of earmuff is given in the following figure:



Attenuation curve for one model of earmuff

As can be seen from the graph, the earmuffs cut out more decibels at higher frequencies than they do at lower frequencies.

There is great variation in the **attenuation characteristics** of different makes and models of hearing protection. It is therefore essential that the attenuation characteristics of the hearing protection selected are suitable for use in the particular noise environment in which they are to be worn. These attenuation characteristics are supplied by the manufacturer in the form of a data table.

Example of manufacturer's data table for a pair of earmuffs

	Octave band centre frequency (Hz)							
	63	125	250	500	1000	2000	4000	8000
Mean attenuation (dB)	11.5	11.8	11	20.4	22.9	29.8	39.5	39.6
Standard deviation (dB)	4.4	3.2	1.9	3.6	2.2	2.5	2.7	4.9
APV = mean attenuation - std. dev. (dB)	7.1	8.6	9.1	16.8	20.7	27.3	36.8	34.7
Single number values	H	27	M	19	L	13	SNR	22

(Based on an original in L108 Controlling noise at work (2nd ed.), HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm))

APV is the **Assumed Protection Value** at each octave band centre frequency. It is calculated as the mean attenuation minus one standard deviation. Note that three different sets of data are presented in the table, three rows of octave band data, three High, Medium, Low (HML) numbers and one Single Number Rating (SNR) number.

These characteristics have to be compared with the characteristics of the noise in the workplace. This requires data about the workplace noise, which will come from a noise survey using an octave band analyser or an integrating sound level meter.

There are three methods for predicting the effects of hearing protection so that its suitability can be assessed:

- The **octave band method** is the most accurate but requires a full octave band spectrum of the noise in the workplace as derived from octave band analysis.
- The **HML method** is less accurate if noise is dominated by single frequencies, but only requires two bits of information about the workplace noise - A-weighted and C-weighted average sound pressure levels.
- The **SNR method** is the simplest but least accurate (but still suitable for most general applications). One piece of information is required about the workplace noise - C-weighted average sound pressure level.

Calculating the predicted level of protection offered by an item of hearing protection can be done using the formulae presented in the UK HSE publication - L108 Controlling noise at work (Appendix 3). Alternatively, a calculator is available on the HSE website. This spreadsheet allows any of the three methods described to be used and the result can be saved for reference.

Whichever method is used, a 4dB addition is always made to the predicted noise exposure at the ear to take account of '**real world**' factors. This reflects the fact that the attenuation data for hearing protection is collected in idealised laboratory conditions by the manufacturer and so a margin of error has to be included to allow for imperfect use.

TOPIC FOCUS

Example Use of the SNR Method

A noise survey and assessment has shown that hearing protection must be worn in a workroom. One type of hearing protection has been selected for use, but it must be checked to ensure that it gives the correct level of protection.

The noise survey has indicated that the C-weighted average sound pressure level in the workroom is 92dB(C). The manufacturer's data sheet for the hearing protection gives the SNR number as 30.

To calculate the estimated sound pressure level at the ear, take the SNR number away from the C-weighted average:

92 - 30 = 62dB(A)

We must then make a 4dB addition to take account of 'real-world' factors:

62 + 4 = 66dB(A)

So, a worker wearing the selected hearing protection in the workroom would receive 66dB(A) at their ear.

We must then evaluate this predicted exposure against the relevant legal standards. If we use the UK/EU standards, we find that we may be below the UEAV (85dB(A)) and the LEAV (80dB(A)) but, unfortunately, we are also below the guideline 70dB(A), which shows that we are 'over-protecting' the worker's hearing. This hearing protection is therefore **not** suitable for use in the workroom, so another type, offering a lower level of protection, should be found.

Problems of Over-Protection

Using the methods described above, the level of noise that will be experienced by an individual at the ear when wearing a certain type of hearing protection can be reliably estimated. This predicted noise level must be below the limits set in the noise assessment. Ideally, it will be between 75-80dB(A). If predicted noise levels are less than 70dB(A) then the hearing protection is unsuitable because it '**over-protects**' the ear.

Over-protection causes difficulties with communication and hearing-warning signals. Users become isolated from their environment, leading to safety risks, and may be inclined to remove the hearing protection and risk damage to their hearing.

Health Surveillance (Audiometry)

The ILO Code of Practice - *Ambient Factors in the Workplace* (CoP) (Section 9.4) specifies the conditions under which health surveillance may be required. The CoP states that health surveillance may be required when a worker's noise exposure reaches levels prescribed in national law or in international standards. The records of health surveillance should be retained in a confidential medical file and shared with the worker.

The technique of checking hearing is known as 'audiometry'.

Advantages and disadvantages of wearable technologies

In the music industry, earphones that limit sounds from other instruments, to enable the musician to focus on the sound they are generating, have been in common use for many years.

Noise suppression technology recognises the different properties of sound, allowing some noises to be reduced while retaining others (refer to the section on 'special hearing protectors').

Wearable ear pieces are available that are able to monitor, upload and collate information on noise exposure. These types of devices can also incorporate alarms when noise exposure is exceeded on a single shift, to provide a means of reducing exposure.

As wearable devices and the associated analytical software becomes cheaper, it will become more reasonably practicable to use it. A clear benefit is that the wearable devices may replace monitoring activities undertaken by supervision.

Disadvantages are the same for any PPE where user comfort and willingness to wear the device are important factors.

MORE...

www.hse.gov.uk/noise/index.htm

The hearing protection spreadsheet calculator is available from:

www.hse.gov.uk/noise/calculator.htm

Schedule 1 of the **Control of Noise at Work Regulations** can be found at:

www.legislation.gov.uk/uksi/2005/1643/schedule/1/made

ACoP and Guidance - L108 - Controlling Noise at Work is also relevant here (available as before).

STUDY QUESTIONS

1. How does the ILO define 'noise'?
2. Explain the terms 'amplitude' and 'frequency' as applied to a noise wave.
3. Explain the term 'pitch'.
4. What is the A-weighted scale and what is its purpose?
5. Why can't decibel values be added together directly?
6. Describe how the ear converts sound waves into nerve stimulation to the auditory centres of the brain.
7. Explain how the damaging effects of noise are related to the dose that the ear receives.
8. Which of the two types of hearing loss - conductive and sensorineural - is more relevant to the health and safety practitioner?
9. Explain the term 'threshold shift'.
10. What are the main types of equipment available for measuring noise levels and noise exposure?
11. Identify the sources of noise and the tasks that give rise to noise exposure.
12. What are the three ways in which a sound wave front may interact with a slab of material?
13. List the three priorities of noise control.
14. Describe the principal design features of an acoustic enclosure.
15. What is the difference between a noise enclosure and a noise haven?
16. What are the various types of ear protection available?

(Suggested Answers are at the end.)

Summary

Basic Concepts of Noise

We have described how:

- Noise is defined as 'any audible sound'.
- A noise source generates pressure waves in air. Two characteristics of these pressure waves, their amplitude and frequency, are important in understanding their nature:
  - The amplitude determines the intensity of the noise - measured using the decibel scale (dB).
  - The frequency determines the pitch of the noise - measured in hertz (Hz).
- The decibel scale is a logarithmic scale. The addition of 3dB is a doubling of noise intensity.
- The human ear is not equally sensitive to all frequencies; consequently, the A-weighting matrix (represented by dB(A)) is used to correct for this frequency bias when calculating the amount of energy that has been delivered into the inner ear.
- The amount of damage done to the inner ear is determined by the dose of noise received. Dose is determined by two factors: the intensity of the noise (dB(A)) and the duration of exposure.
- The human ear detects noise by mechanically transmitting sound pressure waves from the outer ear through to the inner ear. There, fine sensory hairs respond to the pressure waves in fluid, sending nerve signals to the brain.
- Exposure to excessively loud noise can physically damage the transmission structures of the ear and can also cause deterioration of the sensory hairs in the inner ear.
- Tinnitus, Temporary Threshold Shift (TTS), Permanent Threshold Shift (PTS) and Noise-Induced Hearing Loss (NIHL) are all health effects associated with exposure to loud noise.
- Audiometry can be used as a form of health surveillance to determine the sensitivity of a person's hearing. The graphs produced (audiograms) can be used to differentiate between age-related hearing-loss (presbycusis) and NIHL.
- Noise surveys must be carefully planned to ensure that representative measurements are taken, to give a true reflection of real noise exposures occurring at work.
- Several different instruments are available for measuring noise; simple sound level meters, Integrating Sound Level Meters (ISLM), dosimeters and octave band analysers.
- ISLMs used for noise surveys must be calibrated before use and must be tested and certificated for results to be valid.
- Key information recorded during a survey is the equivalent continuous A-weighted sound pressure level (L_{Aeq}), maximum C-weighted peak sound pressure level (L_{CPeak}) and the duration of exposure.
- L_{Aeq}, in combination with duration of exposure, is then used to calculate a daily personal noise exposure ($L_{EP,d}$). This can be done using formulae, the HSE web-based calculator, or the HSE ready reckoner.
- Calculated daily personal noise exposures ($L_{EP,d}$) can then be compared to the legal standards.
- Noise control can be achieved by applying a hierarchy of controls:
  - Reduce noise at source by eliminating hazardous noise at source, changing the source, re-locating the source, re-designing the source (e.g. damping) and maintenance.
  - Attenuate noise transmission by isolating the source, using acoustic barriers or using an acoustic enclosure for the source.

  - Control noise exposure at the receiver using acoustic havens, hearing protection zones, and the use of passive and active hearing protection, limiting exposure time and health surveillance.

- Hearing protection must be carefully selected by reference to its attenuation data and the noise profile of the workplace. Three different methods exist to determine the attenuation achieved: octave band analysis, High, Medium, Low (HML) and Single Number Rating (SNR).

Learning Outcome 9.12

NEBOSH International Diploma for Occupational Health and Safety Management Professionals

ASSESSMENT CRITERIA

- Recognise what vibration is, what effects it can have on people, how it can be assessed, the control measures that can be used and the legal duties to manage exposure to excessive vibration at work.

LEARNING OBJECTIVES

Once you've studied this Learning Outcome, you should be able to:

- Explain the basic physical concepts relevant to vibration.
- Explain the effects of vibration on the individual.
- Explain the measurement and assessment of vibration exposure.
- Explain the principles and methods of controlling vibration and vibration exposure.

Contents

Basic Concepts of Vibration

IN THIS SECTION...

- Hazardous vibration can be divided into two types: Hand-Arm Vibration (HAV) and Whole-Body Vibration (WBV).
- Vibration can be characterised using several factors, notably the magnitude (measured in $m.s^{-2}$), frequency (hertz, Hz) and direction (in three dimensions, x, y and z).
- The harm caused by vibration is determined by dose, in turn determined by the vibration magnitude and duration of exposure. The eight-hour energy-equivalent vibration magnitude is used as the standard daily exposure.
- Workers at risk of HAVS include those using cutting and grinding tools and pneumatic hand tools.
- Those at risk of WBV are principally vehicle and plant driver/operators, especially when moving over rough terrain.
- The main health effect of WBV is back pain.
- The main health effect of HAV exposure is Hand-Arm Vibration Syndrome (HAVS), often characterised by blanching of the fingers on exposure to cold (often called 'vibration-induced white finger').
- The severity of HAVS can be quantified using the Stockholm scale.
- Vibration risk assessments should be carried out which consider:
  - The potential sources of vibration and tasks carried out.
  - The possibility of exposure to cold environments and the nature of the vibration (HAV or WBV).
  - Any exposure limits that apply.
  - Expected vibration emission levels from equipment.
  - The need for measurements to quantify and characterise vibration and assess effectiveness of existing controls.
  - The potential for elimination of vibration and other controls, such as training.
  - Vibration magnitude can be measured directly using an accelerometer, or taken from manufacturer's data. This data, in combination with duration of contact, can then be used to reliably estimate personal exposures.
- Actual vibration exposure can be calculated using formulae, the UK's HSE web-based calculators or the HSE ready reckoner (HAV only).
- These personal exposures can then be compared to the standards in the standards established in national legislation.
- The action values require the employer to act to control exposure. The limit values must not be exceeded.
- Control of vibration exposure can be achieved by applying controls in a priority order:
  - Elimination of exposure.
  - Purchase of equipment with low vibration performance.
  - Equipment maintenance.
  - Reduction in the time of exposure.
  - Providing information, instruction and training.
  - Providing PPE (not an option for WBV).
- Health surveillance must be provided for workers exposed to HAV above the EAV and those diagnosed with HAVS.

Definition of Vibration

Compactors and other tools can generate a lot of vibration, which is then delivered into the hands and arms of the worker

Vibration is the term given to an oscillatory motion involving an object moving back and forth.

Under **ILO Convention C148**, Article 3, vibration is defined as:

> *"Any vibration which is transmitted to the human body through solid structures and is harmful to health or otherwise dangerous."*

Occupational exposure to vibration can result in two distinct effects - Hand-Arm Vibration Syndrome (HAVS) and Whole-Body Vibration (WBV).

Under the UK's **Control of Vibration at Work Regulations 2005**:

- **Hand-arm vibration** is defined as:

  "Mechanical vibration which is transmitted into the hands and arms during a work activity."

- **Whole-body vibration** is defined as:

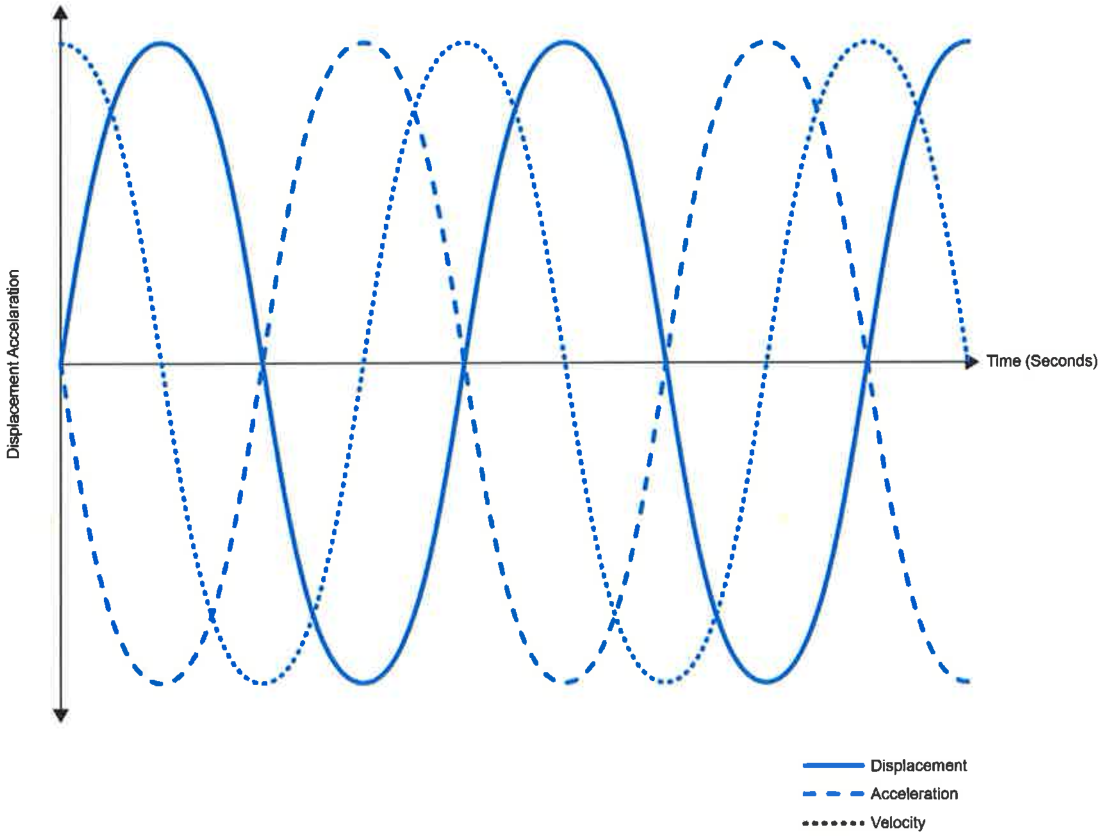
  "Mechanical vibration which is transmitted into the body, when seated or standing, through the supporting surface, during a work activity."

Basic Concepts of Vibration

Axes of vibration for hand-transmitted and whole-body vibration

When an object (such as the end of a ruler clamped over the edge of a desk) vibrates, it starts from a position of maximum displacement, accelerates towards the equilibrium position from which it has been displaced, overshoots this equilibrium position at its maximum velocity, and begins to decelerate due to a restraining force, until it comes to rest (temporarily) at maximum displacement in the opposite direction. The restraining force then begins to propel the object towards the equilibrium position and the process is repeated.

The following figure shows the relationship between **acceleration**, **velocity** and **displacement** over time.



Sinusoidal vibration - the relationship between displacement, acceleration and velocity

The key terms to consider are:

- **Amplitude**

  Amplitude is the distance (in metres) from the point of rest to the point of maximum displacement in either direction.

- **Frequency**

  The frequency of vibration is expressed in cycles per second or hertz (Hz), as used for noise measurement.

- **Acceleration**

  Acceleration is a measure of the rate of change of velocity of a vibrating object (in units of metres per second, m/s^2). This is used as the basis for measuring vibration magnitude.

- **Vibration Magnitude**

  Vibration magnitude is expressed in terms of acceleration. Since the acceleration of a vibrating object changes in a sinusoidal manner with time (see graph), the magnitude of the vibration is taken as an average measure of the acceleration. For sinusoidal motion, the average value used is the root-mean-square value - rms acceleration.

- **Vibration Direction**

  With complex vibrating objects, there may be displacement in all three dimensions (x, y and z). Vibration in all three dimensions will contribute to the overall vibration received by the hand or body, so the amount of vibration in each dimension may have to be considered.

Vibration Dose

Legislation, such as the UK's **Control of Vibration at Work Regulations 2005 (CVAWR)** work on the basis that the amount of harm done by exposure to vibration is dependent on the dose of vibration energy received. The principle being that a given **dose** of vibration energy, however delivered, will cause an equivalent degree of harm.

This dose is determined by the **magnitude** of the vibration (RMS acceleration) and the **duration** of exposure.

The daily dose of vibration received by a worker can therefore be expressed as the **eight-hour energy-equivalent vibration magnitude**. In the **EU Directive 2002/44/EC**, this is described as being "standardised to an eight-hour reference period". This idea is very similar to the idea that a person's noise exposure can be expressed as a daily personal noise exposure, L_{EPd}.

All of the exposure values in the Regulations are expressed using this standard dose. So, if a worker's personal vibration exposure is to be compared to the standards, their personal **eight-hour energy-equivalent vibration magnitude exposure** will have to be reliably estimated (either by reference to available data or by direct measurement).

It must be remembered that the UK Regulations (CVAWR) cover both Hand-Arm Vibration (HAV) and Whole-Body Vibration (WBV). In both instances, the same concept of personal daily dose still applies. However, different exposure values exist for the two different sorts of vibration exposure and two different sets of formulae are used to determine the dose.

MORE...

The main vibration page of the HSE website links to lots of relevant pages and downloads:

www.hse.gov.uk/vibration/index.htm

ACoP and Guidance on the **Control of Vibration at Work Regulations 2005** is also available from the HSE in the form of two guides, L140 - *Hand-Arm Vibration* and L141 - *Whole-Body Vibration* available from:

www.hse.gov.uk/pubns

The pocket card INDG296(rev2) *Hand-arm vibration - A guide for employees* provides concise information on HAVS, the symptoms and how to reduce the risks of developing the disease, available at:

www.hse.gov.uk/pubns/indg296.htm?ebul=hsegen&cr=17/23-jun-14

The **Control of Vibration at Work Regulations 2005** can also be viewed in full online at:

www.legislation.gov.uk

Whole Body Vibration (WBV)

Groups of Workers at Risk from Exposure to WBV

Typical work activities involving risk of whole-body vibration exposure include:

- Drivers of heavy vehicles, e.g. tractors and earth-moving vehicles.
- Drivers of forklift trucks.
- Operators of heavy machines, e.g. power presses.
- Aircraft personnel.

WBV exposure is particularly associated with drivers and operators of plant and vehicles that have to move over rough terrain, such as forestry tracks.

Especially vulnerable workers would include those with pre-existing back injuries, pregnant women, young people and those who have undergone back surgery.

Exposure to Whole-Body Vibration

Exposure to whole-body vibration can cause great discomfort. However, the principal health risk associated with WBV is back pain.

There are many causes of back pain, such as poor manual handling technique and poor posture. But, back pain is also caused or exacerbated by WBV exposure.

WBV has been anecdotally linked to many other ill-health conditions, such as vertigo, bowel disorders, circulatory disorders and respiratory disorders, but as yet no proven link exists between WBV and any other specific condition. The focus of the British HSE guidance relating to WBV is back pain.

Hand-Arm Vibration (HAV)

Groups of Workers at Risk from Exposure to Hand-Arm Vibration (HAV)

There is a wide range of occupations which are at risk from exposure to hand-arm vibration in the workplace. Examples include:

- Construction workers - using concrete breakers, cut-off saws and hammer drills.
- Estates workers - using powered lawnmowers and brush cutters (strimmers).
- Mechanics and bodyshop workers - using powered tools, such as orbital sanders and torque wrenches.

The following table shows examples of the typical vibration levels that might be experienced when working with common tools:

Tool type	Lowest	Typical	Highest
Road breakers	5 m/s^2	12 m/s^2	20 m/s^2
Demolition hammers	8 m/s^2	15 m/s^2	25 m/s^2
Hammer drills/combi hammers	6 m/s^2	9 m/s^2	25 m/s^2
Needle scalers	5 m/s^2	-	18 m/s^2
Scabblers (hammer type)	-	-	40 m/s^2
Angle grinders	4 m/s^2	-	8 m/s^2
Clay spades/jigger picks	-	16 m/s^2	-
Chipping hammers (metal)	-	18 m/s^2	-
Stone-working hammers	10 m/s^2	-	30 m/s^2
Chainsaws	-	6 m/s^2	-
Brushcutters	2 m/s^2	4 m/s^2	-
Sanders (random orbital)	-	7-10 m/s^2	-

Typical vibration levels for common tools
Source: https://www.hse.gov.uk/vibration/hav/advicetoemployers/assessrisks.htm

Typical work activities associated with hand-arm vibration exposure include:

A petrol driven disc cutter is used to cut concrete. Vibration is delivered into both hands during use. Noise and dust will also be major health hazards

- Percussive metalwork tools, including:
  - Riveting.
  - Chipping hammers.
  - Fettling tools (used to remove excess metal from castings).
  - Impact wrenches (used to tighten nuts and bolts).
  - Hammer drills.
  - Percussive chisels.
- Rotary tools and grinders, including:
  - Rotating abrasive wheels (hand-held angle grinders).
  - Disc cutters.
  - Workpieces held against pedestal grinders.
  - Dental tools.
- Percussive hammers and drills, which are used to break up rocks, concrete and masonry.
- Chainsaws, brush-cutters and other horticultural and arboricultural equipment.

Certain workers may be more vulnerable to continued vibration exposure. These include persons suffering from:

- Existing hand-arm vibration syndrome.
- Raynaud's phenomenon.
- Peripheral vascular disease.
- Trapped nerves in the hand or arm.
- Neurological disorders.
- Past history of injuries or malformation of the hand-arm system.
- Exposure to toxic agents or medication that affects peripheral blood circulation.

Exposure to Hand-Arm Vibration

Exposure of the fingers or hands to regular and prolonged vibration can result in a range of disorders:

- Circulatory disorders (blanching of the fingers).
- Neurological disorders (numbness and tingling).
- Muscular effects (difficulty with grip and reduced dexterity).
- Articular effects (bone and joint problems).

Collectively, these are known as Hand-Arm Vibration Syndrome (HAVS).

Carpal tunnel syndrome (compression of the median nerve in the wrist) can also be caused by exposure.

Hand-Arm Vibration Syndrome (HAVS)

The symptoms of HAVS include:

- Numbness and tingling in the fingers, and a reduced sense of touch and temperature, due to damage to nerves in the hand. This damage can make it difficult to feel and handle small objects.
- Periodic blanching attacks during which the blood circulation in the fingers is impaired and parts of the fingers become white. This is usually known as Vibration-Induced White Finger (VWF). During these attacks, the fingers feel numb. As blood circulation returns to the fingers they are throbbing, red and painful. The main trigger for these symptoms is exposure to the cold (rather than exposure to vibration). In rare advanced cases, blood circulation may be permanently affected.
- Joint pain and stiffness in the hand and arm. Grip strength can be reduced due to nerve and muscle damage.

Finger blanching
Source: L140 Hand-arm vibration, HSE, 2005 (www.hse.gov.uk/pubns/books/l108.htm)

An individual employee with HAVS may not experience the complete range of symptoms, e.g. there may be nerve damage symptoms without there being blood circulation problems and vice versa. The symptoms of HAVS are usually progressive as exposure to vibration continues, e.g. the effects on blood circulation are seen initially in the tips of the affected fingers, with changes spreading up the finger.

There is little evidence to indicate that recovery from VWF occurs when exposure to vibration ceases. Reports indicate recovery is only slight and very slow.

As an attack can be brought on by cold and damp conditions, those affected often have to give up outdoor activities in an effort to reduce the painful blanching attacks that occur.

Aggravating Factors for HAVS

- Exposure to low temperatures not only brings on blanching attacks in those already suffering from HAVS, but would appear to speed up the development of the condition. Workers exposed to hand-arm vibration in cold, wet conditions are therefore at greater risk.
- Worker lifestyle also has an effect, with smokers being more at risk of the condition.
- Individuals with pre-existing circulatory disorders, such as Raynaud's phenomenon (sometimes known as Raynaud's disease or syndrome), will also be more at risk.

Standardised Diagnostic Tests for HAVS

Several tests are available for quantifying the severity of HAVS in an individual. They can be used in conjunction with reported symptoms in clinical diagnosis by a physician, and to track the progression of the condition.

One common use is the Stockholm workshop scale.

The Stockholm scale is subdivided into two components (the grading is made separately for each hand):

Vascular (Blood Flow) Tests

These use a cold challenge to the hands (immersion in cold water):

- Time taken for the finger to return to full circulation after a Cold Provocation Test (CPT).
- Finger Systolic Blood Pressure (FSBP) test.

Sensorineural Tests (for Assessing Nerve Damage)

- Vibrotactile Perception Threshold (VPT) - based on perception of vibrations applied to the finger.
- Thermal (temperature) Perception Threshold (TPT) - based on subjective judgments on perception of 'hot' and 'cold' with the finger.

Stockholm workshop scale: vascular component

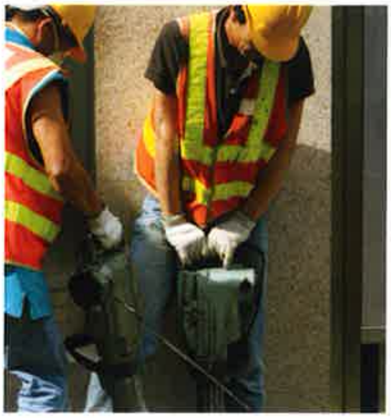
Stage	Grade	Description
0	-	No attacks
1	Mild	Occasional attacks affecting only the tips of one or more fingers
2	Moderate	Occasional attacks affecting tips and middle (rarely, but also parts closest to palm) of one or more fingers
3	Severe	Frequent attacks affecting all parts of most fingers
4	Very severe	As in Stage 3, with degenerate skin changes in the fingertips

Stockholm workshop scale: sensorineural component

Stage	Symptoms
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 and/or manipulative dexterity

Occupational Vibration Exposure Risk Assessment and Planning for Control

The ILO Code of Practice - *Ambient Factors in the Workplace* (Section 10.2) recommends that an assessment of risk from vibration is carried out if workers or others are frequently exposed to hand-arm vibration or whole-body vibration. The aim should be to eliminate vibration at source or reduce it to the lowest practicable level by all appropriate means.


Vibration exposure may lead to risk assessment

The employer might make use of an external consultant to undertake a vibration assessment. Or, it might be undertaken by an internal person. In either case, the person must be competent. Qualifications from recognised training providers can be used as proof of competence, as can experience and membership of organisations, such as the British Occupational Hygiene Society (BOHS), etc.

Since the Regulations deal with both HAV and WBV, detailed guidance has been issued on the risk assessment process and the technical aspects of measurements and control in two separate UK HSE guides: L140 and L141. The following section presents an overview of key ideas common to both sets of guidance.

A vibration exposure **risk assessment** follows a familiar five-step approach:

Step 1 Identify the potential sources of vibration and the tasks carried out. Look to see whether vibration exposure might be a problem that needs to be managed and identify likely HAV and WBV exposures. The assessment should consider:

- Specific working conditions, such as low temperature.
- Information from health surveillance.
- The availability of replacement equipment.
- Information provided by manufacturers.

Step 2 Identify all workers likely to be exposed to either HAV or WBV. Especially the health effects on the employees particularly at risk.

Step 3 Evaluate the risks arising from the vibration exposure, using any exposure limits that apply - estimate daily vibration exposures. Quantify and characterise the vibration and assess the effectiveness of existing controls. Identify appropriate further actions, such as elimination of vibration and training to control the risk and comply with the Regulations.

Step 4 Record findings.

Step 5 Review the assessment and revise it as required. The assessment must be reviewed immediately if there is reason to believe it is no longer valid or there has been significant change in the work to which the assessment relates.

In many instances, an estimate of personal exposure can be made from manufacturers' data and other data sources. In some instances, measurements of vibration exposure may have to be carried out.

Planning the Survey

- **Who Should Be Assessed?**

  All workers likely to be exposed at, or above, a daily exposure action value, e.g. workers who spend some of their day using vibrating hand-held equipment (such as a chainsaw operator), or sit behind the wheel of equipment likely to cause a significant WBV exposure (e.g. dumper truck drivers on a construction site).

- **Where?**

  For hand-arm vibration, the vibration passing into the hands and arms is of interest and therefore measurements are taken at the hand-grips of the hand-held equipment. For whole-body vibration exposure, it is the vibration passing into the feet (if stood) or seat (if sat) that is of interest and therefore measurements are taken at the surface that is being stood or sat on.

- **How?**

  If using a vibration transducer (accelerometer) to take actual readings, then the instrument is firmly attached to the vibrating surface or handle. Alternatively, published vibration magnitude data might be used, provided that data gives a reliable estimate of actual vibration magnitude exposures.

- **For How Long?**

  Measurements need to be sufficient to account for variations in the vibration magnitude that would naturally occur during the working day.

  As with integrating sound level meters, measurements should be long enough to obtain an indication of the average level of exposure.

- **Group Sampling**

  If several workers work on the same task, it would be possible to assess the exposure for all by doing measurements on one, provided the work is genuinely of the same type. Choose the work tasks and durations so as to determine the highest exposure someone is likely to receive.

Using Published Data

There are many sources of information on vibration magnitudes that can be used to estimate exposures. These include:

- Manufacturers of the tools, machinery, plant or vehicle under investigation.
- Trade associations who have experience with the equipment and work processes in use.
- Peer organisations that are involved in the same industry or process.
- Authorities such as the UK's HSE, who publishes guidance on the typical vibration magnitudes associated with various work activities and items of equipment.

Whatever the source of vibration exposure data, it is essential that it is used appropriately in any evaluation of vibration exposure. The information used must reflect the real situation occurring in the workplace and allowances must be made to take account of 'real world' factors (such as the wear-and-tear that occurs as equipment ages). Provided the margin of error is taken into account and caution is applied during the evaluation process, these data sources can be used to allow a meaningful assessment.

Instrumentation for Taking Measurements

Vibration is measured using a vibration meter or accelerometer that has three electronic sensors that measure the acceleration caused by the vibration in each of the three dimensions, x, y and z. This meter must comply with the appropriate BS EN ISO standards in terms of design, construction, use, calibration, maintenance and testing. Further details of all of the relevant standards can be found in L140 and L141.

The monitoring device is attached to the surface, handle or workpiece in contact with the worker. Measurements have to be taken over a long enough period of time to ensure that truly representative average readings have been collected.

During measurement, frequency-weighting is applied to the vibration magnitudes, to account for the fact that certain frequencies increase health risk (this is similar to the A-weighting applied during noise measurement).

Once representative measurements of vibration magnitude in all three of the dimensions (x, y and z) have been taken, the treatment varies depending on whether the assessment is for HAV or WBV. In either instance, the vibration magnitude data are combined to give an overall vibration magnitude figure that can then be used to calculate personal daily exposure.

Calculation of vibration dose can be done using the three methods described below (Schedule 1 or 2 formulae, HSE website calculator or ready reckoner for HAV). Calculations by any method will require information about the duration of exposure to the vibration. This can be derived by observation or by reference to work schedules, worker interviews, etc.

Note that, for HAV, the total time taken to carry out a task is not important; what is important is the amount of contact time, or **trigger time**, when the worker is in contact with the vibrating surface.

Importance of Calibration

As for sound level meters, the accelerometer should be calibrated before and after use, to ensure the vibration measurements accurately reflect the actual vibration magnitudes. A separate calibrator is used for this purpose; this produces a vibration of a set intensity against which the meter can be adjusted.

Both calibrator and accelerometer must be tested and certificated every two years to ensure scientific accuracy.

Interpretation and Evaluation of Results

Calculating Vibration Exposure

Three different methods can be used to calculate a worker's personal exposure:

- **Use the Equations - Presented in Schedules 1 and 2 to the Regulations**

  For single exposures to **hand-arm vibration**:

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

  where:

  - a_{hv} is the vibration magnitude in metres per second squared (m/s²).
  - T is the duration of exposure to the vibration magnitude ahv.A(8) is the daily exposure to vibration normalised to an 8 hour working day.
  - T_0 is the reference duration of eight hours (28,800 seconds).
  - For multiple exposures in the same working period:

$$A(8) = \sqrt{A_1(8)^2 + A_2(8)^2 + A_3(8)^2 + \ldots}$$

  where A1(8), A2(8), A3(8), etc. are the partial vibration exposure values for the different vibration sources, each calculated as above.

  For single exposures to whole-body vibration:

$$A(8) = K.a_w\sqrt{\frac{T}{T_0}}$$

where:

- a_w is the vibration magnitude (root-mean-squared frequency-weighted acceleration magnitude) in one of three orthogonal directions, **x**, **y** and **z**, at the supporting surface.
- *T* is the duration of exposure to the vibration magnitude a_w.
- T_0 is the reference duration of eight hours (28,800 seconds).
- *k* is a multiplying factor.
- For multiple exposures in the same working period:

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{wi}^2 T_1}$$

where:

- *n* is the number of individual operations within the working day.
- a_{wi} is the vibration magnitude for operation *i*.
- T_i is the duration of operation *i*.

- **Use the UK's HSE Calculators**

  Two simple spreadsheet calculators are provided by HSE on their vibration website, one for HAV and one for WBV. These allow for multiple exposures and exposure durations to be entered and output a figure for A(8).

  For each calculator, the measured or estimated vibration magnitudes and the respective durations of exposure are entered. The spreadsheet then calculates the A(8) exposures and indicates where this lies with regards to the legal standards.

- **Use the UK's HSE Ready Reckoner for HAV**

  The guidance to the UK's **Control of Vibration at Work Regulations 2005** (L140 - Hand-Arm Vibration) contains a ready reckoner, which uses a points system to calculate the daily vibration exposure. This ready reckoner is also available on the HSE website.

Key
- Above ELV
- Likely to be above ELV
- Above EAV
- Likely to be at or above EAV
- Below EAV

Vibration magnitude, a_{hv} (m/s²)	5 min	15 min	30 min	1 h	1 h 30 min	2 h	3 h	4 h	5 h	6 h
40	265	800								
30	150	450	900							
25	105	315	825	1250						
20	67	200	400	800	1200					
19	60	180	360	720	1100	1450				
18	54	160	325	650	970	1300				
17	48	145	290	580	865	1150				
16	43	130	255	510	770	1000				
15	38	115	225	450	675	900	1350			
14	33	98	195	390	590	785	1200			
13	28	85	170	340	505	675	1000	1350		
12	24	72	145	290	430	575	885	1150	1450	
11	20	61	120	240	365	485	725	970	1200	1450
10	17	50	100	200	300	400	600	800	1000	1200
9	14	41	81	160	245	325	485	660	810	970
8	11	32	64	130	190	255	385	510	640	770
7	8	25	49	98	145	195	295	390	490	500
6	6	18	36	72	110	145	215	290	360	455
5.5	5	15	31	61	91	120	180	240	305	365
5	4	13	25	50	75	100	150	200	250	300
4.5	3	10	21	41	61	81	120	160	205	245
4	3	8	16	32	48	64	96	130	160	190
3.5	2	6	13	25	37	49	74	98	125	145
3	2	5	9	18	27	36	54	72	90	110
2.5	1	3	6	13	19	25	38	50	63	75
2	1	2	4	8	12	16	24	32	40	48
1.5	0	1	2	5	7	9	14	18	23	27
1	0	1	1	2	3	4	6	8	10	12

Exposure time, *T*

The ready reckoner - available from the HSE website
Source: L140 Hand-arm vibration, HSE, 2019 (www.hse.gov.uk/pubns/books/l140.htm)

MORE...

The HSE calculators and ready reckoner are available from the main vibration page of the HSE website:

www.hse.gov.uk/vibration/index.htm

From there, you can browse the specific HAV and WBV pages.

Comparison with Legal Limits

There are no internationally recognised standards or exposure limits for the control of vibration. We will consider some national and regional examples in this section.

Europe and the UK

In Europe, the directive **2002/44/EC** (known as the Physical Agents (Vibration) Directive) established limits that were to be implemented. In the UK this was achieved through the **Control of Vibration at Work Regulations 2005**, which specify exposure limit values and action values for both hand-arm and whole-body vibration.

- Hand-arm vibration:
  - The daily exposure limit value is 5m/s² A(8).
  - The daily exposure action value is 2.5m/s² A(8).

- Whole-body vibration:
  - The daily exposure limit value is 1.15m/s² A(8).
  - The daily exposure action value is 0.5m/s² A(8).

Where an **Exposure Action Value (EAV)** is likely to be reached or exceeded, the employer must:

- Reduce exposure to as low a level as is reasonably practicable by introducing appropriate organisational and technical measures.
- Provide appropriate health surveillance.
- Provide information, instruction, and training to employees.

The employer must ensure that his employees are not exposed to vibration above the **Exposure Limit Value (ELV)**.

If exposure above the limit value does occur then the employer must:

- Immediately reduce exposure to below the limit value.
- Identify the reason for that limit being exceeded.
- Prevent the limit from being exceeded again.

The directive and corresponding UK Regulations also require that health surveillance and information, instruction, and training are provided where there may be a health risk to individuals exposed below the EAV. This would be appropriate for workers who are particularly vulnerable to the effects of HAV or WBV, for example those who are:

- Identified as suffering from HAVS.
- Known to suffer from Raynaud's phenomenon or other circulatory disorders.
- Known to have a pre-existing back injury.
- Recovering from back surgery.

Australia

Australia has developed standards for:

- Whole-body vibration - AS 2670.1-2001 - *Evaluation of human exposure to whole-body vibration*, which is identical to **ISO 2631-1:1997**, *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration.*
- Hand-arm vibration - AS 2763-1988 - *Vibration and shock - Hand-transmitted vibration - Guidelines for measurement and assessment of human exposure*, which is aligned with **ISO 5349:2001**, *Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration.*

These Australian Standards do not define what the safe limits of exposure to vibration are, but provide guidance on how to evaluate exposure to vibration.

In Australia, there are no specific vibration Regulations, but the **Commonwealth Occupational Health and Safety Code of Practice 2008** has a specific section on vibration, and prescribes a process for controlling the risks of vibration exposure in accordance with the hierarchy of controls. It also states that where hazardous vibration has been identified, employers must measure the vibration levels and recommends that employers should regularly monitor and review the exposure levels of workers, assess the control measures in place, and undertake regular medical checks of workers.

USA

In the USA, the **Occupational Safety and Health Administration (OSHA)** has not developed standards for occupational exposure to vibration, but the American Conference of Governmental Industrial Hygienists (ACGIH) has developed Threshold Limit Values (TLVs) for vibration exposure (see the following table). These represent acceleration levels and exposure durations to which most workers may be exposed repeatedly without severe damage to the fingers. The ACGIH advises that these guidelines be applied in conjunction with other protective measures, including vibration control.

The ACGIH is not a policy-making organisation and the TLVs they recommend are not enforceable or a form of Regulation in America.

ACGIH Threshold Limit Values	
Total Daily Exposure Duration (hours)	**Maximum value of frequency-weighted acceleration (m/s^2) in any direction**
Between four and eight hours	$4m/s^2$
Between two and four hours	$6m/s^2$
Between one and two hours	$8m/s^2$
Less than one hour	$12m/s^2$

Once an individual worker's or group of workers' eight-hour energy equivalent vibration magnitude exposure has been reliably estimated, it must then be compared to the national standards contained in legislation or local guidance.

Comparison of the estimated magnitude of exposure in the workplace with national or regional standards will allow the correct actions to be identified to achieve compliance.

Employees should not be exposed to vibration above the ELV

Practical Control Measures to Prevent or Minimise Exposure

Section 10.3 of the ILO Code of Practice - *Ambient factors in the workplace*, gives practical control measures to prevent or minimise exposure to vibration.

The process starts with elimination of processes that use vibrating tools, and where this cannot be achieved using tools that have information provided by manufacturers on vibration characteristics. Manufacturers of vibrating tools must avoid resonating frequencies and, as far as practicable, provide anti vibration handles that are consistent with national laws and Regulations.

When employers purchase vibrating tools they must ensure that vibration exposure is within prescribed national laws and Regulations.

Where old machinery is in use, engineering control methods must be used to modify the vibration characteristics, using damping techniques. Where transmission is through flooring materials then the machine should be mounted on vibration isolators, which may require retrospective design if the machine was not supplied with them.

Administrative controls must also be employed. Workers must be instructed to grip the handles of vibrating tools as lightly as possible. Older tooling, where retrofitting engineering controls are not practicable, should be replaced with more modern tooling with lower vibration characteristics. Machinery must be maintained regularly since worn parts are more likely to have increased vibration characteristics.

Where exposure of the worker to vibration is still likely to cause harm, the employer should rearrange working schedules to give rest periods, or use job rotation to reduce overall exposure to within safe levels.

Whole-body vibration is also considered in the code. Seating in vehicles should be designed to minimise vibration transmission. Whole-body vibration is dependent on the speed the vehicle is being driven and the nature of the terrain. Employers must therefore ensure that workers travel at reasonable speeds and that roads under the employer's responsibility are well maintained.

Part 2 of the UK's HSE document - *Hand Arm Vibration* L140 provides a hierarchy of control that is consistent with the ILO code and which, if followed, minimises the risk of exposure to vibration.

The hierarchy of control and practical control measures for reducing occupational exposure to **hand-arm vibration** include:

- **Eliminate Vibration Exposure**

  It is sometimes possible to eliminate vibration exposure from a task completely. Where the ELV is exceeded, this may be the only way of reducing exposure. Elimination might be achieved by changing work methods entirely, or by changing items of plant and equipment. For example:

  – Changing fabrication methods, e.g. using adhesives or welding to avoid using pneumatic riveting hammers.

  – Replacing pneumatic 'buzz' saws with laser profilers for cutting thin steel sheets.

  – Using prefabricated components to reduce the need for 'cutting and patching' to fit on site.

  – Mechanising or automating processes that use hand-held machines.

  – Using machine-mounted breakers, mobile road-cutting machines and/or trenching machines instead of hand-operated road breakers for trench-work.

  – Splitting large blocks using hydraulic expanding devices inserted into pre-drilled holes ('bursting').

- **Reduce Exposure by Mechanisation**

  The use of robotics, remote control machines or automating a process can eliminate exposure to vibration for the employee. For example:

  – Use of a vehicle-mounted hedge cutter to eliminate the use of handheld hedge cutters.

  – Use of a remote control breaking (chisel) machine to break up concrete. Eliminating handheld pneumatic breakers.

  – Use of remote control swing grinders in foundry fettling operations to eliminate the use of handheld grinders.

Equipment will suffer wear and tear during normal use

- **Reduce Exposure by Good Process control**

  Good process control will ensure quality is sustained and rework significantly reduced. This will contribute to reduced exposure to vibration. If power press dies are clean and well maintained, then the components pressed will have a reduced requirement for reworking. Improving the accuracy of moulding equipment will reduce the amount of 'flash' on mouldings that will subsequently require less rework.

- **Avoid High-Vibration Tools, Machines and Accessories**

  After doing all that is reasonably practicable to minimise exposure by elimination, mechanisation and process control, exposure to vibration may persist. The careful selection of power tools can further reduce exposure by the following:

  - Establish a purchasing policy that specifies vibration as one criterion of selection and vet new equipment on this basis.
  - Use manufacturer's data to select low-vibration magnitude equipment.
  - Choose equipment that will be efficient in use; the less time the equipment is in use, the lower the exposure time and the lower the dose.
  - Choose equipment that is lighter to hold, so requires less grip-strength.
  - Look at the ergonomics of use and choose equipment that is comfortable to use, as this usually indicates less force is required in use.

- **Maintain Machines and Accessories**

  Tools and equipment suffer wear and tear during normal use. This inevitably increases the vibration magnitude generated:

  - Power tools should be serviced and maintained in line with the manufacturer's instructions.
  - Replace worn parts and correct unbalanced equipment.
  - Maintain any anti-vibration devices or features on equipment (such as anti-vibration handles).
  - Sharpen tools to reduce both vibration generated and the duration of the job (exposure time).
  - Tuning and adjusting engines for optimum (lowest vibration characteristics) performance.

- **Reduce the Transmission of Vibration into the Hand**

  It may be possible to reduce exposure to vibration by limiting the vibration transmitted to the hand by minimising grip and pushing forces. Gripping and pushing forces are required to manipulate the machine and/ or the workpiece. The cause of excessive grip/push forces may be due to incorrect machine selection, poor maintenance, or the competence of the worker. Improvements in excessive grip/push forces can be achieved by:

  - Providing supports for workpieces.
  - Counter-balance weights that avoid the worker having to fully support the machine's weight.
  - Changing texture and material of grips to enable lighter grip forces.
  - Ensure the machine is well maintained, e.g. dressing, and balancing grinding wheels to improve concentricity when running.

- **Reduce the Duration of Exposure**

  When exposure has been reduced by engineering methods, further exposure can be reduced by administrative controls. These could include:

  - Job rotation.
  - Supervision.
  - Tool timing devices to log duration.

- **Keeping Warm and Dry**

  Low body temperature, especially in the hands, can increase the risk of reduced blood circulation which can lead to an increased likelihood of blanching. Gloves and other items of clothing should be used to keep the hands and body warm and dry. The selection of clothing should not increase the risk, e.g. of entanglement, to the worker.

- **Information, Instruction and Training**
  - Information on the risks of the use of vibrating equipment and the associated health conditions should be provided.
  - Instruction on the control measures, to minimise the risk, should be given.

  Practical control measures for reducing occupational exposure to **whole-body vibration** include:

- **Elimination**

  Since most WBV exposure is to vehicle drivers and operators, elimination is unlikely to be an option in many instances.

- **Equipment Selection**

  Vehicle and plant manufacturers include low vibration or anti-vibration features in their design, e.g. anti-vibration cab and seat suspension systems. Manufacturers are also required by law to make vibration data available to purchasers:
  - Establish a purchasing policy that specifies vibration as one criteria of selection and vet new equipment on this basis.
  - Use manufacturer's data to select low-vibration magnitude equipment.
  - Choose equipment that is going to be suitable for the job and environment of use (e.g. adequate load capacity, right size wheels for the terrain, capable of required speeds, etc.).
  - In particular, focus on the suspension systems for seats, cabs, and vehicle body, all of which isolate the driver from the movement of the tyres over rough ground.

- **Care and Maintenance**
  - Balance wheels to eliminate judder.
  - Maintain any anti-vibration devices or features (such as seat or cab suspension systems).
  - Maintain traffic routes by grading surfaces and filling potholes to keep surfaces as smooth as practical.

- **Reduced Time Exposure**
  - Job rotation and rest breaks can reduce exposure time.
  - Maximum duration of use can be applied to vehicle and plant provided reliable vibration magnitude data is available. The HSE online calculator can be used for this purpose.

- **Information, Instruction and Training**
  - Information on the risks of exposure to WBV and the associated health conditions should be provided, including:
    - Sources of vibration.
    - How risk is influenced by severity of exposure and duration.
    - The findings of the risk assessment.
    - How to report back pain.

    - Health monitoring scheme in use.
    - The significance of adjusting the vehicle speed over rough terrain.
- Instruction and training on the control measures to minimise the risk should be given. This will relate to vehicle use, care and maintenance, including:
    - Training on the avoidance of potholes.
    - Adjusting driver weight settings on suspension seats, where fitted.
    - Adjusting the seat position and controls, to optimise good lines of sight, back support, ease of reaching, plus foot and hand controls

Part 3 of L141 advises that driver competence, knowledge and skills are some of the most important aspects of reducing risk for WBV.

PPE is not available to control against WBV.

The Advantages and Disadvantages of Wearable Technologies

Wearable technology has been used for decades. Devices such as hearing aids, pacemakers and fitness devices are common in society.

Sensors are an important part of wearable technologies; they are becoming smaller and more sensitive. The most successful devices are those that use algorithms to process raw data into meaningful numbers for the user. The wearable device must be able to communicate with the world outside of the device, i.e. by being able to download data into a computer for further analysis.

Advantages of Wearable Technologies

- Data gathered can be used to provide useful information to inform a suitable and sufficient risk assessment. The method of gathering the data can use the UK's HSE's total exposure points system that combines trigger time with the vibration value programmed into the device.
- The vibration measured is experienced by the user, rather than on the tool. The assessment of exposure is during the entire use of the tool, and so may be more accurate than using 'trigger' times.
- Data gathered can be used to inform risk reduction control strategies and identify trends.
- The constant reminder from the wearable device on exposure data can be useful in supporting worker behaviour changes.

Disadvantages of Wearable Technology

- The validity of the measurements provided by the programme in the devices worn is the responsibility of the employer and not the supplier of the equipment. A number of sources of predefined vibration magnitude can be used, and the local authorities may require justification of the choice made. Alternatively, a sensed exposure points value can be calculated - still using an exposure points system, but using a 'real time' magnitude of vibration sensed at the wrist, in combination with the trigger time. Local authorities may require evidence that the vibration levels are appropriate.
- Devices may have limited operation time (from fully charged to fully discharged). Battery life may have a limited number of recharges. They will need to be maintained, stored and disposed of correctly.
- Some workers may find them uncomfortable, due to their size (typical sizes are 38mm square x 15mm thick).

- Many wearables have a video display or a touch screen for user interaction. A significant challenge for such small displays is ease of use. Maintaining usability requires the right balance between how much information can fit on the screen, compared to how readable the resulting information is.
- Managing the power consumption of these displays is a significant factor in the usefulness of the device. Wearable devices must be powered by rechargeable batteries or other charging methods. This commonly requires a port for connected power to recharge the batteries. Wireless power transmission is emerging as a key feature to be integrated in new wearable devices. However, this presents the problem of waterproofing and heat when charging. Wireless charging is also less energy efficient.
- Ruggedness as a concept is relative, and can only be defined in terms of the application. The ruggedness requirements for a hearing aid are different to those for a vibration monitor.
- Any monitoring device needs to be used with the cooperation of the worker. They can be prone to being tampered with, or abused, so that data recorded is unreliable.

STUDY QUESTIONS

1. What is meant by 'vibration dose'?
2. Describe the range of effects that vibration can have on the human body.
3. Describe the condition 'vibration-induced white finger'.
4. List the range of work activities associated with hand-arm vibration.
5. Which workers might be exposed to whole-body vibration hazards?
6. Outline a strategy to implement a risk assessment for hand-arm vibration.
7. State three methods for reliably estimating the daily exposure of a worker to hand-arm vibration if the vibration magnitude and duration of exposure are known.
8. Discuss the control options available to reduce the risk from hand-arm vibration.

(Suggested Answers are at the end.)

Summary

Basic Concepts of Vibration

We have described how:

- Hazardous vibration can be divided into two types: Hand-Arm Vibration (HAV) and Whole-Body Vibration (WBV).
- Vibration can be characterised using several factors, notably the magnitude (measured in $m.s^{-2}$), frequency (hertz, Hz) and direction (in three dimensions, x, y and z).
- The harm caused by vibration is determined by dose, in turn determined by the vibration magnitude and duration of exposure. The eight-hour energy-equivalent vibration magnitude is used as the standard daily exposure.
- Workers at risk of HAVS include those using cutting and grinding tools and pneumatic hand tools.
- Those at risk of WBV are principally vehicle and plant driver/operators, especially when moving over rough terrain.
- The main health effect of WBV is back pain.
- The main health effect of HAV exposure is Hand-Arm Vibration Syndrome (HAVS), often characterised by blanching of the fingers on exposure to cold (often called 'vibration-induced white finger').
- The severity of HAVS can be quantified using the Stockholm scale.
- Vibration risk assessments should be carried out which consider:
  - The potential sources of vibration and tasks carried out.
  - The possibility of exposure to cold environments and the nature of the vibration (HAV or WBV).
  - Any exposure limits that apply.
  - Expected vibration emission levels from equipment.
  - The need for measurements to quantify and characterise vibration and assess effectiveness of existing controls.
  - The potential for elimination of vibration and other controls, such as training.
  - Vibration magnitude can be measured directly using an accelerometer, or taken from manufacturer's data. This data, in combination with duration of contact, can then be used to reliably estimate personal exposures.
- Actual vibration exposure can be calculated using formulae, the UK's HSE web-based calculators or the HSE ready reckoner (HAV only).
- These personal exposures can then be compared to the standards established in national legislation.
- The action values require the employer to act to control exposure. The limit values must not be exceeded.
- Control of vibration exposure can be achieved by applying controls in a priority order:
  - Elimination of exposure.
  - Purchase of equipment with low vibration performance.
  - Equipment maintenance.
  - Reduction in the time of exposure.

Summary

- – Providing information, instruction and training.
- – Providing PPE (not an option for WBV).

- Health surveillance must be provided for workers exposed to HAV above the EAV and those diagnosed with HAVS.

Learning Outcome 9.13

NEBOSH International Diploma for Occupational Health and Safety Management Professionals

ASSESSMENT CRITERIA

- Summarise the hazards and controls for the different types of radiation.

LEARNING OBJECTIVES

Once you've studied this Learning Outcome, you should be able to:

- Outline the nature of the different types of ionising and non-ionising radiation.
- Explain the effects of exposure to non-ionising radiation, its measurement and control.
- Outline the effects of exposure to ionising radiation, its measurement and control.

Contents

Nature and Types of Ionising and Non-Ionising Radiation

IN THIS SECTION...

- Radiation can be grouped into two main types: ionising and non-ionising.
- Ionising radiation causes ionisation in the material that absorbs it - this delivers energy into the material and promotes unusual chemical reactions that would otherwise not occur.
- The electromagnetic spectrum is the full range of frequencies that electromagnetic radiation can be found at; from high-frequency gamma-rays to low-frequency radiowaves.
- All types of non-ionising radiation are electromagnetic waves and can be broadly categorised as optical (ultraviolet, visible and infrared radiation) and electromagnetic fields (or radiofrequency: microwaves and radiowaves).
- Ionising radiation can be grouped into five different types: alpha and beta particles, neutrons, x-rays and gamma-rays. These vary in their properties and characteristics, particularly in their ability to penetrate matter. Three of these types of ionising radiation are particulate in nature - alpha particles, beta particles and neutrons. The two others, gamma- and x-ray, are forms of high-energy electromagnetic radiation.

Introduction to Radiation

Radiation is energy that is emitted by a source.

There are two basic kinds, known as electromagnetic and particulate radiation respectively. Electromagnetic radiation is made up of energy waves.

The visible light that the eye responds to is a form of electromagnetic radiation. It can be useful to think of all electromagnetic radiation as being different forms of light, some of which the eye can see, but a lot of which the eye cannot see.

Radiation can be ionising or non-ionising

Particulate radiation is made up of particles (these particles carry energy, just as waves do, but they also have mass). Some radiation can cause ionisation when it strikes matter, and so you will also find that radiation may be referred to as ionising or non-ionising. Particulate radiation considered in this section is all ionising radiation. Some forms of electromagnetic radiation can also be ionising, but some forms are not. We'll look at these terms (ionising, non-ionising, electromagnetic, particulate) in more detail below.

Distinction Between Ionising and Non-Ionising Radiation

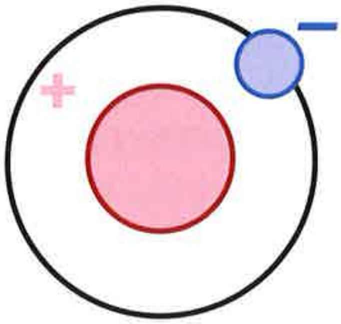
Simply put, ionising radiation is radiation that **causes** ionisation in the material that absorbs it; and non-ionising radiation is radiation that **does not cause** ionisation in the material that absorbs it.

In order to understand ionisation, it is first necessary to explain basic atomic structure.

9.13 Nature and Types of Ionising and Non-Ionising Radiation

Sub-Atomic Physics

Unfortunately, sub-atomic physics is unavoidable when discussing radiation, so let's look at a simple way of thinking about atomic structure:



Hydrogen atom
One proton in the nucleus at the core and one electron orbiting in a shell around the nucleus

- All matter is made up of atoms.
- Atoms have a structure rather like an onion: a central core surrounded by layers or shells.
- The shells of the atom contain one or more electrons moving around at high speed.
- The core of the atom contains the atomic nucleus, which is made up of two types of sub-atomic particle: protons and neutrons.
- Electrons are relatively small and light with a negative (-ve) electrical charge (-1).
- Protons are relatively big and heavy with a positive (+ve) electrical charge (+1).
- Neutrons are relatively big and heavy with no overall electrical charge (neutral).
- The number of protons in the nucleus of an atom determines which chemical element that atom is. For example, hydrogen has one proton in its nucleus, carbon has six and uranium has 92.
- The number of electrons in the shells around the nucleus normally matches the number of protons in the nucleus. This means that the positive electrical charge of the protons is exactly balanced by the negative electrical charge of the electrons (e.g. for hydrogen, one proton in the nucleus plus one electron in orbit around the nucleus = +1 + -1 = 0 charge). In this way, a hydrogen atom has a net neutral electrical charge.

Having set the scene, we can now move on to define 'ionisation'.

Ionisation

Ionisation occurs when one or more electrons are removed from its shell around the nucleus of an atom:

- Removal of an electron means that the number of protons in the nucleus is no longer balanced by the number of electrons. The result is that the atom has a net **positive charge**. It is referred to as an **ion**.
- Ions take part in chemical reactions very readily. For example, hydrochloric acid has a large number of hydrogen ions available for chemical reaction. That is why the acid reacts easily with other substances and why it is corrosive.
- If an atom is joined to other atoms to form a molecule, ionisation of that atom will often mean that the molecule falls apart.

As we noted earlier, ionising radiation **causes** ionisation in the material that absorbs it:

- So, if ionising radiation is absorbed by living tissue, then atoms inside that living tissue will be converted to ions by the radiation. In effect, the radiation kicks electrons out of their shells.
- This is why ionising radiation is damaging to living tissue. The radiation causes the destruction of molecules making up the cell and, in particular, it causes the destruction of DNA.
- Simply put, the ionising radiation delivers energy into the living tissue that causes high-energy chemical reactions to take place.

(The health effects of ionising radiation will be described in more detail later in this Learning Outcome.)

Note that if you are unfamiliar with the principles being discussed here, it is easy to confuse ionisation and radioactivity. Just because an atom has been ionised does not mean that it is radioactive.

Radioactivity is often a **source** of ionising radiation. Ionisation is the **effect** of that radiation. Radioactivity will be introduced later in this Learning Outcome.

The Electromagnetic Spectrum

The electromagnetic spectrum is the spectrum made up of all possible frequencies or wavelengths of electromagnetic radiation (see diagram below).

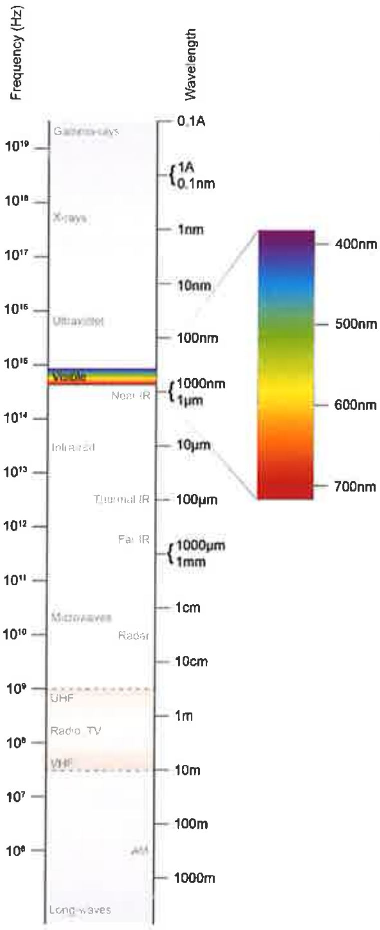
You may remember from previous Learning Outcomes that the wavelength of a waveform is the distance (in metres) from one peak to the next, and that frequency is the number of waves per second (in hertz). Since the speed of electromagnetic radiation is fixed (speed of light), as wavelength increases, frequency decreases. The two parameters are, therefore, inversely proportional to one another.

Visible light is a form of electromagnetic radiation.

The human eye is sensitive to a very narrow part of the electromagnetic spectrum, between wavelengths of 400 to 700 nanometres.

As the wavelength gets shorter (and frequency increases), the light becomes invisible to the human eye and we enter the **ultraviolet (UV)** frequencies. Continue to shorten the wavelength and increase frequency and we move up through the **x-ray** frequencies and **gamma-ray** frequencies. This is the very high-energy end of the spectrum.

If, however, we return to the visible part of the spectrum and then increase wavelength (decrease frequency), we drop out of the bottom of the visible light spectrum and into the **infrared (IR)** frequencies. Again, these frequencies cannot be seen by the human eye but they can be felt (in the form of radiant heat). Carry on increasing wavelength and decreasing frequency and we move down into the **microwave** and then the **radiowave** frequencies. All TV and radio signals, from Ultra-High Frequency (UHF) to long wave, are broadcast in this part of the spectrum. This is the low-energy end of the spectrum.



The electromagnetic spectrum

All electromagnetic radiation has some features in common; it moves at the speed of light (3 × 108m/s) and in straight lines (unless interfered with in some way). Beyond these similarities, electromagnetic radiation at different frequencies has very different characteristics. These can best be understood by looking at the way the spectrum can be broken up into sections:

- **Ionising Electromagnetic Radiation**

  This is the high-energy end of the spectrum, up to 100 nanometres wavelength. **Gamma-rays** and **x-rays** form this part of the spectrum. These rays are so high-energy that they can kick electrons out of their atomic shells and cause ionisation, as described previously:

  - **Gamma-rays** are emitted from the nucleus of many radionuclides during radioactive decay (see later). A typical occupational source of gamma-rays would be the radionuclide Cobalt 60 used for industrial radiography (a form of non-destructive testing).
  - **X-rays** are emitted from the electron shells around the nucleus. X-rays are generated artificially by bombarding a metal target with electrons inside a vacuum tube. A typical occupational source of x-rays would be an x-ray generator used for medical radiography.

Both gamma rays and x-rays, like light, 'shine' in straight lines at the speed of light. They are very penetrating and can shine through many types of material, such as paper, aluminium and human tissues. They are unlikely to penetrate through 50mm-thick lead. They will shine for kilometres through the atmosphere.

- **Non-Ionising Electromagnetic Radiation**

  This is the lower energy end of the spectrum, which includes optical radiation and radio frequencies:

  - **Optical Radiation**

    This section of the spectrum is made up of UV, visible and IR light. These wavelengths do not cause ionisation, but they can still cause damage to the skin and, in particular, to the eye. Typical occupational exposures would include:

    - Ultraviolet - naturally occurring in sunlight, emitted from sunlamps, arc welding, etc.
    - Visible - naturally occurring in sunlight, emitted from visible lasers, arc welding, etc.
    - Infrared - emitted from any hot object but, particularly, things glowing red, yellow or white hot, such as: metal casting, molten glass, furnaces, etc.

  - **Radiofrequencies (RF)**

    This section of the spectrum is made up of microwaves and radiowaves. These wavelengths do not cause ionisation. They can, however, be absorbed by the body to cause internal heating. Typical occupational exposures would include:

    - Microwave - emitted by communications equipment and microwave cookers.
    - Radiowaves - emitted from satellite communications, TV and radio broadcasts, radar, and Magnetic Resonance Imaging (MRI) in medical diagnosis.

You will notice from the above that the electromagnetic spectrum is made up of two types of ionising radiation (x-rays and gamma-rays) and various types of non-ionising radiation (UV, visible, IR, microwaves and radio-frequencies). In fact, **all types** of non-ionising radiation are electromagnetic waves. The same cannot be said for ionising radiation, however.

Particulate Radiation

Earlier in this Learning Outcome, we saw how the electromagnetic spectrum comprises a wide range of types of radiation, some of which (like x-rays) are ionising and some of which (like IR) are not. In this section, we look at **particulate** radiation - alpha particles, beta particles and neutrons - all of which are forms of ionising radiation. These are made of sub-atomic particles rather than electromagnetic rays. They are emitted by radioactive substances. Later in this Learning Outcome, we will return to examine the topics of radioactivity and how radioactive decay produces different forms of ionising radiation. For now, we just need to be concerned with the three principal types of particulate ionising radiation.

Image displayed by an infrared camera sensitive to IR radiation given off by the human body

TOPIC FOCUS

Types of Particulate Radiation

Alpha particles released from a source radionuclide (central white blob) make ionisation trails (fuzzy white streaks) in a cloud chamber

- **Alpha particles** are particles made up of two protons and two neutrons. They are emitted from naturally occurring materials, such as uranium and radium, from the nucleus during radioactive decay. Alpha particles are far less penetrating than gamma-rays. They can only move through a few centimetres of air and are unable to penetrate even thin material, such as paper or aluminium foil. Alpha particles striking the skin are unlikely to be absorbed by living skin tissue as the dead layer of cells at the top of the epidermis (horny layer) will block their entrance. A typical occupational source of alpha particles is a smoke detector. Alpha radiation is used to treat various forms of cancer in a process known as 'unsealed source radiotherapy'. The process involves inserting small amounts of radium into the cancerous mass. The alpha particles destroy the cell, but lack the strength to damage surrounding healthy cells.
- **Beta particles** are particles made up of one electron. They are emitted from the nucleus during radioactive decay (and in case you were wondering what an electron is doing in the nucleus, it is created when one of the neutrons in the nucleus spontaneously splits apart to become one proton and one electron. The proton stays in the nucleus but the electron is spat out). Beta particles can occur naturally from materials, such as strontium 90, during radioactive decay. Beta particles are more penetrating than alpha particles but far less penetrating than gamma-rays. They can pass through metres of air, through paper and through the horny layer at the top of the epidermis. They cannot pass through thicker material, such as several centimetres of aluminium or 1mm-thick lead. A typical occupational source of beta particles is thickness gauges. Beta particle radiation is also used in some phosphorescent lighting, typically for emergency lighting, as it requires no power.
- **Neutrons** are particles from the nucleus emitted during certain types of radioactive events, usually fission reactions inside nuclear reactors. Naturally occurring neutron radiation is found in cosmic rays that originate from the Sun or from outside the solar system. Neutrons are the most penetrating form of all. They can pass through tissue and even relatively thick dense materials, such as 50mm of lead. Neutron-absorbing shields are often made of concrete. Water is an excellent neutron shield, which is why spent nuclear fuel is stored in pools. Neutrons can make objects radioactive and the process of neutron activation is used to produce industrial applications for oil exploration and medical uses. A typical occupational source would be a nuclear reactor at a nuclear power plant.

STUDY QUESTIONS

1. State the two main categories of non-ionising radiation.
2. Suggest five broad regions of the electromagnetic spectrum that can be used to classify non-ionising radiation.
3. What is the source of beta radiation and what is it used for?
4. What is the difference between gamma radiation and x-rays?

(Suggested Answers are at the end.)

Non-Ionising Radiation

IN THIS SECTION...

- Non-ionising radiation is produced by the sun (both UV and visible light from the sun are significant health hazards) and artificially by various types of equipment, such as sunbeds (UV), arc-welding (UV, visible and IR), furnaces (IR), ovens (microwaves) and radio transmitters (microwaves and radiowaves).
- Each type of non-ionising radiation has specific health effects:
  - UV can cause sunburn, arc-eye, premature ageing of the skin and increased risk of skin cancer.
  - Visible light can cause damage to the retina and permanent blindness.
  - IR can cause skin burns and cataracts.
  - Radiofrequencies can cause burns and internal heating.
- Exposure Limit Values (ELV) for non-ionising radiation are set out in national and regional standards, e.g. in the EU, the EU **Physical Agents (Electromagnetic Fields) Directive (2013/35/EU)**.
- Control of exposure to non-ionising radiation is achieved by risk assessment and application of a standard control framework.
- Protection from harmful UV, visible and IR radiation can often be achieved by eye protection and skin protection.
- Protection from EMF radiation is achieved by isolation, interlocks, safe systems of work (including permit systems) and maintaining distance from source.
- Laser light is normally a highly coherent, non-divergent beam of electromagnetic radiation in the UV, visible or IR wavelengths.
- Lasers are used for thousands of different domestic and industrial applications, from CD and DVD players to industrial metal cutters and medical instruments.
- The main health risk from laser light is damage to the eyes; from temporary discomfort to permanent blindness, with different parts of the eye being affected by different wavelengths of light. Skin damage can also occur with high power lasers.

Sources of Non-Ionising Radiation

Non-ionising radiation comprises electromagnetic radiation from the UV, visible, IR, microwave and radiowave wavelengths. Sources of non-ionising radiation can be both natural and man-made.

The sun emits non-ionising radiation at all wavelengths

Workplace Examples

Different man-made sources will emit different forms of non-ionising radiation. Typical examples of sources for each form include:

- UV - sunlamps in tanning salons, arc-welding, science lab equipment, ink and adhesive curing.
- Visible - general lighting, cutting and welding, theatre and photographic lights, and visible light lasers used in various applications.
- IR - metal furnaces, glass furnaces, fire, and heat lamps.

- Microwave - microwave ovens, mobile phone masts, and mobile phone antennae.
- Radiowaves - communications equipment.

In some instances, the wavelength of the radiation emitted can be closely controlled and emission of only one form of non-ionising radiation occurs (e.g. a microwave oven does not emit IR or other radiowaves). In other instances, a source can emit across a wide band of wavelengths and, consequently, may emit several different forms of radiation at once (e.g. arc welding results in the emission of intense UV, visible and IR light - all of which are unwanted by-products of the welding process).

Natural Sources

Naturally occurring radioactivity has existed from the creation of the earth! Radionuclides of uranium, thorium and potassium are abundant on the rocks and soil. This radioactivity can be transferred to anything grown in the spoil and then consumed by humans - Potassium 40 is present in most foods. Radon gas and thoron gas are both naturally occurring radioactive gases that can impact the indoor workplace (or home). A significant source of thoron gas is from construction materials (a material taken from the earth's crust and used as a construction material). The effect of thoron gas is less well understood than that of radon gas. Both gases, however, are associated with lung cancers.

A significant source of many of these forms of non-ionising radiation is the sun. The sun emits non-ionising radiation at all wavelengths, but the wavelengths that are most important from an occupational health point of view are visible and UV light. Any worker required to spend significant periods of time outdoors is exposed to these forms of non-ionising radiation.

Laser Sources in the Workplace

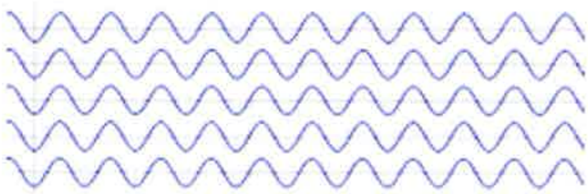
Typical Laser Sources

DEFINITION

LASER

Is an acronym that stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

Laser light is electromagnetic radiation that has been produced in such a way that the light waves are all of one wavelength and all in phase (in step with each other, i.e. the peaks and the troughs are all aligned). Laser light is therefore very coherent and usually non-divergent (the beam does not spread out as it travels through air or materials).



Laser light waves

To give an example of this coherent, non-divergent nature, a laser beam is routinely shone from the earth onto a mirror target, placed on the surface of the moon (by an Apollo mission) and then captured back on earth, so that the exact distance from Earth to moon can be calculated - a round trip distance of half a million miles.

Different types of laser emit laser light at different wavelengths. Some of these wavelengths fall within the visible light part of the electromagnetic spectrum, giving a laser beam that can be seen with the eye. But other lasers produce light in the UV and IR parts of the spectrum; these are invisible to the human eye. Microwave and radiowave lasers also exist, though these are usually called 'masers'.

Lasers are used for many different purposes and have been incorporated into a surprising number of items of equipment. Typical occupational sources of laser light would include:

- Barcode scanners used to identify and track items in retail, wholesale, warehousing, transport and delivery sectors.
- CD and DVD readers and burners in players and computers.
- Distance measuring devices, such as range finders, theodolites and speed guns.
- Marking devices, such as gun sights, laser pointers and laser spirit levels.
- Medical devices, such as dental drills, laser scalpels and those used for eye surgery.
- Lasers used in nightclubs and outdoor light shows.
- Metal-working cutters and welders.

Routes of Exposure and Effects of Non-Ionising Radiation

The routes of exposure to non-ionising radiation will vary to a degree, depending on the type of radiation. The main exposure route for optical radiation (UV, visible and IR) is direct or indirect exposure of the eyes and skin. These are the two parts of the body prone to damage from these forms of non-ionising radiation.


Infrared radiation emitted by fire

Direct exposure can result from directly looking at the source of the radiation, or being adjacent to the source without protection. For example, an arc-welder might glance at their workpiece without putting their face-shield on; this would result in direct UV exposure of the eyes and the skin of their face.

Indirect exposure might occur as a result of reflected light rays. For example, a lab technician might receive a visible laser light strike to their eye, as a result of the laser light reflecting off a shiny surface, accidentally introduced into the beam of the laser.

For microwave and radiofrequencies, since these forms of non-ionising radiation can penetrate into the body, the routes of exposure will be as a result of being within the beam of, or close to, the source of the radiation. Any part of the body, whether covered or not, is likely to absorb the radiation if it is within the radiation pathway.

The health effects of non-ionising radiation depend on the form of radiation.

Ultraviolet

Health effects resulting from an excessive exposure to ultraviolet radiation depend mainly on the wavelengths of the radiation. As penetration into dense material is limited, its effect on the human body will be mainly confined to the outer skin and the eyes.

Acute effects of exposure to ultraviolet radiation include:

- **Skin** - sunburn (reddening of the skin or **erythema**) as a result of exposure to wavelengths below 315nm. The severity depends on the duration and intensity of the exposure; people with a dark skin have a higher threshold than those with fair skin.
- **Eye** - arc-eye (inflammation and temporary blindness, also known as 'snow-blindness' or '**photokeratitis**' or '**photoconjunctivitis'**), as a result of exposure to wavelengths below 315nm. This is essentially sunburn to the outer layers of the eye; the cornea is affected by photokeratitis and the conjunctiva (the membrane lining the inside of the eye socket) by photoconjunctivitis. Symptoms normally start several hours after exposure and will last for 36 hours.

Erythema on the surface layers of the eye

Chronic effects of exposure to ultraviolet radiation include:

- **Premature ageing of the skin** - as a result of destruction of the long collagen molecules in the skin that give it elasticity.
- **Skin cancer** (e.g. melanoma) - as a direct result of UV damage to DNA molecules in skin cells, and as an indirect result of the production of free radicals by UV in skin tissue.
- **Cataracts** - the lens becomes less flexible, becoming cloudier and thicker, blocking light passing through the eye. This commonly occurs with ageing or medical conditions, however the early onset of cataracts with a yellowing of the lens of the eye is caused by exposure to UV light. UV light can damage the lens of the eye, causing it to become opaque and reducing vision.

Other health effects associated with UV exposure include:

- **Photosensitisation** - sensitisation of the skin caused by UV exposure of chemicals in, or on, the skin, such as tar compounds and synthetic dyes. Antibiotics and tranquillisers which can build up in the skin during medication have also been known to produce this effect.
- **Formation of toxic contaminants** - ultraviolet radiation of wavelengths below 250nm has the ability to produce ozone and oxides of nitrogen. These gases have an irritant or corrosive effect on the respiratory system, causing inflammatory conditions similar to bronchitis. Both ozone and oxides of nitrogen form hazardous gaseous environments where arc welding is carried out and must be removed from the breathing zone by exhaust ventilation systems.

Visible

The most obvious effect is nuisance or disability glare as a result of being dazzled by the intense visible light:

- **Nuisance glare** - being dazzled by intense light that causes the pupil of the eye to contract, so making less intense areas more difficult to see (e.g. trying to look at a computer screen when facing a sunlit window).
- **Disability glare** - being dazzled by intense light that causes the retina to become unresponsive to light, resulting in temporary blindness (e.g. staring at a light bulb and then trying to look at an image).

These effects directly affect safety. Other health effects resulting from an excessive exposure to visible light radiation depend on: wavelength, intensity and duration of exposure:

- **Blue light hazard** - photochemical retinal damage as a result of exposure to short wavelength visible light (at the blue end of the spectrum) is retinal damage that was not caused by mechanical or thermal means. This is thought to lead to permanent damage to retina cells and has been implicated in age-related macular degeneration (a form of blindness). This health risk is an area of current medical research and is not fully understood.

- **Permanent blindness** - as a result of exposure of the retina to intense light, as might be encountered when using a laser (especially Class 3B or 4, e.g. for laser surgery or metal cutting) or when using optical instruments, such as a telescope and accidentally looking at the sun.

Infrared Radiation

Infrared radiation is produced by hot bodies and covers the wavelength region of about 700nm to 1mm. Wavelengths between 750nm and 1,300nm are able to penetrate the skin and cornea. A maximum penetration of about 5mm into the skin occurs at about 1,100nm, while maximum absorption in the liquid humour and the lens of the eye occurs at 1,300nm:

- **Acute effects** - reddening of the skin (erythema) and surface layers of the eye.
- **Chronic effects** - cataracts can occur from occupational exposure to white-hot surfaces over a period of about 15 years through the absorption of infrared radiation in the lens of the eye.

Microwaves

Microwave radiation covers the wavelength region between about 1mm and 1m. Biological harm is caused by the process of internal heating, the heat being generated by the vibration or rotation of water molecules. This is the way that a microwave oven works; it heats food by causing excitation of water molecules in the food.

Health effects caused by mobile phone radiation exposure is unproven

While the body as a whole has effective temperature-regulating systems, certain tissues, such as the lens of the eye, have poor or non-existent blood supplies and hence a poor capacity for temperature control by heat transfer.

It is such tissues that are most at risk from microwave exposure, since only a relatively small temperature increase is needed to damage cell proteins. Health effects are only seen at significant exposures, such as accidental exposure to intense microwave radiation inside an industrial oven or microwave transmitter.

Chronic health effects associated with low level exposure (such as the use of mobile phones) are unproven.

Radiowaves

Radiofrequency wavelengths cause a similar internal heating effect to microwaves. Contact with an active transmitter is likely to result in skin and tissue burns. A significant exposure to intense radiowaves would be required to cause internal heating at a distance. So, those in the immediate vicinity of an active powerful radar or radiowave transmitter are at risk.

Chronic health effects from low level exposure are unproven.

Routes and Effects of Exposure to Lasers

The main health risk associated with exposure to laser light is eye damage. Even a very low power (<1mW) laser beam can cause temporary or permanent damage to the retina of the eye. This is because the eye may focus the laser beam through the cornea and lens to a very small spot on the retina, so concentrating the light intensity. This will happen for all visible light wavelengths and some IR wavelengths as well. Other IR wavelengths and UV lasers can cause damage to the tissues at the front of the eye, such as the cornea and lens. High power laser beams can cause permanent blindness in very short exposure times.

The other health risk associated with high power lasers is skin damage; laser light falling on the skin can cause surface burns. If the beam is powerful enough, these burns will extend through the skin and into other body tissues. This is only a significant health risk for high power lasers.

The obvious exposure route for laser light is direct exposure where the light beam hits the eye (either as a result of pointing the laser at the face or by putting the face into the path of the beam). The less obvious exposure route is indirect exposure, where the laser light reflects off shiny surfaces and then strikes the eye. For high power lasers, this exposure route can present a very significant hazard since even momentary exposure to a beam that has been reflected off several surfaces can cause blindness.

Intense Pulsed Light (IPL) sources used for medical and cosmetic skin treatments (such as the removal of skin pigmentation) can also present a risk to the eye and skin. These light sources are not laser sources (the light produced is broad spectrum rather than of fixed wavelength) but the health risks are similar to those associated with laser light.

Radiation Risk Assessment

Before control measures can be identified, the risks must be assessed. The risks associated with exposure to non-ionising radiation depends on wavelength (or frequency), intensity, exposure duration, part of the body exposed, etc.

Assessment of electromagnetic fields and artificial optical radiation may require measurement, though, in many instances, data from the equipment manufacturer can be used. Natural optical radiation, i.e. solar radiation, may be assessed subjectively. The ILO Code of Practice - *Ambient Factors in the Workplace* (Section 7.2) provides guidance on the assessment of risk posed by optical radiation (ultraviolet, visible light and infrared radiation). It states that employers should assess equipment and activities likely to give rise to hazardous levels of radiation, including work outdoors when exposed to the sun.

The risk assessment should consider:

- The sources of non-ionising radiation to which workers are likely to be exposed.
- The wavelength (or frequency), intensity and duration of exposure to the radiation source.
- Parts of the body exposed (especially eyes for UV and visible light).
- Exposure to sunlight.
- The comparison of measured exposure levels with exposure limits and values (where national legislation makes them applicable).
- Workers particularly at risk.
- Interactions between optical radiation and photosensitising chemicals.
- Indirect effects, such as:
  - For optical: glare, explosion or fire (very relevant for higher power lasers).
  - For EMF: interference with medical equipment (including pacemakers), initiation of detonators, fires/ explosions (from sparks caused by induced fields), etc.
- Results of health surveillance.
- Multiple sources of exposure.
- Simultaneous exposure to multiple-frequency EMF fields.
- Information provided by manufacturers.
- The potential for misuse or understanding of safety precautions.

Control Measures for Non-Ionising Radiation

A common framework for control can be applied to both optical (UV, visible and IR) and electromagnetic field radiation:

Signs are examples of control measures for non-ionising radiation

- Design, siting and layout of workplaces and workstations - control over direction, stray fields/reflections (e.g. painting surfaces matt black), etc.
- Stray fields/beams - Analyse each and every optical element in the beam path for stray reflections and install suitable beam blocks. Switch equipment off when not required.
- Eliminate as far as possible - explore alternative technologies, such as remote control and automation. Other working methods that reduce the risk include: administrative controls for routine operation, maintenance, and permits.
- Choose equipment emitting less radiation.
- Technical measures to reduce unwanted emission of radiation - interlocks, shielding, enclosures, screens, etc.
- Maintenance.
- Limit duration and level or intensity of exposure, e.g. time, distance (except lasers where distance doesn't work).
- PPE, e.g. protective eyewear, make sure other areas of the skin are not exposed with the use of lab coats and gloves.
- Follow manufacturer instructions.
- Develop and implement safe systems of work. Protect others using screens/curtains/restricted access.
- Provide information, instruction, and training. Specialist advice may be needed for laser work.
- Signs. Display appropriate warning signs.
- Health screening. If any workers are over-exposed, provide a medical examination and consider whether follow-up health surveillance is appropriate.

A range of commercial instruments are available for monitoring and measuring non-ionising radiation over the whole of the electromagnetic spectrum. Monitoring should be in relation to the standards, to ensure that exposure levels are adequately controlled.

We shall now take a look at specific controls used for each type of non-ionising radiation.

Protection from Ultraviolet Radiation

In occupational settings, ultraviolet radiation often demands the establishment of **safe-person strategies** and personal protection, e.g. where electric arc welding is carried out. Simple shielding of the skin by keeping it covered forms adequate protection. Body areas at risk are the backs of the hands, the forearms and the neck, which can be protected by wearing long-sleeved overalls with high collars and gloves. The face can be protected by the use of a face-shield which cannot be penetrated by ultraviolet radiation.

The eyes must be protected with the use of eye protection that absorbs ultraviolet radiation. Special optical filters have been developed for this. Injury to the retina from intense visible light in welding operations must also be reduced with the use of filters. Mobile or temporary screens may be necessary to protect passers-by from welding flash.

Where ultraviolet radiation is produced in a discharge system and forms part of a process, **safe-place strategies** can be used. The radiation can be contained in screened areas, interlock systems can be fitted to lamp-housing, and all surfaces can be made dull or matt black to prevent reflections. An important point to note is that many cases of 'arc eye' have been caused in people not involved in welding processes, but as a result of reflected radiation.

With a large number of systems using ultraviolet radiation as part of the process, administrative controls involving limitation of access to the radiation area, use of warning signs, limitation of exposure and the use of distance protection, are methods that must be adopted.

Protection from Infrared Radiation

Protection from infrared radiation can be achieved by good engineering design, by enclosing, insulating and shielding IR sources where possible. As with all forms of radiation, maintaining distance from the source will significantly reduce exposure. PPE in the form of IR-absorbing or reflecting eye protection and skin protection is also an effective safe person approach. This method of protection is used by fire-fighting personnel.

Protection from Microwave and Radiofrequency Radiation

To control exposure of persons working in the vicinity of equipment that generates microwave radiation or other forms of radiofrequency radiation, the whole system should be enclosed in a metal structure, to attenuate the level of radiation outside the enclosure to less than the maximum permissible exposure limit. Isolation and lock-off of equipment should be carried out before transmitters are worked on or near to. Any access doors, gates or hatches should be interlocked to prevent activation of the transmitter when access is being gained. Additional administrative controls may also be needed, such as a permit-to-work system to control access to transmitter arrays.

Maintaining distance from the source of EMF is also an effective control and is the primary method of ensuring safety for non-workers. For example, mobile phone transmitters are built on masts to keep them at a distance from members of the public.

An alternative approach is to limit the power output of the transmitter and/or limit the duration of exposure.

Control Measures for Lasers

All laser products should be correctly labelled with their class and appropriate warning signs. The main methods of control for lasers are:

Laser hazard warning sign

- **Engineered controls:**
  - Screening/enclosures to prevent the escape of hazardous beams.
  - Interlocks on equipment and rooms so that power to the laser is isolated when entry to hazardous areas is gained.
  - Non-reflective surfaces. Many high power laser enclosures and rooms are painted matt black to prevent reflection.
- **Administrative controls:**
  - Warning lights (to indicate 'in operation').
  - Signs warning of the laser hazard inside a particular enclosure or in a room/area.
  - Training for users of Classes 3R, 3B and 4 lasers (and possibly even for lower classes such as 1M and 2M, because of the risks associated with magnifying lenses).
  - Safe systems of work and emergency procedures. Permit systems might be employed to control high-risk activities with high power lasers, such as guard removal during use.

- **PPE:**
  - Laser safety eyewear. This will often be goggles to completely encase the eye and prevent access to the eye from the sides. Eyewear must be selected to give protection to the particular wavelengths of light produced.
  - Skin protection may be necessary for high power lasers.

STUDY QUESTIONS

5. What are the hazards of exposure to ultraviolet radiation?
6. What are the hazards of microwave radiation and how can harmful exposure be controlled?
7. Describe the framework or approach for control of exposure to non-ionising radiation.

(Suggested Answers are at the end.)

Ionising Radiation

IN THIS SECTION...

- Ionising radiation is produced by the spontaneous radioactive decay of radioactive substances in rocks, soils, water and air. This is natural background ionising radiation.
- Ionising radiation is also produced and used in many workplace applications, from smoke detectors to industrial and medical radiography equipment, such as x-ray sets.
- Ionising radiation sources can be hazardous outside the body, depending on the radiation's ability to penetrate into body tissues. Sources can also be extremely hazardous inside the body. Radioactive substances can get into the body by the normal routes - inhalation, ingestion, skin absorption and injection. The physical form of a radioactive substance affects its available routes of entry.
- The acute effects of exposure to ionising radiation (radiation sickness) include nausea, vomiting, diarrhoea, fever and death. These effects are non-stochastic; they do not occur below a particular dose threshold.
- The chronic effects of exposure to ionising radiation are an increased risk of cancer and genetic damage. These effects are stochastic; there is no known threshold below which the effects cannot occur and the greater the dose, the greater the risk.
- Control of exposure to external radiation sources is achieved using three principles: time, distance and shielding.
- Control of exposure to internal radiation sources is achieved by preventing the inhalation, ingestion, absorption or injection of the radioactive substance in the first place.
- The annual dose limit set in the ILO Code of Practice - *Radiation Protection of Workers (Ionising Radiations)* for employees over 18 is an effective dose of 50mSv. Dose limits are also set for trainees, pregnant women and members of the public.
- Workers likely to receive certain specified annual doses have to be designated as 'classified persons'. They must then be subject to dose assessment and health surveillance.
- Work areas where workers are likely to receive certain specified doses have to be designated as controlled or supervised areas. These areas must be demarked, signed, monitored for radioactivity and made subject to local rules.
- The employer may have to designate a competent Radiation Protection Officer (RPO) to survey the application of radiation protection Regulations, standards and rules, and to provide advice on all relevant aspects of radiation protection.

Sources of Ionising Radiation

As outlined in the first section of this Learning Outcome, ionising radiation comprises x-ray and gamma-ray electromagnetic radiation and alpha particles, beta particles and neutrons. Sources of ionising radiation can be both natural and man-made.

Nuclear power stations are a source of man-made radiation

Natural Sources

The Earth - a significant source of ionising radiation

A very significant source of most of these forms of ionising radiation is the earth itself. The rocks that make up planet Earth are radioactive, containing dozens of radionuclides. A typical example is uranium 238, found at low concentrations in all rocks, soil and water. The radioactive decay of uranium has 14 steps (this will be explained later in this section). Each uranium atom emits eight alpha particles and six beta particles as it decays through these steps. The half-life of uranium is extremely long, hence this radiation is emitted slowly from the uranium (again, the principle of half-life will be explained later in this section).

Significantly, one of the elements formed by the slow radioactive decay of uranium in the ground is radon 222. **Radon** is a gas at normal temperature and pressure so, once formed, it escapes from the rock and diffuses into the atmosphere. Once in the atmosphere, it may be inhaled. The Sun also emits ionising radiation but most of this is filtered out by the Earth's atmosphere, and very high energy gamma-rays, called 'cosmic rays', bombard the Earth from space.

As a result of these naturally occurring radiation sources, our bodies are being exposed to all of the forms of ionising radiation all of the time. This is referred to as background radiation. This **background radiation** cannot be described as safe, since all ionising radiation carries some inherent health risk. What we do know, however, is that our bodies have very efficient mechanisms to repair the damage caused by this low-level background radiation. So, the background radiation levels give us an idea of the kind of radiation level that might be considered tolerable as a result of occupational exposure.

Artificial Sources

Artificial sources of ionising radiation can consist of naturally occurring radionuclides that have been mined, extracted and concentrated. Alternatively, artificial sources may contain radionuclides that have been made in nuclear reactors. Many of the radionuclides used for cancer radiotherapy are manufactured in this way.

Typical examples of sources for each form include:

- **Alpha particles** - emitted by radionuclides and used in smoke detectors, anti-static devices and certain types of cancer tumour radiotherapy.
- **Beta particles** - emitted by radionuclides and used in thickness gauges, medical and science lab work as tracers and cancer tumour therapy.
- **Neutrons** - emitted by fissile material, such as uranium 235 and plutonium 239 inside nuclear power plants, and generated by high-energy particle beam collisions in nuclear physics research facilities.
- **X-rays** - generated by bombarding a metal target with high-energy electrons in a vacuum tube. They are used for medical radiography, industrial radiography, security scanning of objects and people, quality control during manufacturing and laboratory analysis, such as x-ray crystallography.
- **Gamma-rays** - emitted by radionuclides such as caesium 137 and used in industrial radiography, some medical radiography, cancer tumour radiotherapy and in medical and science lab work.

Concepts in Radioactivity and Radiation Exposure

Radioactivity Explained

RECAP

Just a reminder of where we were with a simple model of atomic structure:

- Electrons (-ve charged particles) are found in shells around the nucleus.
- Protons (+ve charged particles) and neutrons are found in the nucleus at the core.
- The number of protons in the nucleus of an atom determines which chemical element that atom is. This is an important point to remember for the next section.
- The number of electrons in the shells around the nucleus normally match the number of protons in the nucleus, resulting in an overall neutral electrical charge.

So, now to move on to account for radioactivity in this model:

- The number of neutrons in the nucleus of an atom can vary; this gives rise to the existence of different types of the same element that have the same number of protons and electrons but a different number of neutrons. These are called 'isotopes' or 'nuclides'.
- For example, hydrogen normally has one proton, one electron and no neutrons. It can, however, have one proton, one electron and one neutron. This is a nuclide of hydrogen called deuterium. Alternatively, it can have one proton, one electron and two neutrons. This is the nuclide tritium. All three atoms are hydrogen because they all have one proton.
- Most atoms have a stable structure, in that the number of protons and neutrons in the nucleus does not change.

Smoke detector
Contains an encapsulated radionuclide - americium 241

- Some atoms, however, have an unstable nucleus that cannot maintain its structure over time. When this occurs, the nucleus will, at some stage, spontaneously fall apart. This is the process of radioactive decay. An atom with an unstable structure is called a 'radionuclide'.
- In the hydrogen example given above, deuterium is stable (not a radionuclide) but tritium is an unstable radionuclide; it is radioactive.
- When an atom undergoes radioactive decay, it will emit ionising radiation. There are several different forms of ionising radiation that might be emitted and the exact form emitted will depend on the radionuclide involved. The radiation emitted is predictable; any given radionuclide always gives off the same type of ionising radiation.

This leads us to the topics of half-life and decay chains.

Half-Life and Decay Chains

One other factor that is predictable about a radioactive material is how quickly a particular radionuclide will undergo spontaneous radioactive decay.

Some radionuclides decay very quickly, others very slowly. The rate at which radioactive decay occurs is known as the 'half-life'. This is the length of time that it would take for half of the atoms of any given radionuclide to undergo radioactive decay.

For example, the radionuclide uranium 238 has a half-life of approximately 4.5 billion years. This means that if you take a 1kg block of pure uranium 238 and wait 4.5 billion years, then analyse the same block of material, you will find only 500g of uranium 238. Half of the uranium 238 atoms have undergone spontaneous decay and are no longer present.

One thing to note about radioactive elements is that, when a radionuclide atom undergoes radioactive decay, it is not all converted to radiation. Some small part of each atom is emitted as radiation, but the rest remains. Importantly, the number of protons in the atom's nucleus is changed. This means that the atom is converted from one element to another element. Often, this new element is itself a radionuclide. In other words, when a substance undergoes radioactive decay, it often produces a new substance that is also radioactive. This new radioactive substance will then decay, emit ionising radiation and might produce another radioactive substance in turn.

For example, when an atom of uranium 238 undergoes radioactive decay, it gives off ionising radiation (an alpha particle) and the atom is converted to thorium 234. This is a radionuclide, so it decays to form protactinium 234 and emits ionising radiation (a beta particle). There then follow another 12 radioactive decay events, making a total of 14 steps in the decay chain. Finally, we end up with a lead 206 atom. This is stable (not radioactive). See the diagram below for the full decay chain (note this is an example and does not have to be memorised).

Note how each step in the chain is accompanied by an alpha particle (α) or beta particle (β) emission.

The 14-step decay chain for uranium 238 contains one element of particular interest - radon 222 (radon gas) - that will be discussed in more detail later.

Type of Radiation	Nuclide	Half-Life
α	uranium-238	4.5×10^9 years
β	thorium-234	24.5 days
β	protactinum-234	1.14 minutes
α	uranium-234	2.33×10^5 years
α	throium-230	8.3×10^4 years
α	radium 226	1590 years
α	radon-222	3.825 days
α	polonium-218	3.05 minutes
β	lead-214	26.8 minutes
β	bismuth-214	19.7 minutes
α	polonium-214	1.5×10^{-4} seconds
α	lead-210	22 years
β	bismuth-210	5 days
β	polonium-210	140 days
α	lead-206	stable

Uranium 238 radioactive decay chain

Routes of Exposure to Ionising Radiation

The routes of exposure to ionising radiation will depend largely on the type of ionising radiation in question and the nature of its sources.

One critical factor in determining the possible routes of exposure is the penetrating power of the radiation:

- **Alpha particles** have little penetrating power, and can be stopped by a few centimetres of air, a sheet of paper, or the horny layer of dead cells at the surface of the epidermis.
- **Beta particles** have more penetrating power, and can move through several tens of centimetres of air and can penetrate through the horny layer and into living tissue beneath.

- **Neutrons**, **x-rays** and **gamma-rays** are extremely penetrating and can pass through kilometres of air and right through the human body (longer wavelength x-rays are less penetrating and are absorbed by hard tissue, such as bone and teeth).

The conclusion to draw here is that alpha particle sources present little risk to health, provided they are kept **outside** the body, because the radiation cannot penetrate the skin to cause harm. Beta particle sources do present a health risk when **outside the body**, but that risk can be relatively easily controlled by separation from the source. Neutrons, x-rays and gamma-ray sources present a significant health risk when outside the body because the radiation can shine through objects, through air, and into the body to cause harm.

Another critical factor in determining the possible routes of exposure is the nature of the radiation source and its physical form. The influence of physical forms are familiar from previous Learning Outcomes:

- **Solids** - in their massive form are unlikely to get into the body and therefore may be harmful on contact with the skin during handling, but otherwise may present little health risk.
- **Dusts** - can become airborne and may be inhaled. Once in the lungs, the dust may be deposited or may even be absorbed into the bloodstream.
- **Liquids** - can be ingested with relative ease, put into contact with skin or may be able to permeate through the skin (especially if mixed with solvents).
- **Mists, gases and vapours** - can be inhaled into the lungs and absorbed into the bloodstream.

The routes of entry are also familiar; **inhalation, ingestion, absorption** through the skin and **injection** through the skin (by penetration or at region of skin damage).

In radiation terminology, the amount of ionizing radiation energy deposited in a material (or person) is termed the '**absorbed dose**'. The absorbed dose is the measure of energy absorbed per gram of material measured in 'rads'. An alternative unit of measure is the 'gray', one gray (Gy) is equal to one hundred rads. It is worth remembering at this stage that the effect of absorbed radiation is dependent upon the type of radiation and the absorbed dose of radiation.

The effect of radiation is significantly affected by the '**dose rate**'. Low dose rates (mGy per year or milligrays per year) will have much less biological impact than high dose rates Gy/minute.

The exposure to radiation is like the exposure to the Sun. Short term exposure to high energy (dose) levels can result in visible skin damage (sunburn/blisters). At lower dose levels (or dose rates) the skin can support exposure to the Sun for several hours without exhibiting the same damage.

Other measures of radiation exposure include:

- **Equivalent dose** is used to assess how much biological damage is expected from the absorbed dose to a specific organ. Equivalent dose is expressed in **millisiverts (mSv)**.
- '**Effective dose**' is used to assess the potential long-term effects of radiation exposure to the whole body (the stochastic effect). It takes into account the absorbed dose, the relative harm level from the radiation and sensitivities each organ has to radiation.

These factors have to be looked at together in order to determine the most significant routes of entry. For example:

- Uranium 238 is an alpha particle emitter. A solid chunk of uranium can be handled safely with only a pair of gloves for protection. It cannot be inhaled, ingested or pass through the skin. The alpha particles produced have little penetrating power.
- Americium 241 used in smoke detectors is an alpha particle and low-energy gamma-ray emitter. In its metal capsule inside the smoke detector, this material presents little risk to people. But if it were burnt to form a dust and then inhaled, then significant exposure might occur.

- Caesium 137 is an alpha particle emitter that also produces high-energy gamma-rays. This radionuclide cannot be handled safely at all outside of its heavy lead enclosure. Gamma-ray exposure could happen even with the caesium 137 in another room or part of a site.

AN ANALOGY

These four different characteristics can be confusing, so try this analogy.

Imagine standing in front of a wall of shotguns, each of which is firing lead pellets at you. The shotguns vary in the rate at which they fire and the size of pellet that they fire:

- The activity (becquerel) gives an indication of the rate at which the shotguns fire. The larger the number, the more guns fire each second.
- The absorbed dose (gray) gives an indication of the number of pellets that hit you; the larger the number, the more pellets go in.
- The equivalent dose (sievert) gives an indication of how much damage each pellet does to a body part - this varies depending on pellet size. Bigger pellets do more damage so are given a larger weighting factor to account for their larger size (equivalent dose = absorbed dose × pellet weighting factor).
- The effective dose (sievert) gives an indication of how much damage your body suffers **as a whole**, since being shot in the finger is nasty, but being shot in the head will kill you. This is accounted for by giving different body parts a tissue weighting factor. The effective dose is the sum of all of the individual body part equivalent doses multiplied by their respective tissue-weighting factors.

So, if someone hangs around in front of this wall for a minute, they might be hit five times, twice in the arms (one small pellet, one medium-sized), twice in the legs (two large pellets) and once in the torso (medium-sized).

Their absorbed dose is 5Gy.

But their equivalent dose to different body parts is:

Arms $(1 \times 1) + (1 \times 5) = 6$Sv

Legs $(2 \times 20) = 40$Sv

Torso $(1 \times 5) = 5$Sv

Their whole-body effective dose is:

(6 × arm weighting factor (0.01)) + (40 × leg weighting factor (0.02)) + (5 × torso weighting factor (0.05)) = 0.06 + 0.8 + 0.25 = 1.11Sv

Obviously, this analogy breaks down pretty quickly if you stop to think about it seriously, but it can be useful as a way of trying to understand why several different characteristics and units have to be used.

Health Effects of Exposure to Ionising Radiation

Ionising radiation can cause ionisation in the cells that make up body tissues. The part of the cell that is most readily damaged by ionising radiation is its DNA. To explain this health effect, it is necessary to set the scene with a little biology revision.

BIOLOGY REVISION

The human body is made up of trillions of cells. Almost every cell (with the notable exception of red blood cells) contains a nucleus. The nucleus contains the genetic material of the cell, in the form of 23 pairs of chromosomes. Each chromosome consists of one very long single molecule of deoxyribonucleic acid (DNA). Spaced out along each chromosome are genes, sections of the DNA molecule that contain the instructions that tell the cell how to work. Not all of these genes are active all of the time; they are only switched on where and when needed. They are, however, critical in controlling the proper functioning of the cell.

If a chemical change is introduced into a strand of DNA, then that molecule is said to be mutated. Mutations occur all of the time in human body cells; they are a fact of life. Most mutations do not occur in genes, they occur in sections of DNA that do not contain genes. Even if a mutation does occur in a gene, it may be in a gene that is inactive or it may not introduce any change in the way that an active gene functions. There will be times, however, when a mutation occurs that alters the way that a gene works; a damaging mutation. If the gene plays a part in the control of cell division, then it is possible that uncontrolled cell division might occur. This is the basis for cancer cell formation. Uncontrolled cell divisions lead to the growth of a tumour and the potential for tumour cells to spread and invade other tissues. Cells have defence mechanisms to prevent this kind of damaging mutation leading to uncontrolled cell division. These defence mechanisms lead to programmed cell death (apoptosis).

Acute and Chronic Effects of Ionising Radiation

Early or Acute Effects

There are no immediate early/acute ill-health effects of exposure to very low levels of ionising radiation. We are all exposed to background radiation all of the time and no acute symptoms or ill health are detected.

At low doses, ionising radiation causes ionisation in cells. This ionisation damages the DNA that makes up the cell chromosomes. This damage either:

- Is repaired, in which case the cell continues to function.
- Cannot be repaired, causing the cell to undergo programmed cell death.
- Cannot be repaired, leading to a mutation that may have an influence in the future, but has no immediate health effect.

Above a particular threshold dose, however, acute effects will be detected. These effects become more marked as the dose of radiation increases. The effects are the result of massive cell death caused by direct damage to the DNA of cells (the DNA is literally shredded by the radiation) or by indirect programmed cell death as a result of damage. This is **acute radiation sickness** (or 'acute radiation syndrome'). Typical symptoms include:

- Nausea and vomiting.
- Hair loss.
- Diarrhoea.
- Headache.

- Fever.
- Central nervous system impairment.
- Skin burns and ulceration.
- Death.

At low doses, symptoms may not start to become apparent for 24-48 hours. At very high doses, symptoms will appear within minutes of exposure and death will be certain even with medical attention. For example, 31 people died of acute radiation sickness within three months of the Chernobyl nuclear disaster in 1986. Several of these deaths occurred within a few minutes of exposure.

Certain cells in the body are more prone to damage by ionising radiation, most especially:

- White blood cells - leading to low white blood cell count and a suppressed immune system.
- Lining of the intestines - leading to destruction of the gut wall and invasion of the body cavities by gut bacteria.
- Bone marrow cells responsible for red blood cell production - leading to anaemia.

The acute effects of ionising radiation can be described as **deterministic** or **non-stochastic**, meaning that they are predictable and will not occur below a particular threshold level. Above the threshold, there is a clear relationship between the severity of the effect (response) and the dose of radiation received. This is the same dose/response relationship that was seen for many toxic substances.

Late or Chronic Effects

The **chronic ill-health effects or late onset of ill-health effects,** of exposure to ionising radiation are an increased risk of cancer and genetic damage. Exactly the same damage and repair mechanisms described above will occur, but the person may not suffer any symptoms of acute radiation exposure, because the dose of radiation received is too low to cause any significant cell death. Instead:

- Damage to the DNA in the cell nucleus leads to mutation of genes.
- These mutations cause the cell to divide in an uncontrolled manner, forming a tumour.
- The cells' self-repair mechanisms fail to detect the error and so programmed cell death does not occur.

Damage to DNA is a chronic ill-health effect of exposure to ionising radiation

This may happen because the genes responsible for the repair mechanism and apoptosis are themselves damaged or mutated by the radiation. Simply put, if the radiation damages or mutates the right combination of genes, cell division goes out of control and the cell doesn't recognise this and does not kill itself.

The doses of radiation capable of causing the kind of genetic change leading to cancer are known to be very small. There is no known threshold below which this effect does not occur. So, we can say that there is **no known safe level** of exposure to ionising radiation where there is no risk of cancer. As the dose of ionising radiation increases, the risk of cancer increases. At high doses, the risk is greater, but cancer is not a determined outcome. Thus, the chronic effects of exposure to ionising radiation are **stochastic** or chaotic effects; involving the **probability** of an ill-health effect.

The damaging effects of ionising radiation may occur in the **somatic cells**; these are the normal cells of the body, such as bone marrow cells, brain cells, liver cells, white blood cells, etc. Mutation or DNA damage to these cells will result in the **somatic effects**, either the cell repairing the damage, dying, or carrying the mutation forward in time to a point where it starts the cell down the route of carcinogenesis.

Alternatively, the damaging effects of ionising radiation may occur in **germline cells**; these are the cells of the body responsible for passing genetic material on from parent to offspring (specifically, the eggs in the ovaries of a woman and the sperm-producing cells in the testes of a man).

Such damage and mutation to germline DNA results in the **genetic effects** of ionising radiation:

- Sterility.
- Heritable genetic defects in children.

Matters to Consider when Carrying out an Ionising Radiation Risk Assessment

Section 5.2 of the ILO Code of Practice - *Ambient factors in the workplace*, identifies what needs to be considered when assessing the risk from ionising radiation. It is easier to think of this requirement as a 'prior starting' risk assessment.

A new activity must not begin until a radiation risk assessment has been completed that encompasses all aspects of the operation. The assessment needs to be recorded, kept up to date, and discussed with workers and others identified in the risk assessment. The degree of effort, formality and detail of the assessment, while being subjective, should be in line with the magnitude of risk presented by the potential exposure. The Code of Practice includes the following relevant matters;

- The nature of the sources of ionising radiation to be used, or likely to be present, including radon.
- Estimated radiation dose rates that people are exposed to.
- Prior evaluation should be used at the design stage of installation to establish satisfactory working conditions.
- Engineering features, such as: shielding, containment, ventilation, and interlocks should be considered before administrative controls and personal protective equipment controls.
- An assessment of the nature, magnitude and likelihood of the exposure should be made.
- The way in which structures, systems, components, and procedures related to radiation protection or safety might fail.
- The ways in which changes in the environment could affect protection or safety.
- The ways in which operating procedures related to protection or safety might be erroneous, and the consequences of such errors.
- The protection and safety implications of any proposed modifications.
- The safety assessment should be documented and reviewed.
- If operating experience or other information indicates that the current assessment might be invalid.

Reasons for reviewing the assessment would include: the radioactive source emitting different types or strengths of radiation; modifications to the production plant, including changes to engineering controls; changes to the process method; and changes arising from human factors (staff turnover).

Control Measures for Ionising Radiation

The practical control of ionising radiation can, in some instances, be highly technical and, in other instances, very simple and straightforward. Control measures used must be chosen to match the specific circumstances of the work. Often, generic control measures can be applied; in other instances, a specific set of controls have to be designed specifically to meet a particular application. These controls are always based on some basic principles.

External Radiation

External radiation arises from outside the body and may irradiate skin, tissues or internal organs, depending on the type of radiation and its ability to penetrate the body.

Protection from external ionising radiation is based on three principles:

- **Time** - by reducing the time of exposure to the radiation, the accumulated dose is reduced. This follows the same principles as for toxic chemicals, noise and vibration:

  Dose = Intensity × Time

- **Distance** - by increasing the distance from the source to the person, the dose of radiation is reduced (or eliminated):
  - Alpha and beta particles do not travel long distances through air (they collide with the air molecules and lose their energy). Therefore, separation by a few centimetres or metres is sufficient to eliminate all exposure.
  - Neutrons, x- and gamma-rays travel much greater distances through air (kms), but in doing so they obey the inverse square law: the dose of radiation decreases as a function of the square of the distance from source to person.

    So:

    - if the dose at 1m distance is X,
    - the dose at 2m distance will be ¼ X,
    - and the dose at 4m distance will be 1/16 X.

- **Shielding** - using materials to absorb the radiation so that it cannot pass through. This is the best method of control, since it applies a safe place approach and relies less on human behaviour (safe person approach). Different types and thicknesses of shielding material are used for different radiation sources:
  - Alpha particles are easily shielded with virtually any material, since they have very low penetration power.
  - Beta particles can be stopped with a few millimetres of aluminium or thin brass.
  - X- and gamma-rays require thicker, denser materials, such as lead.
  - Neutron sources are often enclosed in thick concrete or hydrogen-rich materials, such as paraffin wax or water (neutrons are not stopped by dense materials such as lead).

  In some instances where the shielding needs to be removed for maintenance or other access (e.g. on an x-ray generator), an interlocked shielded enclosure will be required.

IRR Regulations require, firstly, the restriction of exposure by means of engineering controls, such as shielding, ventilation and containment. Once these measures have been implemented, procedural controls, involving systems of work and the provision of personal protective equipment, may need to be employed.

Practical Control of Internal Radiation

Internal radiation stems from radioactive materials that have been deposited in the body (by inhalation, ingestion, injection or absorption through the skin) and are continually irradiating internal organs and tissues from within. Radiation sources may also contaminate open wounds in the skin, which will promote entry to the body.

Sealed source

(Source: The International Atomic Energy Agency, www.iaea.org/sites/default/files/sealedradsource1013.pdf)

Once a radionuclide has entered the body, it is difficult, if not impossible, to limit personal exposure. If the substance is taken up by the body then it will pass into the bloodstream and, from there, all parts of the body will receive a dose. The substance may then accumulate in specific target organs as it is metabolised, delivering a greater dose to these organs (e.g. polonium 210 accumulates in the liver and kidneys).

Even if the substance is not taken up by the body but is simply deposited in the lungs or gut, these organs do not possess thick epidermal cell structures; they are made of delicate epithelial tissue that will receive the radiation dose. Thus, even an alpha particle emitter that would be virtually non-hazardous outside the body becomes extremely hazardous if swallowed or inhaled.

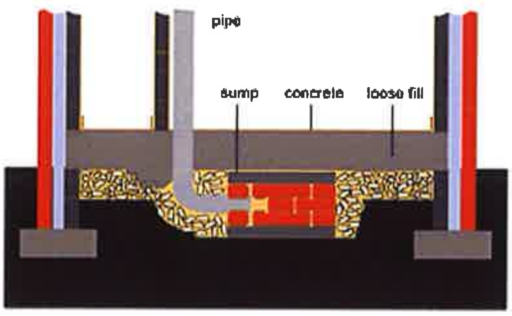
The control of exposure to internal radiation sources is therefore based entirely on keeping the radioactive material out of the body.

This is done using standard methods appropriate for toxic substances and biological agents, such as:

- Containment of unsealed radioactive material within ventilated glove boxes.
- Partial containment in fume hoods under negative pressure.
- Respiratory protective equipment.
- Other PPE to prevent skin contamination.
- Prohibition of eating, drinking and smoking.
- Good hygiene practices, such as routine hand-washing after source handling.

One control measure that is relevant to both types of radiation exposure is the use of **sealed sources**. A sealed source is a source of radiation where the radioactive material is embedded or encased in a solid container that prevents the radioactive material itself from forming a dust, vapour, gas, fume, or any other form that might become airborne or liquefied.

Where inhaling radon is likely for the occupants of a building, the buildings can have a radon proof membrane installed in the floor or underneath the structure. New builds in areas where radon is predicted can have a shallow cellar to act as a radon sump. The sump has a pipe from the sump to the outside, where the radon gas can easily dissipate.



Source: https://www.hse.gov.uk/radiation/ionising/radon.htm

Radiation Protection Code of Practice

The ILO Code of Practice - *Radiation Protection of Workers (Ionising Radiations)* (CoP) outlines some suggested control measures that should be taken to control exposure to radiation. These standards may be exceeded by national or regional legislation.

Notification, Registration and Licensing of Radiation Work

Chapter 3 of the CoP calls for a system of notification or registration of radiation sources to a competent authority.

The requirement to notify radiation work would depend on the nature of the radiation; some processes may be exempted, whilst other processes may be required to submit detailed safety reports in order to demonstrate the safety and integrity of the design. The operator would be granted a licence to use radiation sources in the prescribed manner.

Classification of Workers and Areas

Section 4 of the CoP establishes two categories of workers:

- Workers engaged in radiation work - these people are subject to certain dose limits, which we will consider in a later Topic Focus.
- Workers not engaged in radiation work - these workers should be treated (as far as restricting exposure is concerned) as members of the general public.

The CoP also distinguishes between two working conditions for classified workers:

- Working Condition A - persons whose annual exposure might be in excess of three-tenths of the relevant dose limit.
- Working Condition B - persons whose annual exposure is most unlikely to be in excess of three-tenths of the relevant dose limit.

Persons under 16 years of age should not be classified as radiation workers, whilst pregnant workers and persons under 18 years of age should not carry out work under Working Condition A.

TOPIC FOCUS

Radiological Dose Limits

The radiological dose limits (Reg. 12 and Schedule 3) are specified in terms of **effective dose** (dose to the whole body) and **equivalent dose** (dose to specific tissues) in any **one calendar year** and are expressed in units of millisieverts (mSv). These dose limits work in a similar way to other occupational exposure limits (such as WELs); they are maximum annual doses of ionising radiation that cannot be exceeded.

Annual effective and equivalent dose limits

		Equivalent Dose			
Category	Effective Dose	Lens of Eye	Skin	Extremities	Abdomen
Employees 18 and over	20	20	500	500	13
Trainees < 18 years	6	15	150	150	13
Others	1	15	50	50	-

Note:

- The dose for 'skin' is averaged over any 1cm2.
- 'Extremities' refers to hands, forearms, feet and ankles.
- 'Abdomen' applies to female workers of reproductive capacity only, and is calculated over any three-month period, rather than annually.
- 'Others' includes members of the public.

Where the dose limits are demonstrably impracticable (e.g. given the nature of the work undertaken by that employee), the employer may apply the dose limits as set out in Part II of Schedule 4.

As might be expected, there are additional provisions concerning the working conditions for pregnant women and breastfeeding mothers. In particular, the foetus must not be exposed to more than 1mSv of radiation over the remaining period of the pregnancy, following notification of the employer.

Competent Advice

In the ILO Code of Practice - *Radiation Protection of Workers (Ionising Radiations)*, Radiation Protection Officers (RPOs) are technically competent persons designated by the employer to:

- Survey the application of radiation protection Regulations, Standards and rules.
- Provide advice on all relevant aspects of radiation protection.

Radiation Surveillance

Chapter 7 of the CoP outlines the requirement for radiation surveillance. This simply calls for a programme of radiation surveillance to be established to determine the precautions that are required in order to comply with the dose limits established.

Health Surveillance

Chapter 7 of the CoP also outlines the health surveillance requirements for workers engaged in radiation work. This should be carried out by an occupational physician. Workers classified under Working Condition A should undergo surveillance by an approved medical practitioner (who has been approved by the competent authority).

Health surveillance under normal conditions should include:

- Health assessment appropriate to the work to be undertaken before assignment.
- Periodic health surveillance during the assignment.
- Special health surveillance required by the competent authority for workers under Working Condition A.
- Assessment when pregnancy is reported.
- Other assessments required by the competent authority.

Health surveillance for workers who have had an abnormal exposure to radiation should include special assessment at the following times:

- When the results of radiological surveillance indicate that the person has received radiation dose equivalents in excess of twice the relevant dose limits.
- Before the radiation worker returns to work after restriction on medical grounds following a radiation accident.

MORE...

The ILO Code of Practice - *Radiation Protection of Workers (Ionising Radiations)* is available from:

www.ilo.org/safework/info/standards-and-instruments/codes/WCMS_107833/lang--en/index.htm

The UK HSE also provides a range of useful information and sources about radiation:

www.hse.gov.uk/radiation

www.hse.gov.uk/radiation/ionising/radon.htm

Public Health England in the UK also has a range of information, including useful information on radon gas, available from:

www.gov.uk/topic/health-protection/radiation

Additional information is also available from the UK Building Research Establishment:

www.bre.co.uk

Controls

In broad terms, the control measures for ionising radiation aim to minimise:

- Exposure to external radiation arising from outside the body.
- Exposure to internal radiation arising from radioactive substances that could enter the body.

So, control measures will principally involve:

- Shielding of external radiation.
- Strict containment of radioactive chemicals, particularly dusts, vapours and gases that might enter the body.

How these might be incorporated into the design features of workplaces where radioactive materials are used is discussed below.

Design Features

The actual design of facilities that handle radioactive materials will vary considerably, depending on the nature of the work. So, for example, the design features of a nuclear power station will look very different from those employed in a hospital radioactive tracer laboratory. However, the general principles are common to both.

Easily cleanable surfaces help prevent radioactive contamination build-up

External radiation (from bulk storage and handling of radioactive materials) will be minimised by controls, such as:

- Shielding.
- Remote operation.
- Excluding unauthorised persons.
- Siting facilities away from generally accessible areas.

Internal radiation (from radioactive substances that might enter the body) will be prevented by:

- Sealed storage.
- Handling in ventilated facilities (glove boxes and fume cupboards).
- Provision of easily cleanable surfaces (floors, walls, benches, ceilings) to prevent accumulation of radioactive contamination.
- Provision of facilities for hand-washing (and possibly full change of clothing).

Ventilation and Building Design

Ventilation is an important control for radioactive contamination, and the principles are very similar to those used for the control of airborne contaminants.

A general principle of building design is to ensure a negative pressure gradient from the external environment of the workplace, to the area where the radioactive materials are stored and used. So, for example, we ensure that we handle radioactive materials in ventilated facilities, such as glove boxes or fume cupboards at a negative pressure (i.e. less than atmospheric pressure). In the event of any loss of containment of the glove box (e.g. a torn glove), the direction of airflow will be from the workroom into the facility, minimising the amount of radioactive material likely to escape. Similarly, the corridor outside the workroom will be at slightly higher pressure than the workroom, but still less than the external environment. This ensures that the airflow is always into the building, then into the workroom and then into the glove box, maximising the containment of the radioactive materials, and minimising any possible release and spread of radioactive contamination.

Some more specific design fundamentals for facilities handling radioactive materials are as follows:

- **Siting** - facilities should be located away from areas where security cannot be guaranteed. Entry to the working area should be through a lobby, via an overshoe barrier (this may be a simple step-over barrier or a more substantial one allowing persons to sit while putting on overshoes; it may also provide areas for shoe/overshoe storage), personal monitoring for contamination, and a washing area.
- **Space requirements** - layout should be planned to avoid unnecessary movement of radioactive materials.

- **Ventilation and containment** - general dilution ventilation should be provided in the workroom, and local exhaust ventilation facilities (fume cupboards and glove boxes) used where radioactive materials are handled. Air movement should be maintained from less contaminated areas (e.g. corridor, lobby, or workroom) towards potentially more contaminated areas (e.g. fume cupboard, and glove box), with extraction through the facility to a discharge stack.
- **Surfaces** - walls and ceilings should be coated with a smooth, hard gloss finish to ensure ease of cleaning. Floors should be covered with an impervious surface, such as PVC, with joints and edges to walls smooth and sealed. Bench working surfaces should be smooth, hard and non-absorbent, with all gaps and joints sealed to avoid contamination traps.
- **Radioactive waste disposal sinks** should be dedicated for radioactive materials, to ensure that radioactive liquids can be safely disposed of, without contaminating other equipment. These should be sealed to the back wall and provided with splash backs and drains connected directly to the main sewage system.
- **Hand wash sinks** should be provided in the lobby area before entry into the workroom with elbow- or knee-operated taps.
- **Monitoring facilities** for hand and feet contamination should be provided on both sides of an overshoe barrier (to prevent contamination spreading by foot).
- **Storage of radioactive materials** - secure storage for both stocks and waste material is required.

STUDY QUESTIONS

8. Explain the following terms:
   (a) Half-life.
   (b) Absorbed dose.
   (c) Equivalent dose.
9. What is the difference between stochastic and non-stochastic effects?
10. For each type of ionising radiation, give an example of its use or application in the workplace
11. What is the difference between exposure to external radiation and exposure to internal radiation?
12. Outline the three principles of radiation protection.

(Suggested Answers are at the end.)

Summary

Nature and Types of Ionising and Non-Ionising Radiation

We have described how:

- Radiation can be grouped into two main types: ionising and non-ionising.
- Ionising radiation causes ionisation in the material that absorbs it - this delivers energy into the material and promotes unusual chemical reactions that would otherwise not occur.
- The electromagnetic spectrum is the full range of frequencies that electromagnetic radiation can be found at; from high-frequency gamma-rays to low-frequency radiowaves.
- All types of non-ionising radiation are electromagnetic waves and can be broadly categorised as optical (ultraviolet, visible and infrared radiation) and electromagnetic fields (or radiofrequency: microwaves and radiowaves).
- Ionising radiation can be grouped into five different types: alpha and beta particles, neutrons, x-rays and gamma-rays. These vary in their properties and characteristics, particularly in their ability to penetrate matter. Three of these types of ionising radiation are particulate in nature - alpha particles, beta particles and neutrons. The two others, gamma- and x-ray, are forms of high-energy electromagnetic radiation.

Non-Ionising Radiation

We have described how:

- Ionising radiation is produced by the spontaneous radioactive decay of radioactive substances in rocks, soils, water and air. This is natural background ionising radiation.
- Ionising radiation is also produced and used in many workplace applications, from smoke detectors to industrial and medical radiography equipment, such as x-ray sets.
- Ionising radiation sources can be hazardous outside the body, depending on the radiation's ability to penetrate into body tissues. Sources can also be extremely hazardous inside the body. Radioactive substances can get into the body by the normal routes - inhalation, ingestion, skin absorption and injection. The physical form of a radioactive substance affects its available routes of entry.
- The acute effects of exposure to ionising radiation (radiation sickness) include nausea, vomiting, diarrhoea, fever and death. These effects are non-stochastic; they do not occur below a particular dose threshold.
- The chronic effects of exposure to ionising radiation are an increased risk of cancer dosimetersand genetic damage. These effects are stochastic; there is no known threshold below which the effects cannot occur and the greater the dose, the greater the risk.
- Control of exposure to external radiation sources is achieved using three principles: time, distance and shielding.
- Control of exposure to internal radiation sources is achieved by preventing the inhalation, ingestion, absorption or injection of the radioactive substance in the first place.
- The **Ionising Radiations Regulations 2017** set strict requirements for the control of ionising radiation exposure at work.
- The annual dose limit set for employees over 18 is an effective dose of 20mSv. Dose limits are also set for trainees, pregnant women and members of the public.
- Workers likely to receive certain specified annual doses have to be designated as 'classified persons'. They must then be subject to dose assessment and health surveillance.

- Work areas where workers are likely to receive certain specified doses have to be designated as controlled or supervised areas. These areas must be demarked, signed, monitored for radioactivity and made subject to local rules.
- The employer must consult with competent Radiation Protection Advisers (RPAs) to assist them in achieving regulatory compliance and must appoint Radiation Protection Supervisors (RPSs) to oversee designated areas and local rules.

Ionising Radiation

We have described how:

- Ionising radiation is produced by the spontaneous radioactive decay of radioactive substances in rocks, soils, water and air. This is natural background ionising radiation.
- Ionising radiation is also produced and used in many workplace applications, from smoke detectors to industrial and medical radiography equipment, such as x-ray sets.
- Ionising radiation sources can be hazardous outside the body, depending on the radiation's ability to penetrate into body tissues. Sources can also be extremely hazardous inside the body. Radioactive substances can get into the body by the normal routes - inhalation, ingestion, skin absorption and injection. The physical form of a radioactive substance affects its available routes of entry.
- The acute effects of exposure to ionising radiation (radiation sickness) include nausea, vomiting, diarrhoea, fever and death. These effects are non-stochastic; they do not occur below a particular dose threshold.
- The chronic effects of exposure to ionising radiation are an increased risk of cancer dosimetersand genetic damage. These effects are stochastic; there is no known threshold below which the effects cannot occur and the greater the dose, the greater the risk.
- Control of exposure to external radiation sources is achieved using three principles: time, distance and shielding.
- Control of exposure to internal radiation sources is achieved by preventing the inhalation, ingestion, absorption or injection of the radioactive substance in the first place.
- The **Ionising Radiations Regulations 2017** set strict requirements for the control of ionising radiation exposure at work.
- The annual dose limit set for employees over 18 is an effective dose of 20mSv. Dose limits are also set for trainees, pregnant women and members of the public.
- Workers likely to receive certain specified annual doses have to be designated as 'classified persons'. They must then be subject to dose assessment and health surveillance.
- Work areas where workers are likely to receive certain specified doses have to be designated as controlled or supervised areas. These areas must be demarked, signed, monitored for radioactivity and made subject to local rules.
- The employer must consult with competent Radiation Protection Advisers (RPAs) to assist them in achieving regulatory compliance and must appoint Radiation Protection Supervisors (RPSs) to oversee designated areas and local rules.

Learning Outcome 9.14

NEBOSH International Diploma for Occupational Health and Safety Management Professionals

ASSESSMENT CRITERIA

- Explain the different types of musculoskeletal issues and why an organisation must control risks from repetitive physical activities, manual handling and poor posture.

LEARNING OBJECTIVES

Once you've studied this Learning Outcome, you should be able to:

- Outline types, causes and relevant workplace examples of injuries and ill health conditions associated with repetitive physical activities, manual handling and poor posture.
- Explain the assessment and control of risks from repetitive activities, manual handling and poor posture.

Contents

Musculoskeletal Injuries and Ill Health

IN THIS SECTION...

- The human skeletal system is made up of the skeleton with its associated muscles, cartilage, tendons and ligaments.
- Musculoskeletal Disorders (MSDs) include back injury and back pain; upper limb disorders; and muscle, tendon and ligament injuries.
- Certain work activities, such as production line work, DSE use and manual handling have a high risk of MSDs.
- Many risk factors influence the risk of MSDs associated with a particular activity. These include repetition, force, posture, twisting, rest, equipment design, equipment adjustability, lighting, other environment parameters and individual capabilities.
- MSD risk assessments often follow a format established by relevant legislation. For example, a manual handling risk assessment considers the load, task, environment and individual capabilities.
- Assessment tools are available to assist with the risk assessment of both manual handling and repetitive activities. The UK's HSE has published four such tools: the MAC, VMAC, ART, and RAPP tools.
- The control measures introduced following such risk assessments will vary, depending on the nature of the activity in question. Manual handling control measures are very different to those employed for DSE use. Generally, hazard elimination by automation or mechanisation are preferred solutions. Where this is not possible, the provision of equipment and aids, task re-design and alterations to the work environment might be used. Ultimately, control may rely on good practices with regards to posture and technique. This will necessitate training.

Basic Understanding of the Human Musculoskeletal System

The human musculoskeletal system is made up of the skeleton and associated soft tissues, such as muscles, tendons and ligaments:

- The **skeleton** forms the bone frame of the body, upon which everything else is supported. Bones protect vital organs, allow movement, store minerals, particularly calcium, and hold bone marrow, which creates blood cells.
- **Cartilage** is joined to this bone in certain areas either to support anatomical structures (such as the nose and ear) or to form articulating surfaces in joints (such as in the spine or knee).
- **Skeletal** muscles are able to contract (shorten) and relax (extend), so as to achieve movement.
- **Tendons** are tough connective tissues that join muscle to bone so that when a muscle contracts, the bone it is joined to moves.

Human musculoskeletal system showing the skeleton with muscle tissues overlaid
Source: HSG60 Upper limb disorders in the workplace (2nd ed.), HSE, 2002 (www.hse.gov.uk/pubns/priced/hsg60.pdf)

- **Ligaments** are tough connective tissues that join bones to bones to form the joints, such as the knee, hip, spine and shoulder joints.

- **Nerves** - the central nervous system is made up of the brain and spinal cord. This is connected to a network of peripheral nerves that carry sensory information from the body to the brain, and nerve signals from the brain to muscles to control movement.

Types of Injury and Ill-health Conditions Resulting from Work Activities

The types of injury and ill health associated with poor ergonomic design of work will depend on the nature of the work activity and the individual concerned. Manual handling, use of Display Screen Equipment (DSE), repetitive activities and poor posture whilst sitting or standing for long periods of time are all significant causes of Musculoskeletal Disorders (MSDs) and other associated conditions.

DEFINITIONS

ERGONOMICS

The study of the relationship between the worker, the work that they are doing and the environment in which they are doing it.

MANUAL HANDLING

The lifting, carrying, pushing and pulling of a load by bodily force.

Typical forms of ill health associated with poor work design are:

- **Back Injury and Back Pain**

  The spine is made up of individual bones (vertebrae) separated by tough pads (intervertebral discs). Wear and tear can occur to these discs so that they become distorted (prolapsed disc). This causes extreme pain and discomfort and is often accompanied by nerve pain because the distorted disc traps nerves where they enter the spinal cord. This type of injury is perhaps the most serious of all manual handling injuries, since recovery is often slow, incomplete and, in some instances, the casualty will have to undergo surgery to repair the defect or may end up permanently disabled.

- **Work-Related Upper Limb Disorders (WRULDs)**

  A collection of conditions that affect the arms, wrists and hands (collectively known as upper limbs). Examples include: carpal tunnel syndrome (inflammation of a nerve in the wrist that causes tingling sensations, pins and needles, numbness in the fingers and arm pain) and tenosynovitis (inflammation of the tendons in the forearm that makes finger movement difficult and painful). Early symptoms of WRULDs often include tingling sensations, numbness and discomfort but then progress to more severe pain and immobility. These conditions sometimes require corrective surgery (which is not always successful) and can lead to disability. They are sometimes referred to as Repetitive Strain Injuries (RSIs).

- **Musculoskeletal injury and discomfort (MSDs)**

  MSDs is a collective term used to describe injuries and conditions that can affect the back, joints, and limbs. Workers can have several different kinds of MSDs at the same time. MSDs can result from poor posture (bending or crouching), poor working environment (high temperatures), poor work organisation (unable to take rest breaks) or the worker themselves (a pre-existing health condition). The MSD itself may be an ache or pain in the lower back. This may cause discomfort to the worker when movement is required or with extended static posture, such as crouching.

- **Tendon and Ligament Injuries**

When tendons and ligaments are overloaded, they tear causing painful injuries that can take a long time to heal. In some instances, recovery is incomplete and an operation may be required. Though tendons and ligaments are tough, they are prone to overuse injury (from repetitive use) or overload injury. They do not repair well, because they have a fairly poor blood supply. Many WRULDs are tendon and ligament injuries.

Joint sprains result from overstretching or tearing of ligaments. Ligaments are the bands of tissue that connect two bones together in a joint.

Joint strains result from overstretching or tearing of muscles or tendons. Tendons are the dense fibrous cords of tissue that connect bones to muscles.

An uncomfortable static posture leads to musculoskeletal disorders such as neck pain and knee pain. Long duration work of this nature is almost certain to lead to MSDs of one sort or another

- **Muscle Injuries**

Overloaded muscle tissue can tear. This is painful and likely to lead to short-term impairment. Skeletal muscle does, however, have a rich blood supply, so will tend to repair quickly and effectively in most instances. Sheet muscle, such as the muscle surrounding the intestines in the abdominal cavity, does not repair so well, which is why hernias (bulges or splits) in this sheet muscle can last for a long time, can be extremely painful, and may require corrective surgery.

- **Fractures and laceration**

These are straightforward physical injuries as a result of dropping a load or picking up a load that is hot, sharp or otherwise hazardous.

Fractures are often described by the type of fracture line they form across or along the bone. The main types of fractures are:

- Transverse – straight across the bone.
- Oblique – at an angle across the bone.
- Spiral – twists around the bone resulting from a twisting injury.
- Impacted – the bone fragments are driven into each other, which reduces bone length.
- Comminuted – the bone shatters into three or more pieces.

Fractures are also given names after the doctors that first treated them, e.g. a Colles' fracture' (after Abraham Colles) is a distal radius fracture in the wrist due to a fall with an outstretched hand. An 'Essex-Lopresti fracture' (after Peter Essex-Lopresti) is a comminuted radial head fracture, due to falling from height.

- **Other Chronic Soft-Tissue Injuries**

These are associated with sitting, standing or kneeling for long periods of time at work, e.g. painful knee joints as a result of having to kneel down for long periods of time. This can lead to a condition known as 'beat knee' where a thick callus of skin develops under the knee as a result of pressure.

Non-musculoskeletal conditions include:

- **Eye Strain**

  This is often associated with the use of Display Screen Equipment (DSE) or assembly line work, where a high degree of visual acuity is required (such as soldering circuit boards or handling small components). Temporary eye fatigue is commonly associated with prolonged use of DSE screens. There is no evidence to suggest that long-term eye damage results.

- **Fatigue and Stress**

  Often associated with some types of DSE work (e.g. call centre staff) and manual or repetitive handling where a high level of output has to be maintained.

MORE...

There are several useful sources of information on musculoskeletal risk and injury, including:

www.hse.gov.uk/msd

www.hse.gov.uk/msd/uld/index.htm

www.backcare.org.uk

The HSE publication, INDG171 Managing upper limb disorders in the workplace - A brief guide, is aimed at employers and managers in small businesses and is available at:

www.hse.gov.uk/pubns/indg171.pdf

Ill-Health Conditions Resulting from Sitting for Long Periods

Many jobs and work activities have an associated risk of MSDs. In fact, most people's jobs will have an element of MSD risk since one or more of the risk factors are likely to be present for some, or most, of the time. Most people would associate MSDs with active work, however sedentary work also has significant risk.

Sedentary work is where the activity is characterised by low energy consumption, in combination with sitting or standing postures. Developments in automation and computerised activities have increased sedentary activities.

Sitting for long periods of time is linked with several health concerns. When the job role requires the worker to sit for extended periods, the metabolism slows, which itself affects the body's ability to regulate blood sugar, which increases the risk of diabetes. A significant health concern is obesity, which itself involves a cluster of associated conditions, such as high blood pressure. Sitting for long periods is also associated with an increase in cardiovascular disease.

Sitting is also closely associated with lower back pain, due to the increase in pressure on the fibrocartilaginous discs (the disc acts as a cushion between the vertebrae allowing movement of the spine). When the discs become compressed, the vertebrae come into contact with each other and pain will be experienced.

Neck and shoulder pain can also result from working postures. Consider the situation of holding your hand on a typical computer mouse - the neck and shoulder muscles are statically loaded supporting your arm. The muscles hold the posture while becoming depleted in oxygen rich blood. Waste products build up in the blood, which are not released, leading to muscle fatigue and subsequently pain.

Control Measures

Control measures that can be used are:

- **Workplace design** - ensure sufficient space for postural movements. Workplaces that allow sitting and standing postures (height adjustable desks).
- **Workplace design in common areas** - cafeterias, meeting rooms, and mailrooms should all accommodate different posture (counters at standing height).
- **Work design** - ensure job roles offer the opportunity for standing/sitting or keeping moving, e.g. meetings conducted standing. Ensure sufficient rest breaks are added into tasks.
- **Specialist furniture** - sit/stand desks, ergonomically designed chairs with lumbar support, etc.
- **Wellbeing initiatives** - encourage activities that support exercise. Provide information on health management. Provide, and actively encourage, sitting correctly. 'Sitting correctly' not only includes consideration of posture, but also frequent posture change, dynamic sitting (rocking the pelvis back and forth, rotating shoulder muscle).

Use of Display Screen Equipment (DSE)

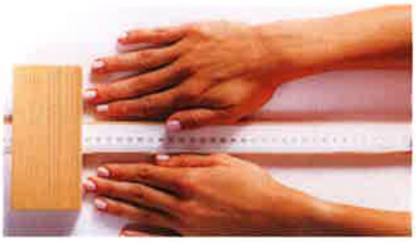
Use of Display Screen Equipment (DSE) or computers and keyboards is a common workplace activity that has several associated ill health issues:

- **WRULDs** - associated with repetitive use of the keyboard and mouse for long periods of time.
- **Eye strain** - temporary eye fatigue associated with prolonged use of the screen.
- **Back pain** - and other MSDs associated with sitting in a fixed position, perhaps with poor posture, for long periods of time.
- **Fatigue and stress** - associated with the type of work being done, e.g. call centre staff may be subjected to verbal abuse during telephone calls.

These health effects can occur when using desktop computers, but are becoming increasingly common in association with the use of laptops when they are used for long-duration work.

Principles of Ergonomic Design

The key principle of ergonomics is to fit the machine to the human - not the human to the machine. The focus is on the needs of the person, before looking at the task being performed. By applying the science of ergonomics to the design of work equipment, worker fatigue and discomfort can be reduced, which will have positive influences on safety, productivity, and quality.



Anthropometry: a woman's hands being measured

Ergonomics combines many disciplines, depending on the particular aspect of work that is under consideration:

- **Anatomy** - the structure of the body and its relationship to movement.
- **Biomechanics** - movement of body parts and forces involved during a particular activity.
- **Physiology** - the body's metabolism and changes in metabolic rates because of activity.
- **Psychology** - and its relationship to mental capacity (memory, concentration, etc.).
- **Anthropometry** - the science of body dimensions used to establish optimal sizes for work equipment.

An ergonomic risk assessment needs to be a systematic analysis of all the hazards presented by the person, the work task, the workstation, the work environment, and the work system.

Musculoskeletal Risk Factors

The specifics of manual handling risk assessment and DSE workstation assessment will be discussed in the next section. There are, however, some general risk factors that contribute to ergonomic risk.

These risk factors include:

- **Repetition** - the need for repetitive movements when carrying out the task (e.g. typing for several hours).
- **Force** - the physical force required to perform the task and the strain this puts on the body (e.g. closing stiff catches on a machine).
- **Posture** - any requirement to adopt an awkward posture (e.g. stooping over into a bin to pick out contents).
- **Twisting** - any twisting action required by the task (e.g. twisting the wrist when using a screwdriver).
- **Rest** - the potential for the worker to rest and recover from any fatigue (e.g. a worker on a production line cannot stop the line; they have to keep working even when fatigued).
- **Equipment design** - the shape of the equipment and how this affects ease of use (e.g. a large, shaped handle on a scraper makes it easier to hold and use).
- **Equipment adjustability** - the scope there is for the user to adjust the equipment to suit their personal preferences (e.g. the height of the seat for a computer user).
- **Lighting** - the availability of natural and artificial light, and the effect on the worker's ability to see the work clearly.
- **Other environment parameters** - in particular, temperature, humidity and ventilation will directly affect the worker's ability to perform the task and their comfort.
- **Individual capabilities** - of the person doing the work. In particular, young persons and new and expectant mothers. Other vulnerable groups might include disabled people and those with a known existing injury or ill health condition (such as recovering from surgery).

When a Manual Handling Risk Assessment is Required

When manual handling cannot be completely eliminated, a hazardous manual handling activity must be assessed. This risk assessment will be slightly different from the general risk assessment you are already familiar with, because it focuses exclusively on the hazard of manual handling, and ignores all other hazards.

The British HSE publication - L23 *Manual Handling, guidance on the regulations* provides a useful framework for assessing risks from manual handling activities. A web link is provided to the document in the 'more' box later in this section.

In determining if the manual handling operations involve a risk of injury, and to determine suitable steps to manage the risk, the employer must consider:

- The physical characteristics of the worker to carry out the operation, e.g. age, gender, health conditions.
- The clothing, including footwear, the worker is wearing. Clothing, including PPE, that may restrict movement.
- The level of knowledge and training the workers have. The worker must clearly understand the system of work that ensures their safety when manual handling tasks are being undertaken.
- Whether the worker is identified as being especially at risk. The worker may be a new mother, or have a disability which can affect their capacity to undertake manual handling. The worker may have a history of injury (hernias, back or knee conditions) that could reduce their capability for manual handling. The worker may be an older person or a younger person.
- The results of any health surveillance where it has been identified in a risk assessment.

Using L23 to Decide if a Risk Assessment is Required

Guidance note L23 *Manual Handling* includes an appendix that explains how to choose the right level of detail for manual handling risk assessments.

There are three levels of detail:

- Simple filters to distinguish low-risk tasks from the tasks which need a more detailed assessment.
- The Manual Handling Assessment Charts (the MAC tool) or the Risk Assessment of Pushing and Pulling (RAPP) tool, which are HSE's tools for assessing the most common manual handling risk factors of these tasks. They help to prioritise action to control the risks.
- A more detailed risk assessment:
  - If an assessment with the HSE tools (MAC or RAPP) has been carried out then any necessary information can be added to ensure adequate coverage of the factors required by the Regulations.
  - A stand-alone detailed risk assessment can be carried out using online checklists.

The flowchart in Figure 19 of L23 (link below) describes this process.

Simple Filters

There are different filters for four types of manual handling operations:

- Lifting and lowering.
- Carrying for up to 10m.
- Pushing and pulling for up to 20m.
- Handling while seated.

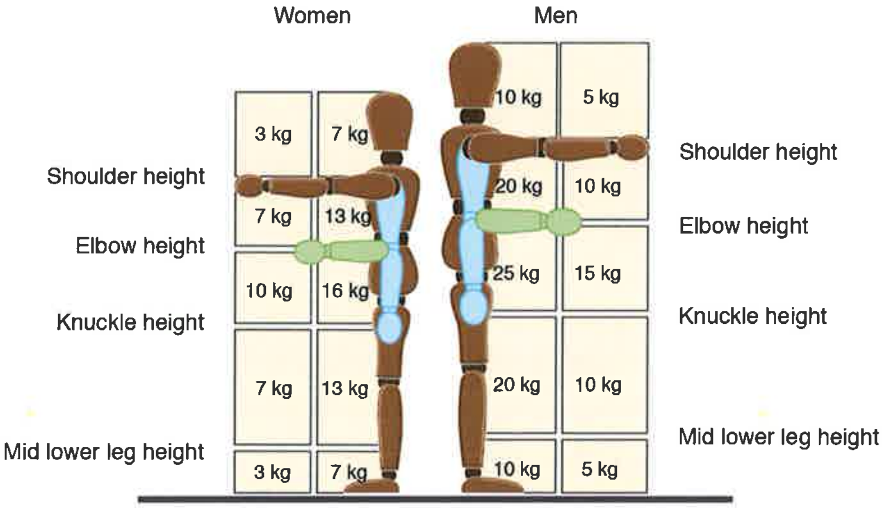
MORE...

Details of these filters are contained in the guidance on the **Manual Handling Operations Regulations 1992**, L23, available at:

www.hse.gov.uk/pubns/priced/l23.pdf

Lifting and Lowering

The diagram for the lifting and lowering risk filter is reproduced below.



The lifting and lowering filter

(Source: L23 Manual handling, HSE, 2016 (www.hse.gov.uk/pubns/priced/l23.pdf))

Each box in the diagram contains a filter value for lifting and lowering in that zone. The filter values are reduced if handling is done with arms extended, or at high or low levels, as that is where injuries are most likely to happen. If the maximum weight being handled is less than the value given in the boxes where the lifter's hands pass through when moving the load, then the operation is within the guidelines. If the weight lifted exceeds the filter weight, then the MAC tool can be used to do a more detailed assessment, or a full risk assessment can be carried out using the online checklists.

The weight values are not maximum limits. They can be exceeded if a risk assessment assesses the risk as safe. In other circumstances, such as repetitive work, a risk assessment may identify significantly lower weight than the filter shows. Where the manual handling task is mostly repetitive handling of light loads, then the use of the HSEs ART tool may be appropriate. The filter assumes that the load is easy to grasp with both hands, that the worker is in a stable body position, and the working environment is reasonable.

Carrying up to 10 Meters Filter

The filter weights in the lifting and lowering filter apply to carrying weights. When carrying weights the following conditions apply:

- The load is held against the body.
- The load is carried no further than 10 meters.
- The load does not prevent the worker walking normally.
- The load does not obstruct the view of the worker.
- The load does not require the hands to be held below knuckle height or much above elbow height.

When the load can be carried on the shoulder, without first lifting the load from the ground (e.g. unloading sacks from a lorry) the carrying distance can be increased to 20 meters.

If the weight exceeds the filter weight, then the MAC tool can be used to carry out a more detailed assessment.

Pushing and Pulling for up to 20 Meters Filter

The pushing and pulling filter applies where the load is slid, rolled or moved on wheels. The task is low risk where the force to move the load:

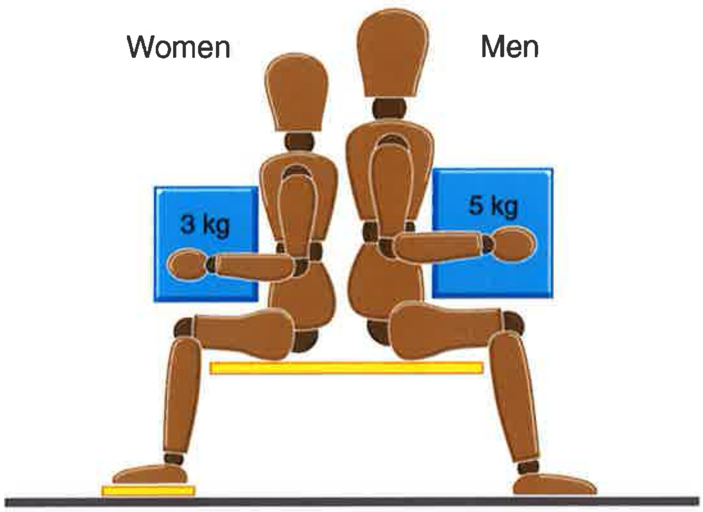
- Is applied with the hands.
- The torso is largely upright and not twisted.
- The hands are between hip and shoulder level.
- The distance involved is no more than 20 meters.

Additionally, if the load can be pushed/pulled and controlled with one hand, it is likely to be low risk. Where the task requires more significant effort to push or pull the load, and where the criteria for low risk pushing/pulling cannot be achieved, then the RAPP tool should be used to complete a more detailed assessment.

The initial pull/push force used to start the load moving will be higher than the push/pull force to keep the load moving. Guidelines for safe pushing and pulling are given in the table.

	Men	Women
Guideline figure for stopping or starting a load	20kg	15kg
Guideline figure for keeping the load in motion	10kg	7kg

Handling While Seated Filter



The filter values for handling while seated are 3kg for women and 5kg for men. The values only apply when the hands are in the box zone. If handling while seated involves loads greater than those shown, or hand movement outside the area shown, then a full risk assessment will be required.

Areas to Consider when Assessing Risks

The ergonomic risk assessment method applied to a work activity will depend, to a large degree, on the repetitive and physical nature of the work activity and the set of Regulations that apply. In particular, manual handling and the use of DSE each have their own risk assessment methods under their respective legislation and guidance. The main areas to address for manually handling a load are:

Assessing Manual Handling Risk

- The task.
- The load.
- The force
- The working environment.
- Equipment
- Individual capabilities.

Holding a load away from your torso when lifting increases the risk of injury

Task

The focus here is on the movements required of the worker as they handle the load. The **task** can be assessed by considering questions, such as:

- At what height is the load being picked up, carried or put down?
- Is the task very repetitive?
- Is a long carrying distance involved?
- Does the task involve stooping (the worker keeping their legs straight and bending their back) to move the load? Does the task involve twisting (turning the shoulders while the feet stay still)?
- Can rest breaks be taken as the worker requires them?
- Does the task involve lifting the load through a vertical distance?
- Does the task involve reaching above shoulder height?
- Does the task involve the worker holding the load away from their trunk (torso)?

Load

Here, the focus is the load that is being handled. Though the load is usually an inanimate object, in some workplaces it may be an animal or a person, e.g. in a hospital, patients have to be moved from bed to gurney (a wheeled stretcher/trolley), or from wheelchair to bath, etc.

The **load** can be assessed by considering questions, such as:

- How heavy is the load?
- How large and bulky is the load?
- How stable is the load?
- Where is the centre of gravity of the load?
- Is the load difficult to grip?
- Is the load hot, sharp or otherwise hazardous?

Uneven load

Force

Force can be described as the strength or energy required for the physical action or movement undertaken. This can be assessed by the facts that:

- When pushing and pulling a load, the force required to start the load moving is greater than the force required to keep the load moving.
- Greater force will be required to move a load up an incline (due to gravity). The greater the incline, the greater the force required to keep the load moving.
- Resistance to movement, expressed as frictional forces, will also vary with load characteristics, such as size, shape and rigidity.
- Uneven surfaces significantly impact on the force required to start or keep a load moving.
- The use of manual handling aids: such as levers, hoist and wheelbarrows can improve the way bodily force is used; and reduce the risk of injury.
- Workers should be encouraged to apply force gradually when testing whether a load can be moved.

Working Environment

The focus here is the environment in which the handling takes place.

The **working environment** can be assessed by considering questions, such as:

- Are there restrictions on the space available?
- Is the floor surface slippery or uneven?
- Are there changes in floor level (steps, stairs, etc.)?
- What are the light levels like?
- What is the temperature and humidity?

Equipment

When an individual is being moved, a specific person assessment must identify how the person may be able to help with the manoeuvre and any handling **equipment** that will be used in the manoeuvre, e.g. hoists and slings. The layout of equipment can also significantly reduce the amount of twisting that may be required. Important considerations with equipment are:

- Is the equipment the correct type for the load involved?
- Is the equipment provided well maintained, especially lubrication of wheels and the efficiency of any braking systems?
- Is the work equipment fitted with the correct type of wheels for the work surface involved?
- Is the work equipment accessible at a suitable height, e.g. vertical handles to facilitate pushing while standing upright?
- Is the equipment provided with adequate information, instruction and training in its use?
- Does the transfer of the load require the equipment to be used in a working environment or a task that may restrict the type of equipment provided?
- Does the equipment need to be height adjustable?

In common manual handling tasks the equipment used may remove or reduce the need for twisting, stooping, and stretching. The equipment must be the correct type for the load involved and be well maintained. If the equipment is provided with handles they should be at a suitable height (vertical handles may allow the user to operate the equipment at an angle that avoids stooping).

Individual Capabilities

The focus here is on the **worker** carrying out the handling activity. The nature of the task, the load and the working environment should be fitted to the individual, rather than the other way round.

Individual capabilities can be assessed, in combination with the task and load, by consideration of questions, such as:

- Does the task require unusual ability? For example, dexterity when picking up the load.
- Does the task require unusual strength or stamina?
- Is the physical size of the individual important (for reaching objects)?
- Does the task present significant risk to vulnerable individuals, such as pregnant women or people with pre-existing back injuries?

It may also be relevant to the risk assessment to consider levels of obesity, frailty, age, and engagement with physical activities. An additional aspect of assessment may be to consider the worker's attitude to the task at hand and their willingness to follow instructions.

Deciding if a More Detailed Assessment is Required

The decision to undertake a more detailed assessment, following the criterion of the appendices to L23 paragraph 7, is that a MAC/RAPP analysis (or an equivalent tests) or full risk assessment will need to be required when any of the following statements apply:

- Lifting or lowering takes place outside the box zones identified in the filters used. This will be where lifting takes place with extended arms (stretching), or lifting below floor level, or lifting above head height.
- The handling is more frequent than a single lift every two minutes, because the onset of fatigue will induce poor manual handling practices.
- The handling involves torso twisting, and is significantly increased if torso twisting and bending occur simultaneously. This is also likely to include single handed lifting/moving because this loads the spine unevenly.
- Team handling occurs. Two or more people can make an operation possible where that operation is beyond the capacity of a single worker. Teams of more than four workers will need close supervision to ensure the activity of each team member is coordinated with the rest of the team.
- The activities are complex and involve combinations of stooping, twisting, and stretching.
- The load is difficult to grasp or handle, due to it being round in nature, or smooth, or being generally difficult to grasp. The risk of dropping the load increases when it is difficult to grasp.
- Aspects of the working conditions are not favourable: such as restricted headroom, restricted access due to machinery etc., several doors to transport the load through, uneven or slippery floors.
- Carrying happens with the load not held against the body, which increases the stress on the lower back, regardless of good manual handling techniques used. A heuristic given in guidance is that a load at arm's length increases five times the level of stress on the lower back than holding the same load close to the torso.

Circumstances When Assessment Tools Should be Used

Use of Assessment Tools

A variety of assessment tools have been developed to assist in the assessment of manual handling and repetitive activities. The detail of these tools varies, but the general approach is similar: they examine individual risk factors associated with the task and allocate a numerical score accordingly. The numerical score for risk factors is then summed and the total score is used to:

- Give a general indication of MSD risk level and the acceptability/tolerability.
- Prioritise tasks according to MSD risk.
- Highlight individual risk factors that make the most significant contributions to total score, so that those risk factors can be addressed.

It should be noted that these assessment tools do not themselves constitute a detailed risk assessment that would achieve legal compliance, but are simply aids in the assessment process.

Manual Handling Assessment Charts (MAC) Tool

The Manual Handling Assessment Charts (MAC) tool was developed by the UK's HSE primarily for inspectors. They can use this tool during inspection visits as a quick tool to identify and quantify the level of risk associated with manual handling operations. The tool has since been published by the HSE as a tool for assisting in the management of manual handling risk.

The MAC tool uses a numerical score and a traffic light approach to indicate the level of risk. Three types of manual handling operation can be assessed:

- Single lifting operations.
- Single carrying operations.
- Team handling operations.

Each operation is divided into the different manual handling risk factors, and presented as a flow chart. During use, an operation has to be observed and the flow chart used to guide the user through each factor of the manual handling operation, to grade the degree of risk.

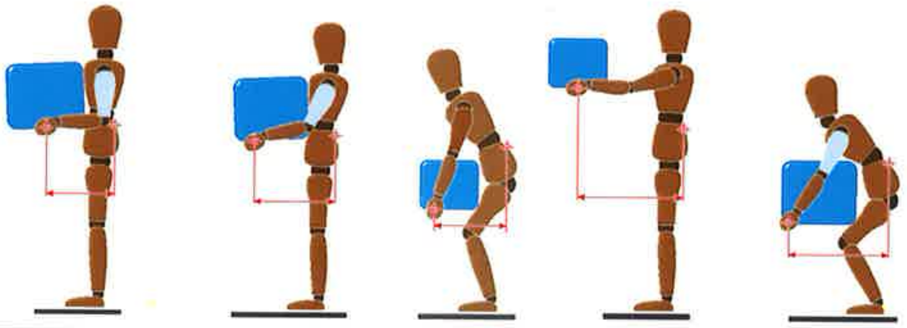
The risk factors assessed include:

A	Load weight/frequency
B	Hand distance from the lower back
C	Vertical lift region
D	Torso twisting and sideways bending
E	Postural constraints
F	Grip on the load
G	Floor surface
H	Other environmental factors

An example of one risk factor and the possible scores allocated is given below:

B Hand distance from the lower back

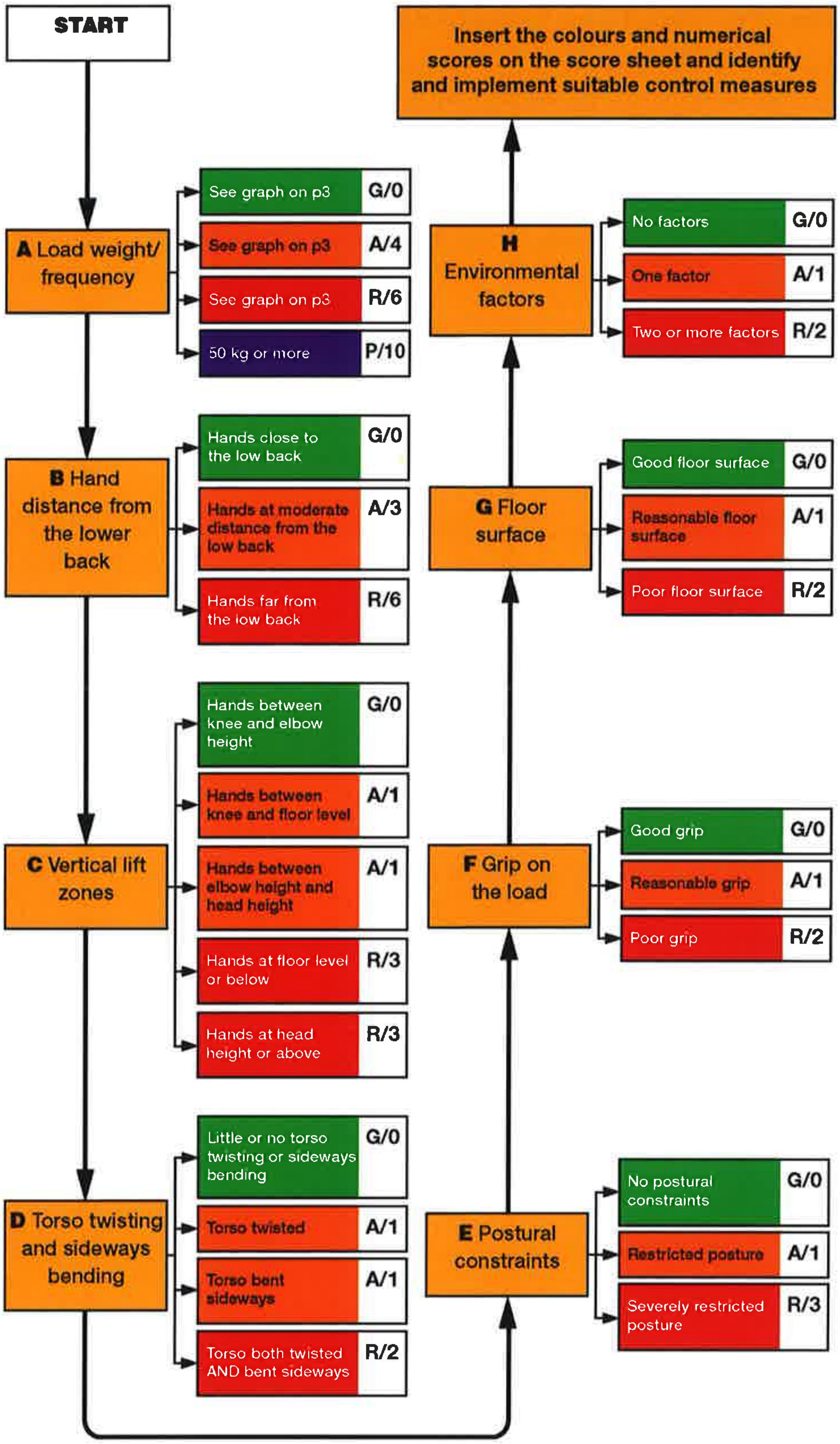
Observe the horizontal distance between the worker's hands and lower back. You should assess the 'worst-case scenario', including picking up and putting down. Use the following illustrations and descriptions as a guide:



Upper arms vertical AND torso upright	Upper arms angled away from torso Torso bent forward	Torso upright. Arms fully outstretched Upper arms angled away from torso AND torso bent forward
Hands close to the low back **G/0**	Hands at moderate distance from the low back **A/3**	Hands far from the low back **R/6**

Example risk assessment
Source: INDG383(rev3) Manual handling assessment charts (the MAC tool), HSE, 2018 (www.hse.gov.uk/pubns/indg383.pdf)

Colour coding for each of the risk factors allows for easy identification of the significant contributing risk factors. The MAC flow diagram for a lifting operation is illustrated next.



MAC flow diagram
Source: INDG383(rev3) Manual handling assessment charts (the MAC tool), HSE, 2018 (www.hse.gov.uk/pubns/indg383.pdf)

Assessment of Repetitive Tasks (ART) Tool

The Assessment of Repetitive Tasks (ART) tool was developed by the HSE to assist in the assessment of tasks that require repetitive moving of the upper limbs (arms and hands). It examines some of the common risk factors in repetitive work that contribute to the development of upper limb disorders.

In general, the approach used in the ART tool is similar to the MAC tool. A specific activity is observed for a period of time, a description of the activity is made, then a series of specific risk factors are examined and scored, using a traffic light colour-coding system to indicate significant risk factors.

Risk factors include:

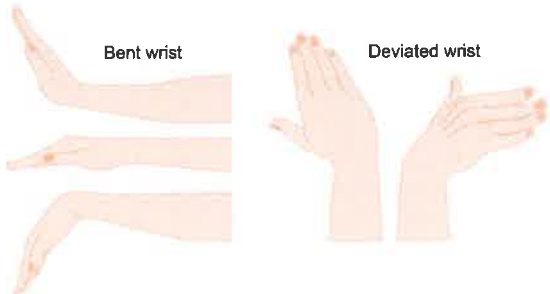
A	Frequency and repetition
A1	Arm movements
A2	Repetition
B	Force
C	Awkward postures
C1	Head/neck posture
C2	Back posture
C3	Arm posture
C4	Wrist posture
C5	Hand/finger grip
D	Additional factors
D1	Breaks
D2	Work pace
D3	Other factors
D4	Duration
D5	Psycho-social factors

An example of one risk factor and the possible scores allocated is given next:

C4 Wrist posture

The wrist is considered to be bent or deviated if an obvious wrist angle can be observed.

The wrist is:



	L	R
Almost straight/in a neutral position	0	0
Bent or deviated part of the time	1	1
Bent or deviated more than half of the time	2	2

Based on: INDG438 Assessment of repetitive tasks of the upper limbs (the ART tool), HSE, 2010 (www.hse.gov.uk/pubns/indg438.pdf)

The overall risk score is calculated by summing the score for factors A1-D3. The sum is then multiplied by a duration multiplier (D4) which is derived from the length of time that a worker performs the activity during a day (multiplier ranges from 0.5x to 1.5x). D5 is not assigned a score, but identifies additional factors to be considered.

Overall exposure scores can be used to prioritise repetitive tasks on the basis of WRULD risk and can also be used to give an indication of acceptability/tolerability.

Exposure Score	Risk	Action
0-11	Low	Consider individual circumstances
12-21	Medium	Further investigation required
22 or more	High	Further investigation required urgently

Variable Manual Handling Assessment Chart (VMAC) Tool

MORE...

The VMAC tool is available online at www.hse.gov.uk/msd/mac/vmac/index.htm and can be downloaded in spreadsheet form.

The MAC tool was designed for assessing handling operations, where the operative handles the same weight throughout the working day. However, load weights are often variable. For example, with order picking, parcel sorting, trailer loading/unloading and parts delivery in manufacturing, the actual weight of the load may vary considerably. In response to this, the UK's HSE developed the VMAC tool.

The VMAC tool is designed for assessing manual handling operations where the weight of the load varies. It is an online tool to be used with the MAC tool, to highlight high-risk tasks. However, it is more complex than is needed for assessing many manual handling operations and it can be difficult or time-consuming to obtain weights of each item that a person handles during a shift. Like the MAC tool, it incorporates a numerical and colour-coding score system. It can be used to assess jobs where the weights handled change during the working day. It's based on the same data as the MAC tool and it uses the same colour bands. The additional data needed to use it are the weights of the items and the distance carried.

Risks from repetitive DSE Work

DSE Workstation Assessment

The employer must protect workers from the health and safety risks associated with the use of display screen equipment (DSE), such as computers (desktop machines or laptops), tablets (a mobile computer typically with a touchscreen display and rechargeable battery) and smartphones (a phone with advanced technology to enable sending of text messages or interacting with the web to send/receive emails).

In the UK, under the **Health and Safety (Display Screen Equipment) Regulations 1992**, employers are required to carry out a DSE assessment of the user's workstation, to ensure that the equipment and environment meets minimum standards and that the workstation can be adjusted to suit the user.

During the DSE assessment, it will be necessary to check the:

- Screen.
- Keyboard.
- Chair (including foot rest, if required).
- Desk.
- Other associated equipment, such as telephone.
- Environment, such as lighting, space, noise and temperature.

MORE...

Guidance note L26: Work with display screen equipment is available as a free download from:

www.hse.gov.uk/pubns

It is also available from the HSE website in an updated form, entitled *Display Screen Equipment (DSE) Workstation Checklist*, as an independent document (series code ck1).

Guidance note L26: *Work with display screen equipment* contains a checklist that can be used to facilitate and record the workstation assessments. The checklist is included as Appendix 5 to the guidance.

The checklist prompts the assessor to examine a range of characteristics to determine if the equipment provided at the workstation is of an acceptable standard and set-up properly. Key characteristics the assessor should examine include the:

- Display screen.
- Keyboard.
- Mouse.
- Furniture.
- Environment.

An example of part of the checklist is included below for illustration:

RISK FACTORS	Tick answer YES	Tick answer NO	THINGS TO CONSIDER	ACTION TO TAKE
3 Mouse, trackball etc				
Is the device suitable for the tasks it is used for?			If the user is having problems, try a different device. The mouse and trackball are general-purpose devices suitable for many tasks, and available in a variety of shapes and sizes. Alternative devices such as touchscreens may be better for some tasks (but can be worse for others).	
Is the device positioned close to the user?  ✔  ✘			Most devices are best placed as close as possible, eg right beside the keyboard. Training may be needed to: ▪ prevent arm overreaching; ▪ tell users not to leave their hand on the device when it is not being used; ▪ encourage a relaxed arm and straight wrist.	
Is there support for the device user's wrist and forearm?			Support can be gained from, for example, the desk surface or arm of a chair. If not, a separate supporting device may help. The user should be able to find a comfortable working position with the device.	
Does the device work smoothly at a speed that suits the user?			See if cleaning is required (eg of mouse ball and rollers). Check the work surface is suitable. A mouse mat may be needed.	
Can the user easily adjust software settings for speed and accuracy of pointer?			Users may need training in how to adjust device settings.	

Part of the DSE assessment checklist; Appendix 5 of L26: Work with display screen equipment (Source: www.hse.gov.uk/pubns/priced/l26.pdf)

If employers provide smartphones and tablets to promote mobile working among their workers, there is a duty to provide education on the associated risks, to assess those risks, and to help control those risks.

Musculoskeletal hazards arise from changes to working postures and the physical interactions with the device. Common postures would include leaning over the device, adopting a downward angle of the neck, extending the neck (known as a 'turtle' posture), and extensive use of the thumbs to interact with the devices. Musculoskeletal risk can be increased when working in the following examples:

- When used on trains/planes/cars, etc.
- When used in hotels.
- When used whilst visiting a client or in another person's location.
- During vehicle-based work (delivery drivers).
- When working at home.
- When agile working (hot desking).

L26 advises that where work requires data and text entry or screen monitoring that necessitates sustained attention and concentration, deliberate work breaks must be introduced. When taking breaks, the activities undertaken should not be demanding on the parts of the body intended to benefit from the rest break.

The threshold at which breaks should be introduced should be at the point a break is necessary to prevent further fatigue.

Information provided to workers must enable the worker to distinguish between discomfort that can be managed with rest breaks and the early onset of musculoskeletal disorders which may require an intervention by either the worker informing the employer or seeking support from primary care services.

Appendix 5 of L26 may prove useful in understanding the risks associated with poor body posture and the human/DSE interface. However, the guidance is limited and is now referring to dated technology and has limited references to mobile technology. The principle of the employer completing a checklist with the cooperation of the worker is, however, relevant to managing risks from smartphones and tablets. Additional questions on mobile working situations and equipment that is used or needed, will be required to establish a suitable risk assessment.

Practical Control Measures

Practical control measures are control measures that are concerned with the task being undertaken, the tools and equipment being used, and the workplace environment. Practical controls are what could be done that is likely to succeed in reducing risk.

- **Elimination**

  The first stage in any risk control strategy is to consider if the hazard can be eliminated. This may be achieved by automation, mechanisation or task design. It may be possible to eliminate the need for carrying a load by changing the workplace layout. Instead of having powders delivered as a sack of powder, consider if gravity fed silos or pneumatic transfer of the powder can be achieved. With DSE equipment, it may be possible to eliminate screen flicker by relocating the equipment away from electrical or magnetic interference.

- **Automation**

  Automation covers a wide range of technologies that can be introduced to reduce human intervention. The introduction of automation may create other risks, such as noise, especially where conveyor belts or roller tracks may be used to automate load movement. Automation in computer terminology may include the use of 'software bots' (bot is derived from the term Robot), which are used to automate repetitive tasks, e.g. software bot developed answers at the machine/user interface. Effectively, the software bot is a form of artificial intelligence (AI). The use of a software bot can reduce repetitive keying, e.g. calculating payroll amounts.

- **Alternative work Methods/Job Design**

  An alternative work method to excavation for laying power cables may be to use a boring machine for directional drilling/pipe jacking, to create the tunnel the cable can be fed through. This will reduce the repetitive nature of hand digging and excavation, and achieve the same results. Instead of using needle or hammer scabbling on construction activities that expose the worker to hand arm vibration, use grit blasting.

- **Ergonomic Design of Tools/Equipment/Workstations and Workplaces**

  Good ergonomic design of tools and equipment would include considering:

  - **Force** - choose tools and equipment that require minimal force to hold, use or operate. Choose smaller, lighter tools in preference to larger, heavier ones, where possible. Make use of powered tools/equipment, rather than hand tools/equipment where excessive force has to be used (e.g. air-powered wrench rather than a hand wrench). Also, provide support for tools and equipment that must be held during use, where weight is excessive.
  - **Posture** - select tools and equipment that allow the operator to adopt a comfortable posture during use rather than requiring them to bend, twist, stoop or overreach (e.g. long-handled scraper for cleaning inside a container rather than short-handled scraper, which requires stooping over the container to reach the bottom).
  - **Twisting** - select tools that minimise the need to twist the arm/wrist during use (e.g. a battery-powered screwdriver).

- **Rest** - select tools and equipment that allow the user to rest during use, and provide a rest for the tool, so that the user can put it down during rest periods.
- **Shape** - select tools and equipment that are shaped for ease of use and comfort. Special attention should be paid to the handles of hand-held tools (e.g. a large soft handle on a hand-grip will be more comfortable for long-term use than a narrow, unpadded handle).
- **Adjustability** - the more adjustability the tools and equipment have, the better able users will be to adjust them to suit their personal comfort (e.g. an adjustable-height work-piece platform will be easier to use for a taller or shorter worker than one fixed at standard height).

- **Job Rotation (Fatigue Management)**

  Allowing short, frequent, breaks from work tasks, or the introduction of job rotation to prevent long term duration exposure on any one task, is a way of allowing muscle groups to rest while other muscle groups are being used. The process is one of resting muscles that have been used in activity, and using muscles that have been statically loaded (e.g. the hand hovering over a mouse while reading an email). Job rotation can also enrich the worker's experience, by providing different tasks that reduce monotony and increase attentiveness. In this example fatigue management would include mental fatigue arising from performing repetitive tasks.

- **Work Routines**

  Work routines can standardise processes, tasks can become more habit forming and the worker becomes a master at that task, which can improve quality, production, and safety. Work routines that include rest breaks will almost certainly mean that the rest break is taken by the worker. Work routines can be supported by calendars, spreadsheets, method statements, and checklists. The limitations to human performance can be taken into account when designing the work routine, to ensure the worker is not overloaded physically or mentally.

- **Eyes and Eyesight Testing**

  Extended use of DSE can lead to:

  - Tired eyes.
  - Discomfort.
  - Temporary short-sightedness.
  - Headaches.

  While using DSE, the worker may become aware that their vision level is changing or that they have eyesight problems they were previously unaware of. Changes in vision may also be indicative of other health concerns, such as diabetes, or be a result of medication being taken, such as antihistamines.

  Employees can help their eyes by:

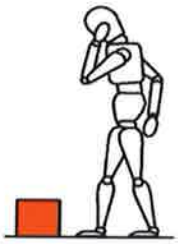
  - Checking that the monitor is well positioned and properly adjusted.
  - Making sure lighting conditions are suitable (avoiding glare).
  - Taking regular breaks from screen work.
  - Early reporting of concerns (such as fluctuating vision).
  - Suitable diets.

  The employer may also support eyesight tests for a DSE user, and the test should be conducted by an optometrist.

- **Training and Information**

  The employer should provide training and information to users on the potential health risks of DSE use and the preventive measures - in particular ergonomic use of the work station. Workers should be trained in basic safe lifting technique. This technique minimises the risk of musculoskeletal disorders.

- **Before Lifting**
  - Check the weight, centre of gravity and stability of the load.
  - Plan the route of the carry.
  - Establish a firm grip.



- **How to Lift**
  - Bend the knees and use the leg muscles to lift.
  - Keep the back upright.
  - Keep the load close to the body.
  - Avoid twisting, overreaching, and jerking.

- **Setting Down**
  - Use the same principles as when lifting.
  - Maintain good balance.
  - Set the load down and then adjust its position using body weight.

- **Efficient Movement Principles**

  Assessing and reducing risk for manual handling activities uses the ergonomic approach, which considers a range of relevant issues, such as the task, the load, the working environment, the individual capabilities, etc. Even if this approach is taken, manual handling will still rely on the use of correct lifting techniques. The assessor may also find that some parameters cannot change, e.g. handling a person in an emergency situation, such as a road traffic incident. The load and the workplace cannot change. Although not a substitute for the ergonomic approach, good handling principles will compliment a risk reduction strategy. Efficient movement principles are the safest way for a body to move while manual handling technique is the way to obtain those postures or movement.

  The principles given in L23 are:

  - Think before you lift (plan the lift).
  - Place the feet.
    - Feet apart, provide a stable base for the lift.
    - Have the leading leg as far forward as is comfortable.
  - Adopt a good posture.
    - Bend the knees.
    - Keep the back straight.
    - Keep the shoulders level.
  - Get a firm and secure grip.
    - Try to keep the arms within the boundary formed by the legs.
    - The optimum grip will vary.

- Do not jerk.
  - Carry out the lift smoothly.
- Move the feet.
  - Do not twist the trunk.
- Keep close to the load.
  - Keep the load close to the trunk.
  - Keep the heaviest side of the load next to the trunk.
- Put the load down, then adjust its position.

- **Personal Considerations**

  Personal considerations are those belonging to, or affecting, a particular person, rather than anyone else. Individuals' capability to lift a load is a function of lifting techniques and force. If the necessary strength is not in the individual, then the task cannot be undertaken. Workstations must be set up to optimise the personal features of the user: such as height, leg length, arm length, body weight, etc. The features of a person will impact on reach and dexterity.

  Personal considerations include the individual's health and age.

- **Wearable Technologies**

  Manual handling is a common physical activity in many occupational contexts and can result in significant harm to the worker if risk is not properly managed. Assistive devices worn by the worker, a wearable technology known as exoskeletons, have been introduced in the workplace.

Person in a factory wearing an exoskeleton suit

  Exoskeletal suits worn by the worker use mechanical drive components to support human movement. Computer programmes, based on sensory inputs, activate motors in the suit to support manual handling. Exoskeletal suits can support workers when they perform manual handling tasks and can reduce the number and severity of musculoskeletal disorders. Technical challenges still exist with the suit's designs (the interface between articulation of the body and the activating motors in the suit) and user acceptability of the suit.

  'Smart watches' may also be used to monitor cardiovascular activities, such as heart rate and blood pressure, to assist in the management of fatigue.

STUDY QUESTIONS

1. What is a WRULD and how might it be brought about?
2. What are the main types of injury associated with manual handling operations?
3. What risk-reduction measures can be introduced to avoid the development of WRULDs?
4. What alterations could you suggest to the organisation of a display screen operator's tasks in order to reduce the physical stress that he/she may be exposed to?
5. What are the characteristics of the load which present a hazard during manual handling operations?
6. Identify the main hazards presented by the working environment in respect of manual handling operations.
7. What is the primary means of minimising the hazards of manual handling?
8. How can manual handling tasks be re-designed to make them less hazardous?

(Suggested Answers are at the end.)

Summary

Musculoskeletal Injuries and Ill Health

We have described how:

- The human skeletal system is made up of the skeleton with its associated muscles, cartilage, tendons and ligaments.
- Musculoskeletal Disorders (MSDs) include back injury and back pain; upper limb disorders; and muscle, tendon and ligament injuries.
- Certain work activities, such as production line work, DSE use and manual handling have a high risk of MSDs.
- Many risk factors influence the risk of MSDs associated with a particular activity. These include repetition, force, posture, twisting, rest, equipment design, equipment adjustability, lighting, other environment parameters and individual capabilities.
- MSD risk assessments often follow a format established by relevant legislation. For example, a manual handling risk assessment considers the load, task, environment and individual capabilities.
- Assessment tools are available to assist with the risk assessment of both manual handling and repetitive activities. The UK's HSE has published four such tools: the MAC, VMAC, ART, and RAPP tools.
- The control measures introduced following such risk assessments will vary, depending on the nature of the activity in question. Manual handling control measures are very different to those employed for DSE use. Generally, hazard elimination by automation or mechanisation are preferred solutions. Where this is not possible, the provision of equipment and aids, task re-design and alterations to the work environment might be used. Ultimately, control may rely on good practices with regards to posture and technique. This will necessitate training.

Learning Outcome 9.15

NEBOSH International Diploma for Occupational Health and Safety Management Professionals

ASSESSMENT CRITERIA

- Outline why suitable working temperatures for all types of work must be maintained and why organisations need to comply with legislation relating to the provision of suitable welfare arrangements for all employees.

LEARNING OBJECTIVES

Once you've studied this Learning Outcome, you should be able to:

- Explain the need for, and factors involved in, the provision and maintenance of temperature in both moderate and extreme thermal environments.
- Explain the need for welfare facilities and arrangements in fixed and temporary workplaces.

Contents

Temperature in Moderate and Extreme Thermal Environment

IN THIS SECTION...

- Thermal comfort is a person's subjective opinion as to whether they feel comfortable with their thermal environment.
- Thermal balance is achieved when the rate of metabolic heat production is balanced by the rate of heat gain or loss by: conduction, convection, radiation and evaporative heat loss. If this balance is upset, then heat stress or hypothermia result.
- Exposure to extreme thermal environments can lead to heat stress and heat stroke or cold injuries and hypothermia. These conditions can be life-threatening.
- Extreme thermal environments are encountered in many indoor industrial workplaces and in outdoor working.
- The environmental parameters that affect thermal comfort are: air temperature, radiant temperature, humidity, and wind speed.
- Other parameters that affect thermal comfort are: work rate, clothing, and duration of exposure.
- The Wet Bulb Globe Temperature (WBGT) Index is used as a tool to assess the likely heat stress on workers if carrying out work in any given thermal environment. It can be used to predict the degree of heat stress and the duration of exposure that is likely to prove acceptable.
- The control measures available for maintaining thermal comfort and a safe thermal environment employ: engineering (lagging/humidifiers, etc.), administrative (control duration of exposure/provide hot drinks, etc.) and behavioural options (supervision to ensure work regimes are followed).

Importance of Maintaining Heat Balance in the Body

A human body responds to the thermal environments in physiological and behavioural ways. Combining metabolic heat generation, clothing being worn, air and radiant temperature, relative humidity, air velocity, perspiration rates, and duration of exposure, can all affect the human response. Work regimes will need to consider the relationship of the thermal environment to the worker.

Heat Balance

The body can be considered to be a chemical factory which carries out a myriad of complex chemical reactions at a temperature of about 37°C and a pressure of one atmosphere. Normal pressure variations do not affect the metabolic processes unduly, but the body temperature is critical and does not vary in general outside the range 36-38°C.

Many body reactions involve oxidation, where heat will be generated. In order to maintain a stable temperature, required for the efficient functioning of the central nervous system and body organs, the metabolic heat loss must be carefully controlled. The body has developed a very sensitive heat control system, which is able to react to the considerable variations in environmental temperatures to which the body is exposed. It can activate mechanisms which will oppose or allow heat loss in an effort to keep the body temperature stable. There are, however, limits.

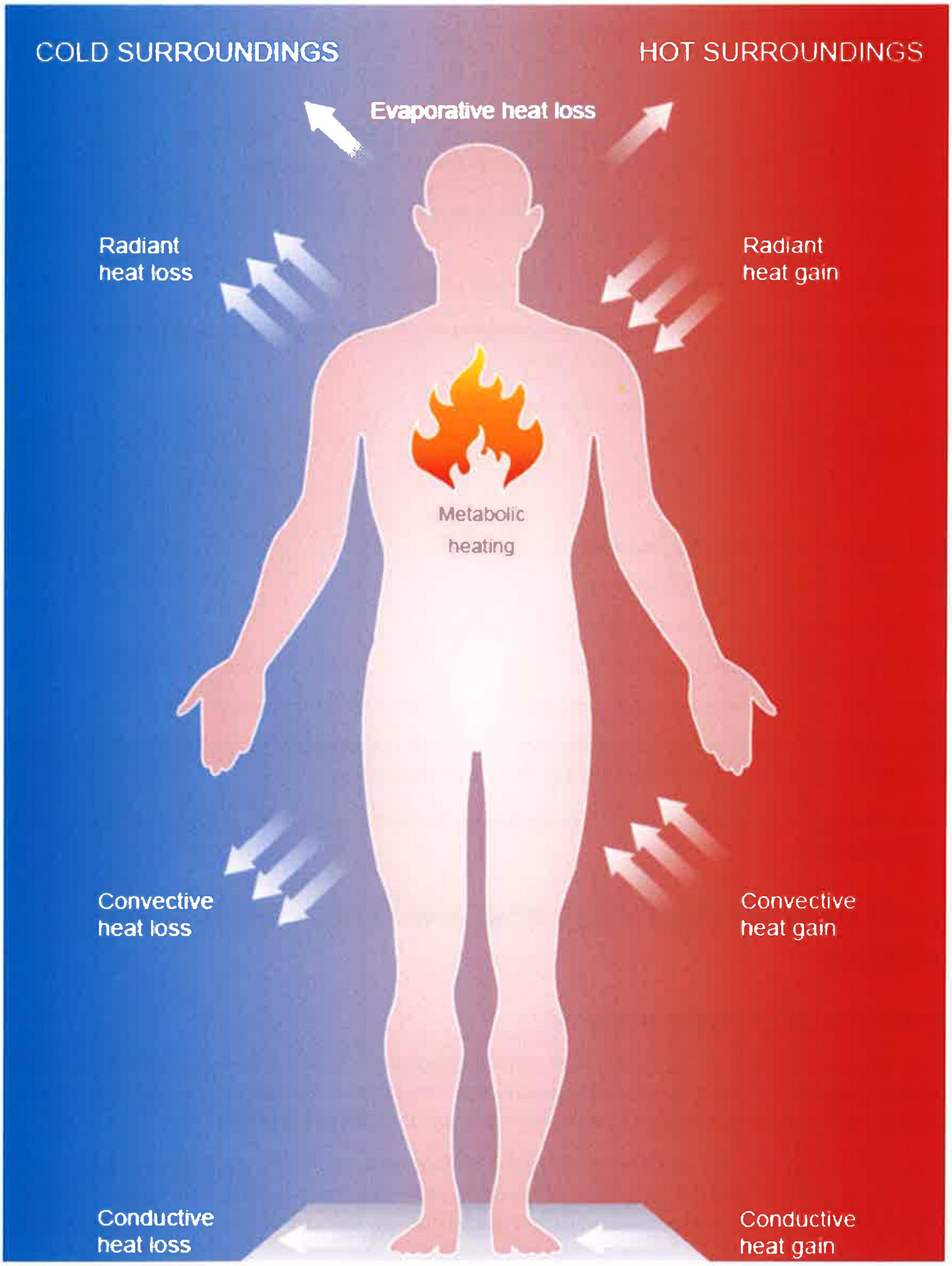
Thermo-Regulatory Mechanisms

As core temperature increases, the body responds by trying to lose heat to the external environment. This is done by transporting heat from the core, to the surface of the body (the skin). Blood vessels in the dermal layer of the skin dilate (vasodilation) so that blood can flow close to the surface of the skin. The increase in temperature at the skin leads to heat loss by radiation (infrared radiation) and direct conduction into colder air. At the same time, sweat (a mixture of water and salts extracted from the blood by the sweat glands in the dermal layer of the skin) is excreted up the sweat ducts and onto the surface of the skin. This liquid spreads over the surface of the skin and evaporates. As it does so, it takes heat from the surface of the skin (this is the heat required to change the state of the water from a liquid to a vapour). This lost heat cools the skin, which, in turn, cools the blood. The cooled blood is returned to the core, where it picks up more heat; and so the cycle is repeated.

As core temperature decreases, the opposite reaction takes place. Blood supply to the skin is reduced by restricting the size of the blood vessels (vasoconstriction). The excretion of sweat onto the surface of the skin stops. Blood is kept in the core of the body and blood supply to the extremities will be reduced to a minimum. Hair on the skin is brought upright. This is done by small erectile muscles in the dermal layer of the skin, attached to each hair follicle - this is what creates the puckered skin effect of 'goose-bumps'. If core temperature cannot be maintained, then the body may respond by trying to create additional heat through muscle activity, in the form of uncontrollable shivering.

In both instances, these mechanisms are entirely automatic and are not under conscious control. There is, of course, a range of actions that the individual can take, that will affect heat loss or heat gain, e.g. for heat: stopping work, seeking shade, removing clothing, splashing water onto the skin, standing in a breeze, etc. or, for cold: increasing work rate, putting on additional clothing, seeking warmth, getting out of moving air, removing wet clothing, etc.

Heat transfer mechanisms are illustrated in the following figure.



Modes of heat exchange between the body and the environment

The important heat transfer mechanisms are:

- Radiation.
- Evaporative cooling.
- Convection.

Conduction is of limited importance, except where there is considerable body contact with a heating or cooling source, such as: motor fitters lying on concrete floors, or people immersed in cold water.

Convection is very important as heat transfer from the body depends on convection currents in the air. Convection currents are also an integral part of evaporative cooling.

Radiation becomes progressively more important as temperature rises.

Evaporative heat loss is the most important heat loss mechanism of all, and becomes the most significant heat loss mechanism once air temperature gets to 35oC or more.

The body's thermal balance can be represented by the equation:

$$M = K + C + R + E$$

Where:

- M is the rate of metabolic heat production.
- K is the loss or gain of heat by conduction.
- C is the loss or gain of heat by convection.
- R is the loss or gain of heat by radiation.
- E is the heat loss from skin or respiratory tract due to evaporation of moisture (so never +ve).

When both sides of the equation balance, thermal balance exists (i.e. the metabolic heat production rate is balanced by the amount of heat being gained or lost through the various mechanisms).

When the equation does not balance, core temperature cannot be maintained and rises or falls cause heat stress or cold stress respectively.

Effects of Working in High and Low Temperatures and Humidity

Exposure to High Temperatures

When air temperature is high, or significant radiant heat is falling on a person, or they are doing heavy work, perhaps whilst wearing protective clothing, then core temperature may increase faster than the body can lose heat. If the body is not able to lose heat quickly enough and core temperature rises, this leads to **heat stress**.

Since one of the major ways that heat is lost by the body is by evaporative heat loss (sweating), the amount of water vapour in the air (humidity level) has a significant effect on the rate of heat loss. When the air temperature reaches 35°C or more, the body loses heat by sweating alone. If relative humidity levels are 80% or more then evaporation of sweat virtually stops. This is why tropical climates can be exhausting; the combination of high air temperature and high humidity means you sweat, but do not enjoy any cooling effect - you simply get wet and dehydrate but it does not cool you down.

The extent of the effects depends on: the individual (in particular, whether they are acclimatised); environmental conditions, such as temperature, humidity and air movement; clothing; work rate, etc.

Typical symptoms of heat stress include:

- Inability to concentrate.
- Muscle cramps (due to salt loss through sweating).
- Heat rash (sometimes called 'prickly heat').
- Severe thirst (due to dehydration) - a late symptom.
- Fainting (sometimes called 'heat syncope').
- Heat exhaustion - fatigue, giddiness, nausea, headache, moist skin.
- Heat stroke - hot dry skin, confusion, convulsions, loss of consciousness. This is the most serious effect as it can lead to coma and death.

These symptoms are caused by a combination of dehydration (loss of water and salts from the blood through sweating), loss of blood pressure (caused by the blood vessels vasodilating to bring the blood closer to the surface of the body) and the increased core temperature (which takes metabolic processes away from their optimal rate).

Depending on circumstances, mild heat stress can develop into heat exhaustion and heat stroke over several days, hours or minutes.

Exposure to Low Temperatures

Exposure to low temperature may lead to **cold injuries**:

- Non-freezing injuries, such as chilblains (painful lumps, often on feet) and trench foot (swollen, infected feet as a result of cold and damp).
- Freezing injuries, such as frostnip (freezing of the surface layers of skin) and frostbite (freezing of skin and deeper tissues), usually to the extremities (fingers and toes).

Exposure to cold conditions may also lead to **cold stress**. This is the exact opposite of heat stress, where the body is unable to maintain core temperature at 37°C and, consequently, the core temperature starts to fall. Once core temperature falls below 35°C, then hypothermia has occurred.

Symptoms of hypothermia include:

- Feeling cold, followed by pain, then numbness.
- Shivering (automatic muscle contractions in an attempt to generate metabolic heat).
- Uncharacteristic mood and behaviour changes.
- Confusion.
- Muscular weakness.
- Drowsiness.

The condition can lead to coma and death. Like heat stroke, hypothermia may take hours to progress, or may take minutes if the conditions are right.

Humidity

Humidity is the amount of water vapour in the air.

The higher the level of humidity, the wetter the air will feel. When the air is holding so much water vapours, its ability to absorb the body's perspiration is limited. If the perspiration stays on the person (and does not evaporate into the air) then they will have difficulty regulating their body temperature, since perspiration is one of the body's temperature control mechanisms.

The lower the level of humidity, the drier the air will feel. When the air is not holding much moisture, respiration may become affected, as the nose and mouth become dry. Low humidity can also affect eye moisture, by increasing the evaporation rate, leading to dry eyes and discomfort. Low humidity is associated with low temperature.

Definitions used to describe humidity include:

- Absolute humidity - the water content in air expressed in grams per cubic meter.
- Relative humidity - expressed as a percentage that indicates the absolute humidity relative to maximum humidity at the same temperature. (Covered in more detail later in this section).
- Specific humidity - which measures the ratio of water vapour to air in a particular volume of air (known as a 'parcel').

Typical Work Situations

Thermal discomfort can occur in any work situation, since it is a personal, subjective state of mind. A number of factors might be indicative of typical work situations where it is likely to arise:

- Large areas of glazing may cause overheating through solar gain (greenhouse effect).
- Air movement is necessary to provide air changes for fresh air requirements, but if the velocity rises above 0.15m/s, there may be complaints about draughts.
- People, artificial lighting and computers can add considerably to the heat generated in a particular area, creating overheating problems.
- Lack of control by individuals over their environment. The absence of adjustable heating controls, opening windows and controllable ventilation systems leads to high levels of dissatisfaction.

Glass blowing furnace

Heat stress and **cold stress** occur in more extreme thermal environments. Typical work situations causing **heat stress** include:

- Furnace work, handling molten metal.
- Glass-making.
- Welding, brazing.
- Boiler and furnace maintenance, boiler-room work.
- Deep-mining work.
- Laundries.
- Kitchens.
- Fire-fighting.

Typical work situations causing **cold stress** include:

- Outdoor work (agriculture, maintenance, etc.).
- Sea fishing, shipping.
- Oil rigs.
- Deep freeze stores, cold rooms.
- Diving.

Thermal Comfort

When looking at the issue of temperature and the thermal environment, it is important to distinguish between working in **extreme thermal environments**, where **significant risk** may arise in relatively short periods of time (such as dehydration and hypothermia) and working in **non-extreme thermal environments**, where no comparable risk is created, but workers experience **discomfort**. For example, fire-fighters have to work in hot environments wearing full protective clothing and breathing apparatus. It is not hard to imagine that even a very fit person might become heat stressed and suffer heat exhaustion, that might prove life-threatening, in a relatively short period of time. On the other hand, office workers might have to sit for long periods of time in a relatively benign environment where the air temperature is 17°C. No-one is going to suffer hypothermia, but most people will feel cold and uncomfortable carrying out sedentary work in such an environment, and the levels of discomfort will increase over time.


Fire-fighters work in an extremely hot environment

In between these extremes, there is, of course, a sliding scale where discomfort (psychological in origin) turns into health risk (physical in origin). The degree of discomfort and the degree of health risk have both been the subject of scientific study over time. However, since they are both subject to many variables, it is difficult to make definitive statements about what is/is not acceptable as we move along that sliding scale. This is particularly the case for discomfort, which is inherently a subjective opinion.

Thermal comfort is defined in British Standard **BS EN ISO 7730** as:

> *"that condition of mind which expresses satisfaction with the thermal environment."*

The term describes a person's psychological state of mind, and is usually referred to in terms of whether someone is feeling too hot or too cold.

Thermal comfort is difficult to objectively determine because allowances have to be made for a range of environmental and personal factors when deciding what will make people feel comfortable. We all know from personal experience what room temperatures will make us feel most comfortable, and we know that this will vary depending on a range of factors, such as the activity that we are performing. For example, as I sit writing these words the air temperature is 18°C and I am feeling a little cold. If I were stood up lecturing, that would be a perfect temperature for me, but probably rather cold for those sat listening (metabolic work rate is higher if you are stood than when you are seated). If I were playing five-a-side football, it would be unbearably hot in an indoor sports hall with no cooling breeze (running makes metabolic work rate soar). We also know from personal experience that what suits us does not suit other people. People have very different opinions about what constitutes thermal comfort. Some people would happily sit in an office heated to 25°C, a temperature that others would find sleep-inducing. You all have your own opinions on the matter.

The best that an employer can realistically hope to achieve is a thermal environment that satisfies the majority of people in the workplace, or put more simply, 'reasonable comfort'. The HSE considers 80% of occupants as a reasonable limit for the minimum number of people who should be thermally comfortable in an environment.

Thermal comfort is not measured by air temperature, but by the number of employees complaining of thermal discomfort.

Parameters that Affect Thermal Comfort

Air Temperature (Surround Temperature)

In terms of temperature, **heat will always flow from a high temperature** to a low temperature. It therefore follows that, as the temperature of the surroundings increases, the body will find it increasingly difficult to lose heat. There will come a point where the body will begin to overheat. Similarly, as air temperature falls, the heat gradient between the body and the surrounding air becomes steeper, causing heat to flow from the body more rapidly, making it difficult for the body to maintain temperature.

Radiant Temperature

Thermal radiation is the heat that radiates from a warm object. Radiant heat may be present if there are heat sources in an environment.

Radiant temperature has a **greater** influence than air temperature on how we lose or gain heat to the environment. Our skin absorbs almost as much radiant energy as a matt black object, although this may be reduced by wearing reflective clothing.

Examples of radiant heat sources include:

- The sun.
- Fire.
- Electric fires.
- Furnaces.
- Road rollers.
- Ovens.
- Walls in kilns.
- Cookers.
- Dryers.
- Hot surfaces.
- Machinery.
- Molten metals, etc.

Relative Humidity

As mentioned previously, humidity is a measure of the concentration of water vapour in the atmosphere. The amount of water vapour is dependent on two main factors, the:

- Presence of liquid water to supply the water vapour; air over water will have a higher concentration than air over a desert.
- Temperature of the air; the higher the air temperature, the greater the capacity of the air to hold water vapour.

At any given temperature, the air can only hold a certain amount of water vapour. Where conditions of maximum water vapour occur, the air is said to be saturated. Cold air can hold a lot less water vapour than warm or hot air. So, cold air becomes saturated at much lower water vapour concentrations than warm or hot air. This is why arctic winds always feel 'dry' (they contain little water vapour), but hot summer breezes can be 'dry' (low water vapour concentration) or 'muggy' (high water vapour concentration or even saturated).

Because of the interplay of temperature and water vapour concentration, humidity is expressed in terms of relative humidity.

Relative Humidity (RH) is a ratio; it has no units (though it is sometimes expressed as a percentage) and is defined by the following formula:

$$RH = \frac{\text{Mass of water vapour present in a given volume of air at a given temperature}}{\text{Mass of water required to saturate that volume of air at the same temperature}} \times 100$$

A relative humidity of 75% means the air is holding 75% of the water vapour it can actually hold. Relative humidity can be measured using a psychrometer (covered later on in this section) or by more modern instruments using electronics to measure the change in conductivity.

Air Velocity or Wind Speed

The rate of evaporative cooling depends on the air velocity - or air change rate. With low air-change rates, the evaporation zone (the layer of air near the skin that sweat is evaporating into) soon becomes saturated with water vapour and the evaporation rate will decrease, hence the cooling effect stops. When air velocity is high, water vapour leaves the sweat freely and so sweating has a far more marked effect on heat loss rate.

In situations where air is moving over exposed skin but that skin is dry (not sweating), the air will draw heat from the skin by conduction (heat flows from hot to cold). Thus, on a cold day, exposed dry skin is cooled by air movement. The rate of heat transfer increases as air-speed increases, giving rise to the wind-chill effect.

Metabolic Rate

The body's metabolic rate can be expressed as Watts (Joules of energy per second) or Watts per square metre (of body surface area). The metabolic rate in a completely resting body is approximately 45W/m^2 of body surface. If the surface area of a typical male is taken as 1.8m^2 this amounts to a total heat output of about 80W.

As the level of activity or physical work increases, so does the metabolic rate. The following table gives approximate metabolic heat production rates for different levels of activity, ranging from 75W during sleep to 1,600W during intense athletic activity. An occupational figure of note is that for heavy work, which is around 450W.

Metabolic rates for different activities

Activity	Metabolic Heat Production Rate M(W)
Sleeping	75
Resting	90
Sitting	105
Standing	125
Light work	160
Walking	280
Heavy work	450
Running	1,000
Intense athletics	1,600

Clothing

Clothing, as you might expect, has a significant effect on the ability of the body to lose heat to the external environment. In considering conduction of heat at the body surface through clothing, it is the resistance (or insulation) to heat flow across a given thickness of material that we are concerned about. This parameter is given an arbitrary unit, the 'clo', to express the insulation value of clothing; 1.0clo is defined as the insulation provided by clothing which allows comfort in still air at a uniform temperature of 21°C. Thermally insulating polar clothing provides clo values as high as 3 or 4.

Examples of clo values for typical workplace outfits are given in the following table:

'Clo' values for typical workplace outfits

Clothing	Clo Value
Shorts	0.1
Light summer clothing	0.5
Typical indoor clothing	1.0
Heavy suit	1.5
Polar clothing	3-4

Sweat Rate

Sweat rate needs to be within certain narrow limits for us to feel comfortable (put simply, sweating helps us cool down, but excessive moisture makes us feel uncomfortable - we like to be largely free of sweat).

Duration of Exposure

The longer someone is exposed to thermal discomfort, the more severe the effects are likely to be. Prolonged exposure to heat or cold can affect fatigue levels. This can result in lower levels of concentration, impaired reflexes and a reduction in physical coordination. Duration of exposure is also relative to age, obesity and use of medication.

Purpose of the Heat Stress Index Wet Bulb Globe Temperature (WBGT)

The purpose of heat stress indices is to estimate the physiological responses of an individual to their environment. The end result is to provide a value that allows a comparison between environments, different working situations and different types of clothing to be made.

Various types of heat stress index have been developed that summarise environmental, and other, parameters into a single number, which can be used to quantify the severity of the thermal environment. The most widely used is the **WBGT Index**.

The Wet Bulb Globe Temperature (WBGT) heat stress index is the most widely accepted heat stress index and forms the basis of many standards. It has been published as British Standard **BS EN ISO 7243:2017**.

The **Dry Bulb temperature** is the temperature most often referred to when people mention the temperature of the air. It can be measured with a standard thermometer freely exposed to air but shielded from radiation and moisture.

WBGT is calculated from:

WBGT = 0.7 WB + 0.3 GT indoors

or

WBGT = 0.7 WB + 0.2 GT + 0.1 DB outdoors

Where:

- WB is the wet bulb temperature.
- GT is the globe thermometer temperature.
- DB is the dry bulb temperature.

The outdoor formula reduces the influence of the globe contribution from direct sun.

The index takes account of radiant and air temperatures, humidity and low air velocities. The index value must be used in conjunction with empirical recommendations (set out in **ISO 7243**) to indicate a level that is safe for most people who are physically fit and in good health. Different values are quoted to distinguish persons that are acclimatised or unacclimatised to heat. If conditions of exposure fluctuate, a time-weighted average exposure can be derived and used.

Metabolic rate M (W/m^2)	Reference value of WBGT			
	Person acclimatised to heat (°C)		Person unacclimatised to heat (°C)	
0. Resting M ≤ 65	33		32	
1. 65 ≤ M ≤ 130	30		29	
2. 130 ≤ M ≤ 200	28		26	
	No sensible air movement	Sensible air movement	No sensible air movement	Sensible air movement
3. 200 < M < 260	25	26	22	23
4. M > 260	23	25	18	20

Example of WBGT in Use

If the following workplace parameters are measured in an indoor workplace:

- air temperature = 26°C,
- globe temperature = 26.5°C,
- wet-bulb temperature = 18°C,
- little air movement, and
- acclimatised workers are estimated to be working at 250W/m^2,

the WBGT = 0.7 WB + 0.3 GT = (0.7 × 18) + (0.3 × 26.5) = 12.6 + 7.95 = **20.6°C**

Looking at the table, the WBGT reference value for "Metabolic Rate Class 3" when the 'person acclimatised to heat', and 'no sensible air movement' is a WBGT of = 25°C.

The measured value of 20.5°C is below the WBGT reference value of 25°C and so it can be concluded that heat stress is not a risk in this environment.

If the workplace environment changed so that:

- globe temperature = 33°C, and
- wet bulb temperature = 28°C,

then WBGT = 29.5°C, which is above the WBGT reference value of 25°C. Therefore, risk of heat stress exists.

Metabolic work rate can be estimated by reference to tables of typical work rates associated with particular activities, trades and even use of PPE.

Practical Control Measures

Control measures that can be used to improve unsatisfactory thermal environmental parameters include the following:

- **Control Heat/Cold Sources**

  It may be possible to enclose heat sources and provide lagging/insulation to prevent the escape of heat into the wider workplace environment. For example, a large oven or steam pipes passing through a workspace can be lagged/insulated. It may also be practical to separate areas within the workplace where excess heat and/or humidity are going to occur from other areas where such extremes are not needed, effectively segregating extreme areas from other workspaces.

  Indoor workplaces that present a cold environment will often be refrigerated (such as food industry workrooms, storerooms, freezers and blast chills) and, consequently, are usually heavily segregated and insulated for energy efficiency purposes. It may be possible to enclose processing equipment and provide lagging/insulation so that the wider workplace environment can be maintained at a reasonable temperature.

- **Control Environmental Parameters**
  - Use a humidifier or dehumidifier to manage relative humidity.
  - Ventilation can be used to remove or dilute hot/humid air and replace it with cool/dry air. Air conditioning can be used for internal workspaces.
  - Increased air velocity can aid bodily cooling through heat loss due to increased sweat evaporation. Air handling units and fans can be used for internal workspaces.

- Reduce draughts by directing ventilation units away from workers.
- If the indoor workspace is simply cold because of ambient outdoor temperatures and there are no operational reasons for the low temperature, then the workplace should be heated to achieve the minimum temperatures set out in any relevant Regulations or Codes of Practice, such as the British Approved Code of Practice to the **Workplace (Health Safety & Welfare) Regulations 1992**.
- Heating may be provided by fixed installations or using portable heaters, such as LPG-fuelled space heaters or electrically powered IR radiant heaters. This heating might be applied to the entire workplace, or it might be localised to the workstations where workers spend much of their time.

- **Separation**
  - Erect barriers to shield the workers or redesign the task to remove the proximity of the worker.
- **Workplace Design**

Radiation barriers placed between the source of heat and the worker can reduce the level of radiant heat exposure. (Barriers should be good insulators and high-heat reflectors to prevent them heating up and becoming radiant heat sources themselves.)

In outdoor workplaces, shade from the heat of the sun can be supplied. If this is not practical, then shade and fans might be supplied in external rest areas to help workers cool down between work rotations.

Cool refuges can be incorporated into very hot and humid environments, so that workers can temporarily seek relief from the extreme environment, to cool down.

In low temperature outdoor workplaces, protection from the wind might be supplied. Weather protected rest areas, such as a heated porta-cabin, must be provided to help workers warm up between work rotations.

Warm refuges can be incorporated into very cold internal environments (such as a sub-zero frozen foods warehouse) so that workers can temporarily seek relief from the extreme environment, to warm up.

- **Job Design and Job Rotation**

For outdoor workers, restrict work to the cooler parts of the day or work at night. Avoid work during the hottest parts of the day:

- Control the duration of each work period and ensure that sufficient rest breaks are incorporated into work routines, so that workers can cool down. Heat stress indices, such as the WBGT index, can be used to make calculations of the maximum allowable work period and the rest period required to achieve heat balance.
- Supervision is necessary to ensure that the work regimes are followed and that potential heat stress is detected at an early stage.
- Acclimatisation is important to enable workers to become used to the more extreme thermal environments. Acclimatisation allows the worker's body to adjust physiologically, and it also allows workers to adjust mentally how they plan and manage their work.
- Easy access to drinking water or other cold drinks is important for workers in hot environments, as is access to electrolytes (salt) so that salts lost by sweating can be replaced.

- **Providing Hot/Cold Drinks**

  Dehydration effects can be minimised by replacing the lost fluids with hot or cold drinks. The cooling effect from a cold drink is more closely related to re-hydration effects, as the body transports heat away from vital organs to the skin surface. Warm drinks do not affect core body temperature but, counter intuitively, may cool a worker by triggering perspiration responses.

- **Clothing/Personal Protective Equipment**

  Personal protective equipment insulates the body and reduces evaporative heat loss, which increases the risk of heat stress if physically demanding work is carried out. If protection is needed against radiant heat, heat-resistant clothing gives limited protection, with ice-cooled jackets and air-cooled or water-cooled suits needed for longer periods of exposure. However, the use of such personal protective equipment is likely to increase the metabolic rate and possibly lead to thermal strain.

  The wearing of uniforms must be carefully evaluated in extremes of temperature. Materials should be considered that improve thermal comfort. Allowing workers to relax uniform requirements may also be beneficial for controlling thermal comfort (removing jacket/ties, etc.).

  Wearing multiple layers of clothing allows the worker's discretion when controlling the thermal environment. Layers can be removed when the worker is warm, and put back on if the worker gets cold.

  Protective clothing is an important control measure against cold stress and may need to incorporate the following features:

  - Thermal insulation provided by a fibrous structure that traps air.
  - An outer, tightly woven layer that is windproof.
  - Waterproofing for cold, wet, environments. However, this type of clothing may be impermeable to water vapour escaping from the skin, and condensation within the clothing may reduce its effectiveness. This can be a significant issue for physically active workers in an extremely cold environment. They sweat as a result of intense physical activity and then become hypothermic once the physical activity stops, as a result of wearing damp or frozen clothing.
  - Semi-permeable ('breathable') fabrics may be needed for active personnel where clothing must be waterproof and windproof, but also allow perspiration to escape.

- **Health Surveillance**

  The regular monitoring of workers is important for those who work in extreme temperatures. The testing of kidney, respiratory and cardiovascular functions, together with general health, are relevant.

- **Information, Instruction, Training and Supervision**

  Workers need to understand the hazards and risk associated with heat stress, dehydration and heat stroke. They must be trained to understand the uses and limitations of the control measures necessary, and how to recognise the signs and symptoms of heat stress in themselves and their fellow workers, so that they can react appropriately.

  Similar to the very hot environment, workers need to understand the hazards and risk associated with hypothermia; the uses and limitations of the control measures necessary, and how to recognise the signs and symptoms of hypothermia in themselves and their fellow workers so that they can react appropriately.

MORE...

General information on thermal environment is available from the HSE at:

www.hse.gov.uk/temperature/index.htm

STUDY QUESTIONS

1. What are the forms of heat transfer relevant to a person in a workplace environment?
2. Define the term 'relative humidity'..
3. Explain the difference between measuring the dry bulb air temperature and the wet bulb air temperature.
4. State the principal categories of control for hot conditions.

(Suggested Answers are at the end.)

Welfare

IN THIS SECTION...

- The employer has to provide adequate sanitary conveniences, washing facilities, drinking water, changing facilities, and facilities to rest and eat meals.
- Special circumstances apply with regards to the welfare arrangements for new and expectant mothers.

Why it's Important to Provide Welfare Facilities

'Welfare facilities' are those that are necessary for the well-being of workers, such as washing, toilet, rest and changing facilities, and somewhere clean to eat and drink during breaks. They are an important control measure in protecting workers by supporting good personal hygiene and restricting methods of entry of hazardous substances. Access to water and sanitation are recognised by the United Nations (UN) as basic human rights. Obligations may exist in national legislation or Codes of Practice, however, there is also a strong moral duty to provide good welfare facilities.

In fixed or temporary location workplaces, welfare facilities should be within reasonable access of everyone on site, and should be kept clean and well maintained. The ILO Code of Practice - *Safety and health in construction,* also states that men and women workers should be provided with separate sanitary facilities.

Where natural lighting levels are inadequate to ensure safe working conditions, suitable artificial lighting must be provided. The artificial lighting provided should not cause glare or shadows. The lighting may require guards, to protect against accidental damage.

Sanitary Conveniences

In the UK, there is an Approved Code of Practice (ACoP) to the **Workplace (Health, Safety and Welfare) Regulations 1992** which details the recommended minimum number of sanitary conveniences that should be provided. Whilst this is not directly applicable worldwide, it can provide good guidance in the absence of an international standard.

Separate sanitary accommodation should be provided for men and women

The number of people at work refers to the maximum number likely to be in the workplace at any one time. Where separate sanitary accommodation is provided for a group of workers, men, women, office workers or manual workers, a separate calculation should be made for each group.

The room containing the facilities should be adequately ventilated, lit, clean and kept in an orderly state. Separate rooms for men and women should be provided, except where the water closet is in a separate room and can be locked from the inside.

The following table shows the recommended number of water closets and wash stations per number of people at work.

Water closets and wash stations per numbers at work

Number of people at work	Number of water closets	Number of wash stations
1 to 5	1	1
6 to 25	2	2
26 to 50	3	3
51 to 75	4	4
76 to 100	5	5

In the case of sanitary accommodation used only by men, the following table may be followed, if desired, as an alternative to the second column of the previous table. A urinal may either be an individual urinal or a section of urinal space which is at least 600mm long.

Water closets and urinals per number of men

Number of men at work	Number of water closets	Number of urinals
1 to 15	1	1
16 to 30	2	1
31 to 45	2	2
46 to 60	3	2
61 to 75	3	3
76 to 90	4	3
91 to 100	4	4

Washing Facilities

The same UK ACoP requires that suitable and sufficient washing facilities are provided. This includes showers, if required by the nature of the work or for health reasons.

Washing facilities should:

- Be provided in the immediate vicinity of sanitary conveniences.
- Be provided in the vicinity of changing rooms.
- Be supplied with hot and cold (or warm) water.
- Include soap or other means of cleaning.
- Include towels or other means of drying.
- Be sufficiently ventilated and lit.
- Be kept in a clean and orderly condition.

Hand-wash facilities must be supplied with soap or some other means of cleaning the hands

Separate facilities for men and women should be provided (except where they are intended to be used by only one person at a time and can be locked from inside).

Drinking Water

An adequate supply of drinking water is provided for all workers.

The UK ACoP to the **Workplace (Health, Safety and Welfare) Regulations 1992** specifies that drinking water should be supplied direct from a tap or pipe, rather than a storage tank or cistern (unless appropriately covered, cleaned and tested). Drinking water sources should not be provided in work areas where contamination is likely to occur. Where sources of non-drinking water exist, these must be marked to clearly distinguish drinking water from non-drinking water.

Accommodation for Clothing

The UK ACoP lays down requirements for suitable and sufficient accommodation to be provided for clothing. It requires that the accommodation be provided for:

- Clothing that is not worn during working hours.
- Special clothing that is worn for work but not taken home.

Special work clothing includes all clothing which is only worn at work, such as overalls, uniforms, thermal clothing and hats worn for food hygiene purposes.

Accommodation for work clothing and workers' own personal clothing should enable it to hang in a clean, warm, well-ventilated place where it can dry out during the course of a working day, if necessary. If the workroom is unsuitable for this purpose, then accommodation should be provided in another convenient place. The accommodation should consist of, as a minimum, a separate hook or peg for each worker.

Where work clothing (including personal protective equipment) which is not taken home becomes dirty, damp or contaminated due to the work, it should be accommodated separately from the worker's own clothing. Where work clothing becomes wet, the facilities should enable it to be dried by the beginning of the following work period, unless other dry clothing is provided.

Changing Facilities

The UK ACoP requires that, for a person who has to wear special clothing for work, suitable and sufficient facilities shall be provided to change the clothing.

Changing rooms are not regarded as suitable unless they are separate for men and women.

Changing facilities should be readily accessible from workrooms and eating facilities, if provided. They should be provided with adequate seating and should contain, or connect directly with, clothing accommodation and showers or baths, if provided. They should be constructed and arranged to ensure the privacy of the user.

The facilities should be large enough to enable the maximum number of persons at work expected to use them at any one time, to do so without overcrowding or delay. Account should be taken of starting and finishing times of work, and the time available to use the facilities.

Rest and Eating Facilities

Many pieces of national legislation include the requirement for the provision of welfare facilities. However, there is also an international requirement in the form of **ILO Recommendation R102: Welfare Facilities Recommendation 1956**. This recommendation includes consideration of the requirement for:

Food preparation and eating areas must be adequately clean to prevent cross-contamination of food

- Feeding facilities in, or near, the undertaking (workplace) - this includes the provision of canteens, buffets/trolley services, or mess rooms, especially where other appropriate facilities are unavailable. Special consideration should be given to the provision of facilities for shift workers.
- Rest facilities in, or near, the workplace. The recommendation states that, where possible, seats should be provided for use during work, with a footrest where necessary. Where alternative facilities are not available, a rest room should be provided for workers to take rest breaks during working hours. The rest room should have a suitable temperature, adequate ventilation and lighting, and an adequate number of seats for those using it.
- Recreation facilities (excluding holiday facilities). The recommendation also calls for the workplace to encourage the provision and development of recreation facilities in the area. Whilst many larger organisations do choose to provide such facilities, this requirement has not been enacted in law in many countries.
- Transportation facilities to and from work where ordinary public transport is inadequate or impractical. The recommendation states that where private cars are used, adequate parking should be provided - unfortunately, this requirement has been somewhat outdated since its conception in 1956 and many workplaces (especially in city centres or high-population-density locations) are finding it increasingly difficult to provide parking for workers. The recommendation also calls for the provision of transport (such as work's buses) where there is inadequate public transport. Again, in many countries, it is the custom and practice to rely on private vehicles, although this is not always the case.

The recommendation excludes workers in the agricultural and sea-transport sectors.

We can see how some of these requirements have been adopted in the UK by, again, returning to the ACoP to the Regulations, which requires the following:

- For people who have to work standing, seats should be provided if the work allows the opportunity to sit from time to time.
- Suitable seats should be provided for workers to use during breaks. These should be in a suitable place where PPE need not be worn. In offices and other reasonably clean workplaces, work seats will be sufficient, provided workers are not subject to excessive disturbance during breaks.
- Rest areas or rooms should be large enough, and have sufficient seats with backrests and tables, for the number of workers likely to use them at any one time.
- Where workers regularly eat meals at work, suitable facilities should be provided for the purpose. Such facilities should also be provided where food would otherwise be likely to become contaminated.
- Seats in work areas can be counted as eating facilities, provided they are in a sufficiently clean place and there is a suitable surface on which to place food. Eating facilities should include a facility for preparing, or obtaining, a hot drink, such as an electric kettle, a vending machine or a canteen. Workers who work during hours, or at places where hot food cannot be obtained in, or reasonably near to, the workplace, should be provided with the means for heating their own food.

- Eating facilities should be kept clean. Responsibility for cleaning should be clearly allocated. Steps should be taken where necessary to ensure that the facilities do not become contaminated by substances brought in on footwear or clothing. If necessary, adequate washing and changing facilities should be provided.
- Canteens or restaurants may be used as rest facilities, provided there is no obligation to purchase food in order to use them.
- Rest facilities for pregnant women and nursing mothers should be sited close to toilets/washrooms. Rest facilities should also include somewhere to lie down if necessary.

Arrangements for Pregnant Women and Nursing Mothers

It is a requirement in some national legislation that suitable facilities be provided for pregnant women and nursing mothers to rest, and this may include the provision of somewhere for the woman to lie down.

It is good practice to provide a private, healthy, and safe environment for nursing mothers to express and store milk. It is not suitable to use toilets for this purpose.

STUDY QUESTION

5. If a person has to wear special clothing for work, what types of facilities need to be provided by the employer?

(Suggested Answer is at the end.)

Summary

Temperature in Moderate and Extreme Thermal Environment

We have described how:

- Several sets of Regulations include a requirement to regulate indoor workplace temperatures.
- Thermal comfort is a person's subjective opinion as to whether they feel comfortable with their thermal environment.
- Thermal balance is achieved when the rate of metabolic heat production is balanced by the rate of heat gain or loss by: conduction, convection, radiation and evaporative heat loss. If this balance is upset, then heat stress or hypothermia result.
- Exposure to extreme thermal environments can lead to heat stress and heat stroke or cold injuries and hypothermia. These conditions can be life-threatening.
- Extreme thermal environments are encountered in many indoor industrial workplaces and in outdoor working.
- The environmental parameters that affect thermal comfort are: air temperature, radiant temperature, humidity, and wind speed.
- Other parameters that affect thermal comfort are: work rate, clothing, and duration of exposure.
- The Wet Bulb Globe Temperature (WBGT) Index is used as a tool to assess the likely heat stress on workers if carrying out work in any given thermal environment. It can be used to predict the degree of heat stress and the duration of exposure that is likely to prove acceptable.
- The control measures available for maintaining thermal comfort and a safe thermal environment employ: engineering (lagging/humidifiers, etc.), administrative (control duration of exposure/provide hot drinks, etc.) and behavioural options (supervision to ensure work regimes are followed).

Welfare

We have described how:

- Adequate welfare facilities have to be provided by the employer under national Regulations and a range of Codes of Practice.
- There are requirements for an employer to provide adequate sanitary conveniences, washing facilities, drinking water, changing facilities, and facilities to rest and eat meals.
- Special circumstances apply with regards to the welfare arrangements for new and expectant mothers.

Unit ID2

Suggested Answers - Part 2

No Peeking!

Once you have worked your way through the study questions in this book, use the suggested answers on the following pages to find out where you went wrong (and what you got right), and as a resource to improve your knowledge and question-answering technique.

Learning Outcome 9.9

Question 1

OELs are concerned with inhalation of airborne contaminants. Therefore, the form of the substance must be one that can become airborne; dust, fibres or fumes, mists and vapour or gas.

Question 2

Two OELs can be set for a chemical - a Long-Term Exposure Limit (LTEL) based on an 8-hour Time-Weighted Average (TWA) exposure; and a Short-Term Exposure Limit (STEL) based on a 15-minute TWA exposure.

Question 3

Initial appraisal - helps establish the need for, and extent of, exposure monitoring. It is conducted in two stages - information-gathering and simple qualitative tests. Depending on the conclusions drawn, a basic survey may then be needed. This estimates an employee's personal exposure using crude methods. The conclusions of this stage will enable you to decide if a detailed survey is required. The detailed survey is conducted in cases such as highly variable exposure and involves more detailed monitoring and analysis. In addition, there are the stages of re-appraisal (to see if changes have had the desired effect) and routine monitoring (to ensure controls remain effective) described in HSG173.

Question 4

The sampling equipment (sampling train) consists of an air pump, connecting hose and sampler (containing a pre-weighed filter):

- Clean and load the sampler with a pre-weighed filter or cassette.
- Fit the sampler to the pump. Run the pump to stabilise airflow and then check and adjust flow rate using the flow meter.
- Attach the sampling train to the operator, not more than 30cm away from the nose-mouth region.
- Record the time at the start of the sampling period and check, record and re-adjust the flow rate as necessary at the end of each hour.
- At the end of the sampling period, note the time and remove the filter for re-weighing.
- Re-check the flow rate using the flow meter.
- Once the weight of dust collected on the filter is known, a simple calculation is carried out to give the weight of dust per cubic metre of air (mg.m-3).

Question 5

- Tubes with incorrectly broken ends may not give correct flow rate.
- Bellows action and the number of strokes are critical in ensuring that the correct volume of air is drawn through the tube.
- Tubes may be cross-sensitive to substances other than the one being analysed.
- Tubes give inaccurate readings at non-standard temperatures and pressures.
- Tubes have a limited shelf-life.
- Measurements obtained are inherently inaccurate so the margin of error of the tube type must be taken into account.
- Hand-operated stain tube systems are capable of only a point-in-time or grab sample.

Learning Outcome 9.10

Question 1

Any micro-organism, cell culture, or human endoparasite, which may cause any infection, allergy, toxicity or otherwise create a hazard to human health. These include viruses and bacteria which can cause infection and disease, dangerous plants and animals (for example parasites or insects), biologically contaminated dusts, or wastes from humans and animals.

Question 2

Fungi, bacteria, viruses and protozoa.

Question 3

Zoonoses are animal infections that may be transmitted to people in the course of their work. For example, anthrax is an acute, infectious disease of farm animals caused by a bacterium.

Question 4

Agricultural workers, and sewage and construction workers; who are exposed to sewage and polluted water (polio, leptospirosis, hepatitis, etc.).

Question 5

- Stage I - Fever with 'flu-like symptoms lasting for about a week.
- Stage II - By the start of the second week, the fever has abated and jaundice becomes more obvious.
- Stage III - In severe cases, jaundice may be present for three or four weeks, followed by a second fever lasting for up to two weeks. Recovery/convalescence can take many weeks or months.

Learning Outcome 9.11

Question 1

All sound which can result in hearing impairment, or be harmful to health, or otherwise dangerous.

Question 2

- The amplitude is the maximum displacement of sound wave pressure.
- The frequency is the number of cycles per second that pass a given location.

Question 3

Pitch is the way the brain interprets the frequency of sound; shrill or piercing sound is high-pitched and associated with high frequencies. Rumbles or drones are low-pitched sound and associated with low frequencies.

Question 4

The A-weighted scale on a sound level meter electronically assimilates the sound pressure and mimics the human ear's response across the range of frequencies. The measurement of noise in dB(A) is a good indication of the physical harm caused to hearing.

Question 5

Because sound intensity levels are given in a logarithmic form.

Question 6

The ear transmits nerve impulses to the brain as a result of detecting and transmitting mechanical vibration through the outer ear, the middle ear and the inner ear.

Question 7

The dose of noise the ear receives depends on the level of noise and the duration of exposure. Short exposure to a high level of noise is considered to cause comparable hearing damage to a long exposure to a lower level of noise.

Question 8

Sensorineural hearing loss (when the hair cells in the cochlea are damaged), in an occupational setting occurs mainly from exposure to excessive noise. Conductive hearing loss (breakdown of the conducting mechanism of the ear from acute acoustic trauma) is a rarer occupational problem.

Question 9

A threshold shift is a reduction in a person's ability to hear, i.e. they need more sound intensity to stimulate their hearing; the condition may be permanent or temporary.

Question 10

- Simple sound level meters (unlikely to be useful for most noise surveys).
- Integrating sound level meters.
- Personal sound exposure meters (dosimeters).
- Octave band analyser (often incorporated into integrating sound level meter).

Question 11

Seek the advice of the competent authority or occupational health service about exposure limits and other standards to be applied.

Seek the advice of the suppliers of processes and equipment about the expected noise emission.

If necessary, arrange for noise measurements to be taken by competent persons to nationally or internationally recognised standards.

Question 12

Reflection, absorption and transmission.

Question 13

Noise reduction at source; attenuation in transmission; control at the receiver.

Question 14

Must be airtight; mounted so that they do not transmit noise and vibrations to the floor; have a heavy noise-reflecting outer skin and a noise-absorbent lining.

Must also have appropriate hatches and doors to allow access to maintenance, etc. May need to be suitably ventilated and lit if entry has to be gained by workers. May need windows or vision panels.

Question 15

A noise enclosure encloses the source of the noise; noise havens enclose the worker from the noise.

Question 16

Ear plugs and ear muffs.

Plugs can be disposable or re-usable types, or custom moulded to fit the ear.

Special types of protector are also available, such as level dependent, flat-response and active noise cancelling and communication protectors.

Learning Outcome 9.12

Question 1

The amount of harm done by exposure to vibration is dependent on the dose of vibration energy received. A given dose of vibration energy, however delivered, will cause an equivalent degree of harm. The dose is determined by the:

- Magnitude of the vibration (RMS acceleration).
- Duration of exposure.

The daily dose of vibration received by a worker can be expressed as the eight-hour energy-equivalent vibration magnitude, or A(8).

Question 2

Hand-arm vibration affects the body through the hands and is caused by vibrating tools or workpieces grasped in the hands. Effects include nerve, muscle and circulatory system damage.

Whole-body vibration, which can be felt when the body is supported on a vibrating surface, e.g. transport employment. Effects are principally back pain.

Question 3

In the early stages, vibration causes slight tingling and numbness in the fingers. With further exposure, the tips of one or more fingers suffer blanching, and with continued exposure blanching will extend to the base of the finger.

When the condition abates, after about an hour, the fingers become flushed, accompanied by considerable pain. There is reduced sensitivity to temperature, pressure and pain, and less manipulative ability.

Question 4

Those working with:

- Percussive metalwork tools.
- Rotary tools and grinders.
- Percussive hammers and drills.
- Chainsaws.

Question 5

Drivers of heavy vehicles; drivers of forklift trucks; operators of heavy machines; aircraft personnel. Exposure is most significant for those operating plant and vehicles over rough terrain.

Question 6

Identify where there is likely to be a significant hand-arm vibration risk - consider which tools and processes expose employees, manufacturer's handbooks, ill-health records; discuss with employees and safety representatives. Next, identify who is at risk. Decide on the level of risk - vibration information from tools and processes identified or from measurements; duration of exposure; comparison with the EAV and ELV (if set by national legislation). Finally, decide what more needs to be done to eliminate or control the risk (including the need for health surveillance).

Question 7

- Use the equations given in the UK's Control of Vibration at Work Regulations.
- Use the vibration exposure calculator available from the UK's HSE website.
- Use the hand-arm vibration exposure ready reckoner available in the guidance to the Regulations or from the UK's HSE website.

Question 8

Elimination at source, followed by reduction of vibration at source using control options, such as:

- Alternative working methods.
- Ergonomically-designed work equipment.
- Provision of auxiliary equipment.
- Appropriate maintenance programmes.
- Design and layout of workplaces, workstations and rest facilities.
- Provision of suitable information and training.
- Limitation of duration and magnitude of exposure.
- Appropriate work schedules and rest periods.
- Provision of PPE.
- No exposure above an exposure limit value.
- Health surveillance.

Learning Outcome 9.13

Question 1

Optical radiation and electromagnetic fields (or radiofrequency).

Question 2

Ultraviolet; visible; infrared; microwave; radiowave.

Question 3

It results from the radioactive decay of certain radioactive substances or radionuclides. Beta radiation is used in many applications, such as medical and biological research and in thickness gauges.

Question 4

Gamma radiation originates in the nucleus of an atom; x-rays originate in the atom's electron layers surrounding the nucleus. Gamma-rays are naturally produced during radioactive decay of radionuclides; x-rays are artificially produced by an x-ray generator (or 'set').

Question 5

- Acute effects, such as sunburn and arc-eye (photokeratitis).
- Chronic effects, such as premature ageing of the skin, skin cancer (melanoma) and cataracts.
- Indirect effects, such as photosensitisation and the formation of toxic contaminants.

Question 6

Biological harm is caused by the process of heating. Certain tissues, such as the lens of the eye, have poor or non-existent blood supplies and a poor capacity for temperature control by heat transfer. It is such tissue which is most at risk from microwave exposure, since only a relatively small temperature increase is needed to damage cell proteins.

To control exposure to microwave radiation, the system should be enclosed in a metal structure; access doors should be introduced by fail-safe means; panels not interlocked should be secured by fasteners that require special tools for their release.

Alternatively, microwave emitters, such as antennae, must be of low power or positioned so that people cannot come close enough to the emitter to receive a significant dose of radiation (above the ELV where set by national legislation). When close approach is required (such as during maintenance work on mobile phone masts), the antenna must be isolated and locked off to prevent accidental power up.

Question 7

The framework or approach for control of exposure to non-ionising radiation:

- Eliminate as far as possible - explore alternative technologies.
- Other working methods that reduce the risk - administrative controls for routine operation, maintenance, etc. (also permits).
- Choose equipment emitting less radiation (depends on work).
- Technical measures to reduce the emission of radiation, e.g. interlocks, shielding, enclosures, screens, etc.
- Maintenance.
- Design, siting and layout of workplaces and workstations - control over direction, stray fields/reflections (by painting surfaces matt black), etc.
- Limit duration and level/intensity of exposure, e.g. time, distance (except lasers where distance doesn't work!).
- PPE, e.g. eye protection.
- Follow manufacturer instructions.
- Signs.

Question 8

(a) Half-life is the time required for one half of a quantity of radionuclide to disintegrate.

(b) Absorbed dose is a measure of energy deposited by the radiation (expressed in a unit called the Gray (Gy)).

(c) The equivalent dose (measured in Sieverts (Sv)) gives a measure of the likely biological damage resulting from radiation exposure, taking into account the type of radiation involved.

Question 9

- Stochastic effects are those that can occur after any level of exposure and are essentially random and unpredictable.
- Non-stochastic effects are those that are dose-dependent and only occur if the dose received is above a certain level, they are therefore predictable.

Question 10

- Alpha radiation: in the nuclear industry, static eliminators and smoke detectors.
- Beta particles: in medical research, thickness gauges.
- X-rays: medical use, security scanning, in chemistry for crystallography.
- Gamma-rays: in industrial radiography (as a form of non-destructive testing), radiotherapy treatment.
- Neutrons: in the nuclear industry, research applications.

Question 11

External radiation, which arises from outside the body, may irradiate skin, tissue or internal organs, depending on the type of radiation and the ability to penetrate the body. Internal radiation stems from radioactive materials deposited in the body by inhalation, ingestion, injection or absorption through the skin, which are continually irradiating internal organs and tissues from within.

Question 12

- Time - by reducing the time for a particular dose rate, the accumulated dose is reduced.
- Distance - the intensity of all radiation is reduced by the distance travelled.
- Shielding - the absorption of radiation energy by interaction with a dense medium.

Learning Outcome 9.14

Question 1

WRULD stands for 'work-related upper limb disorder' and refers to ill health conditions affecting the upper limbs, particularly the soft connecting tissues, muscles and nerves of the hand, wrist, arm and shoulder.

WRULDs arise from the repetition of ordinary movements (such as gripping, twisting, reaching or moving), often in a forceful and awkward manner, without sufficient rest or recovery time.

Question 2

Back injury and back pain; tendon and ligament injuries; muscle injuries; hernias; WRULDs; cuts, burns and broken bones.

Question 3

- The ergonomic design of tools, equipment and workplaces.
- Job rotation.
- Adjusting the work routine.
- Training.

Question 4

- Providing regular breaks.
- Job or task rotation.
- Assigning a second worker to perform particular tasks.
- Enlarging job responsibilities to avoid repetition.
- Limiting overtime.

Question 5

- Weight.
- Size.
- Shape.
- Resistance to movement.
- Rigidity or lack of it.
- Position of its centre of gravity.
- Presence or absence of handles.
- Surface texture.
- Stability of any contents.
- The contents themselves.

Question 6

- Space constraints on movement and posture.
- Conditions of floors and other surfaces.
- Variations in levels.
- Temperature and humidity.
- Strong air movements.
- Lighting conditions.

Question 7

The elimination of risk by the use of automation or mechanisation.

Question 8

- Sequencing - adjusting the sequence of tasks in a process to minimise the number of operations involving lifting and carrying loads.
- Work routine - reducing repetitive operations to allow variation in movement and posture, by such means as introducing breaks, job rotation and providing ways in which workers can operate more at their own pace, rather than the work being conditioned by a continuous supply of materials to be handled.
- Using teams - sharing the load by using teams of workers to carry out the task.

Learning Outcome 9.15

Question 1

Radiation; evaporative cooling; convection and conduction.

Question 2

Relative humidity is an expression of the ratio of water vapour in air relative to the maximum concentration of water vapour that would be required to saturate air at the given temperature.

Question 3

For the dry bulb air temperature, the sensing head is protected from radiant heat exchange by placing a polished silver or aluminium shield around it. The wet bulb air temperature is obtained with the sensing head covered with a muslin sock wetted with distilled water and protected from radiant heat.

Question 4

- Circulation of air and ventilation.
- Workplace design.
- Work organisation.
- PPE.
- Health surveillance.
- Information, instruction, training.
- Supervision.

Question 5

There are two main requirements that relate specifically to special clothing:

- Changing facilities - suitable and sufficient facilities shall be provided to change the clothing. Separate facilities must be provided for men and women. They should be provided with seating and should ensure the privacy of the user.
- Storage facilities - suitable and sufficient accommodation for clothing. This is for clothing which is not worn during working hours and special clothing which is worn for work but not taken home.

This study text provides learners with all the information they need to successfully complete Unit ID2: Do - Controlling Workplace Health Issues (INT) of the International Diploma for Occupational Health and Safety Management Professionals.

Written by health and safety experts in collaboration with education professionals, it follows the structure and content of the NEBOSH syllabus. Each section covers in full the Learning Objectives required by the syllabus, using plain language and practical examples to reinforce understanding.

This study text is updated regularly to reflect changes to legislation, syllabus amendments, and reviewing learner performance in the NEBOSH examination.

See www.rrc.co.uk/news-resources/newsletters for the latest updates.

RRC International
27-37 St George's Road
London SW19 4DS
United Kingdom
www.rrc.co.uk

9 781912 652433 >