Guidelines on the Monitoring of Hazards in the Microelectronics Industry

Compiled on behalf of the Microelectronics Semiconductor Manufacturing Joint Working Group

The Publishers

NMI is the Trade Association for the Semiconductor, Microelectronic and Electronics Systems Community in the UK & Ireland. Please refer to www.nmi.org.uk for further information.

NMI provides a focal point for the industry and, in this capacity is providing support to the Working Group of EHS Professionals from the industry.

Microelectronics Semiconductor Manufacturing Joint Working Group

The Microelectronics Semiconductor Manufacturing Joint Working Group consists of representatives from manufacturers of semiconductors, equipment suppliers, trades unions, and the Health and Safety Executive. The group was set up on an informal basis in 1985, with the general objectives of providing a forum for the discussion of health and safety issues affecting the industry, and publishing guidance where appropriate.

These Guidelines have been compiled from the best sources of information known to the drafting committee at the date of publication. They are written in good faith and belief in their accuracy. The Guidelines are intended for use by technically competent persons and their use does not therefore, remove the need for technical and managerial judgement when applying them in practical situations and with due regard to local requirements including by-laws.

For the assistance of users, references are given, either in the text or Appendices to sources of information on guidance documents, Codes of Practice and current legislation relevant at the time of publication that may be applicable. These Guidelines should be read and used in the context of these references when the subjects have bearing on the local application of the processes or operations carried out by the user.

Monitoring of Hazards in the Microelectronics Industry

1. Introduction

These guidelines have been prepared at the request of the 'Microelectronics Semiconductor Manufacturing Joint Working Group' by representatives of the Joint Working Group.

There are many potential hazards in the Microelectronics Industry and appropriate actions are required to minimise risk to the health and safety of employees and other persons, as well as risk to the integrity of the establishments involved and to the environment. One such action concerns monitoring of the work place and guidelines in this document reflect the best advice on this matter available at the time of compilation.

This document has been prepared in the United Kingdom and reference is to United Kingdom legislative and guidance documents. However, the principles involved could be applied elsewhere.

2. Purpose and Scope of Monitoring

The term monitoring can be used to cover a range of activities namely:

Measurement of the degree of or potential for exposure of personnel to substances hazardous to health as set out in Regulation 10 of the Control of Substances Hazardous to Health Regulations (COSHH).

(a) Similar monitoring of exposure to physical hazards, e.g. ionising and non-ionising radiation.

(b) Preliminary collection of data to help set up appropriate control measures prior to establishing any long-term arrangements.

(c) Checks on control measures and procedures themselves, e.g. measurement of local exhaust ventilation airflow and regular reviews of safety procedures.

For this document, as the title implies, emphasis is on the long term direct monitoring of hazards, i.e. category (a) and (b) above. Guidance on the other types of monitoring is provided, however. Monitoring of effluents or atmospheric emissions is not dealt with in depth although attention is drawn to the need for action on both of these issues.

2.1 HAZARDS IN THE MICROELECTRONICS INDUSTRY

2.1.1 Chemical Hazards

Many of the chemicals used in the Microelectronics Industry can be injurious to the person to some degree. Exposure to hazardous materials may arise by inhalation of airborne matter such as vapours and dusts, by direct contact or by ingestion. The Control of Substances Hazardous to Health Regulations set out measures to prevent or adequately control exposure to these materials. Other materials may have properties, which can indirectly lead to harm. These include materials that are flammable, explosive, or pyrophoric. Regulations apply which control the use and handling of these materials, e.g. The Dangerous Substances and Explosive Atmospheres Regulations.

Suitable design, engineering, and maintenance of the facilities to minimise the risk of release of materials are usually the main control measures. When a hazard is airborne (whether gas, vapour, mist, fume or dust), monitoring of the atmospheric concentrations by instrumental techniques can evaluate the presence or extent of the hazard, or provide assurance of a controlled condition.

Hazards from solids and liquids (e.g. toxicity, chemical burns. flammability) must be handled differently by establishing and following correct procedures and by regular examinations for surface contamination that could lead to exposure.

2.1.2 Physical Hazards

The high technology called for in the Microelectronics Industry brings with it a range of physical as well as chemical hazards. Ionising and non-ionising radiation are examples of hazards, which could be harmful to health unless essential engineering and operational control measures are put in place and used effectively. Monitoring is then required to ensure that actual exposure to these hazards is negligible' or maintained within safe levels.

Noise and vibration are measurable, and quantitative monitoring may be required as part of health risk assessment procedures. A work area may be subjectively noisy, but competent measurement is required to assess any physical harm that may arise from long-term exposure to noise. The levels observed will determine what engineering or other controls are necessary. The possibility should be recognised that noise may be below levels requiring action under The Control of Noise At Work Regulations, but may still affect efficiency and safety in the working environment if it is irritating or distracting.

In any work area, where machinery and equipment are used, mechanical hazards should not be ignored. The risk of physical injury from the handling (or mis-handling) of heavy objects, the trapping or crushing of limbs by moving parts, cuts arising from sharp edges, is minimised by proper engineering, proper working procedures and appropriate training. Monitoring may play its role in insuring that the required standards of accident prevention are maintained.

2.1.3 Biological Hazards

Legionella - Most manufacturing facilities use water systems, which are liable to colonisation by hazardous micro-organisms. Where these problems may exist, the COSHH Regulations require a risk assessment to be carried out and appropriately control measures adopted. Cooling Towers, evaporative condensers, calorifiers, humidifiers, hot and cold water supplies all need to be considered. In the case of the bacterium Legionella Pneumophila, its prevalence means that any water system operating between 20^oC and $45\,^oC$ is suspect, prevalence means that an and is likely to require preventive measures to prevent bacteria multiplying. The risk of infection is increased if bacteria can be transmitted in water droplets, hence the emphasis on cooling tower maintenance. Guidance can be obtained from HS(G) L8 The control of Legionella bacteria in water systems.

2.1.4 Indoor Air Quality

Indoor air quality problems may give rise to so-called "sick building syndrome". The cause of these problems may be attributed to inadequate ventilation, chemical contamination from internal or external sources, and microbiological contamination. The elimination of these problems is beyond the scope of this document, but identification and investigation of this scenario is likely to require systematic occupational hygiene monitoring techniques.

2.1.5 Engineering Control Measures

Where a potential hazard cannot be eliminated or completely isolated, engineering control may become necessary. Given an initial good design of the engineering control, monitoring may then need to be introduced to ensure the continuing effectiveness of control measures. Following commissioning and achievement of the design specification, relevant parameters of the system should be recorded to provide standard performance data for future reference.

All plant deteriorates with time unless adequately maintained. For such maintenance, points to consider are:

a) Frequency of maintenance - this varies for different components.

b) The tasks to be undertaken and the information to make them possible.

c) The Measures required ensuring safety during the work, and the return to normal

d) Staff responsibilities and competence for the tasks involved.

These procedures should cover the full range of maintenance activities from simple visual checks for obvious defects, to major overhauls for preventative and remedial purposes.

2.1.6 Procedural control measures

These need to be established initially and should be kept under review. Such review may be undertaken on the basis of day-to-day experience but this should be supplemented by periodic audit. It is suggested that a more objective audit may result if carried out by people not directly concerned with the operations.

2.1.7 Administrative control measures

These include factors such as nomination of responsible persons and formal authorisations, such as permits to work etc. As with procedural controls, there is a need to ensure that systems once set up remain appropriate and, where needed, changes brought about. Particular attention may be required in relation to staff changes, which affect responsibilities for safety measures. An overview of all control measures through Quality Assurance audit procedures is to be recommended.

2.2 STATUTORY COMPLIANCE

2.2.1 Control of Substances Hazardous to Health (COSHH) Regulations

Under Regulation 10 of the COSHH Regulations, monitoring of the workplace is a requirement where it is needed to ensure adequate control of exposure to substance hazardous to health or to otherwise protect their health. Specific monitoring: requirements as set in Schedule 5 of the Regulations are imposed for vinyl chloride monomer and for processes involving electrolytic chromium (except trivalent chromium).

If monitoring is carried out it must be suitably recorded and the records retained for at least 40 years if the records are representative of the personal exposure of identifiable employees to the health hazard. Otherwise they must be kept for at least five years.

Where monitoring is considered necessary, it should be carried out at least every 12 months (unless monitoring is specified in Schedule 5 of the Regulations.

Monitoring may be necessary to ensure that prescribed occupational exposure limits are not exceeded. Certain substances have been designated to have a Workplace Exposure Limit (WEL). A WEL is defined as the exposure limit approved by the Health & Safety Commission for that substance in relation to a specified reference period when calculated by a method approved by the Health & Safety Commission as contained in the publication EH40, Workplace Exposure Limits.
WEL's are listed in table 1 of EH40 and include substances for which

a) there is scientific evidence that there is likely to be no injurious effect if the employee is exposed day after day to that concentration or less,

b) exposures above that concentration for a reasonable period are unlikely to produce serious effects, and

c) achieving the WEL is reasonably practicable.

As far as inhalation of that substance is concerned, if the WEL is not exceeded, then control of exposure, as required by Regulation 7 is only considered adequate providing employers have abided by the principles of good practice for the control of exposure to substances hazardous to health set out in Schedule 2A of the Regulations .

Note that other countries will have their own equivalent of WELs. For example the Threshold Limit Value (TLV) tabulated ACGIH or Permitted Exposure Levels determined by the Occupational Safety and Health Administration in the United States of America, and the MAK in Germany.

2.2.2 Management of Health and Safety at Work Regulations

Regulation 3 requires risk assessment to identify measures to comply with duties under the Health and Safety at Work, etc. Act and associated legislation.

Regulation 4 then requires Health and Safety arrangements to be made which may include monitoring of the appropriate preventive and protective measures arising from the risk assessment. Monitoring to determine the effectiveness of the measures and suitable review should then lead to progressive improvement and refinement of risk control.

Regulation 5 requires the employee to ensure the provision of adequate health surveillance. This may include measurement and assessment of the biological effects of exposure to the hazard, and measurement of concentration of substances and their derivatives in body fluids and tissues, as well as clinical examination by a medical practitioner. These types of biological monitoring are dealt with later (Section 7.1).

3. Fixed Monitoring Systems

Fixed Monitoring involves the use of simple or multi-point equipment, which may be connected to one or more fixed detector units to enable measurements at different locations to be made continuously or sequentially. The method is directed towards the monitoring plant facilities for containment and control rather than towards providing a measure of personal exposure.

It is strongly recommended that fixed continuous monitoring be used where toxic gases are deployed and appropriate equipment is available. For the purposes of this document, a toxic gas is defined as any gas or mixture of gases which contains any substance which has a limit or Workplace exposure Limit (given in Guidance Note EH 40, The monitoring system should incorporate an active alarm system (see section 3.2) which will cut off the gas at source in the event a pre-set alarm levels being exceeded.

Fixed monitoring equipment should also be considered where toxic gases or chemicals are used if the risk of exposure of personnel or the risk to the facility is assessed as high. The selection of species to monitor depends on the risk assessment. Monitoring of dusts in this way is difficult and is not normally attempted.

3.1 FLAMMABLE GASES OR VAPOURS

The use of fixed continuous monitoring is strongly recommended in enclosed areas where flammable gases are deployed or there is a risk of producing flammable vapours. Such use may be required by some insurance companies for areas where hydrogen is used, e.g. in diffusion furnaces.

Advice on the selection and use of flammable gas detectors is given in HSE Guidance Note CS1 11/04 Industrial Use of Flammable Gas Detectors. It should be noted that most detectors for flammable gases or vapour require at least 10% of oxygen to function. These detectors usually operate in the range 0-100% of the Lower Flammability Limit (LFL), but it is not normally practicable to set alarm levels below 10% of the LFL.

Monitors for- flammable gases of vapours detect the presence of the flammable material itself not the combustion products. Hence these monitors will not detect gas or vapour if this has ignited. Detection of burning gas or vapour requires the use of UV or IR sensors.

3.2 EQUIPMENT CRITERIA

A fixed monitoring system monitoring a potentially hazardous situation can give either a passive or an active response when a particular pre-determined level is exceeded, as might result from a gas leak. Passive alarms give audible and/or visual warnings that require further action to remove the cause. They are acceptable if there is no immediate threat of personal injury and there are procedures for rectification of the defect before immediate danger is likely to arise. Active alarms provide automatic shutdown of hazard at source and may also initiate a mandatory evacuation procedure. These are appropriate where a foreseeable risk of personal injury is present.

For gas mixtures presenting more than one risk (e.g. the toxic gas arsine in flammable hydrogen) the suppliers both of the gases and the detector should be consulted to determine the correct type of 'monitor and the correct location for the detection units. Under such circumstances it is preferable to monitor for the greater hazard or for both components.

3.2.1 Reliability and absence of nuisance alarms

Fixed systems are provided to monitor the safety of conditions in an area where there is a defined hazard, and as such it is important that they should be more reliable than the equipment etc. that they are monitoring. Any nuisance alarm or system failure can be costly, and if either occurs frequently it will generate a mistrust of the system and the temptation to ignore or suppress alarms with the assumption that no danger is present. A further requirement of monitoring systems is that if they do fail, this activates a warning, i.e. they must fail-safe.

There are other points which must be considered and which apply to both preliminary and to long term monitoring. Methods chosen for monitoring, and the strategy employed in using them, must serve the intended purpose. Additionally, attention must be given to the frequency of monitoring operations, and the sensitivity, selectivity, accuracy, reproducibility, and speed of response of measurement techniques. Data output may be recorded manually, however the majority of fixed systems now have the ability to record real time readings and transfer these automatically to a database for traceability and fault finding analysis. Similarly, testing and calibration can be manual, but for long-term use these are preferably built-in to the system and the results transferred automatically to a database.

3.2.2 Factors affecting the choice of toxic gas monitoring equipment

The following characteristics should be considered in detail when selecting a monitoring instrument or system.

(a) Sensitivity

Any gas monitor should have a Lower Detectable Limit (LDL) of better than 0.25 x WEL of the gas being detected and preferably an LDL less than 0.1x WEL. This is important when multi-point systems are being used and several lines are being monitored simultaneously.

(b) Selectivity

Ideally the monitor or monitoring system should be chosen such that it responds only to the gas or gases for which it is set to monitor. Most instruments, however, will respond to some other gases apart from those they are monitoring. It is, therefore, essential before deciding on a monitoring system to determine what other gases may be present during monitoring, at what concentration levels, and whether these could lead to false alarms or to incorrect responses.

(c) Accuracy and Reproducibility

The absolute accuracy of an instrument or system should be checked but it is more important that the reproducibility is good over short and long time scales. Accuracy of between 5 to 20% is acceptable.

(d) Response times

Response time should be as fast as possible to ensure the earliest possible warning of a gas leakage. Where sampling systems are being used, it is also important to check the overall response time of the system, including the lapsed time between sample taking and analysis. Response time may be dictated by the sensitivity required; generally, the lower the concentration of the gas being measured the slower the response time.

(e) Output Capabilities

This very much depends on the monitor and the application. Most portable or mains operated single point monitors do incorporate all of these facilities eg: digital display, 4 to 20 mA outputs and alarm relays. More sophisticated instruments are available with built-in data logging and /or data handling outputs. Multi-point systems may be permanently linked to a dedicated data storage and handling system, which may be a personal computer with appropriate software to store and report data in a suitable format.

(f) Calibration and Testing

Other important factors when selection is made. Generally the act of calibration also tests the system; however, it should be possible to test systems for electronic failures, separate to calibration. Calibration often involves the generation of toxic gas mixtures and great care must be taken with regards to the accuracy of the mixture. There are instruments and systems available where, in the absence of interfering species, no gas testing is required and calibration is with an optical stain card, which is related back to a primary standard.

(g) Cost, Consumables and Maintenance

The cost of ownership on any instrument or system should be taken into account over a period of years. The highest cost can often be maintenance, particularly if the system is unreliable. In this context it is essential to ensure that any supplier of monitoring equipment can react quickly with regards to both spare parts and availability of personnel if a monitoring system goes down. The cost of false alarms or of shutting down a plant in the most extreme case can outweigh maintenance costs.

(h) Alternative Power Supplies (UPSs)

For permanent installations it is recommended that some provision is made for alternative power supplies if the equipment does not have an in-built stand-by arrangement.

3.2.3 Summary

A good long term monitoring system should incorporate the following:

- The confirmation of adequate and efficient controls.
- Fast warning of unplanned events.
- Trend indications to signal requirements for preventive maintenance.

3.3 GAS DETECTION SYSTEMS

The rapid detection of an emission event such as a leak caused by component failure is essential to properly manage gas hazards. The response/analysis is dependent on the type of gas, its concentration and the sensitivity of the detector system. Normally the response becomes slower as the concentration decreases. Where multipoint analysers are in use the response time may be dominated by the cycle time or the time taken for samples to travel through piping to the detector

3.3.1 Detection Techniques

The techniques used for gas detection are summarised in Appendix 1. These include electrochemical cells, semiconductor devices, paper tape, catalytic reaction; Infra-red spectroscopy, mass spectrometry, flame emission spectroscopy, photoionisation, and detector tubes, Each has their different applications, as set out in the appendix.

3.3.2 Monitoring Requirements

It has been found useful in working areas to have two pre-selectable alarm limits for toxic and highly toxic gases:

(a) Lower or early warning limit. 'Set to operate at a maximum of 1.0 times the Workplace Exposure Limit (WEL).

(b) Evacuation or automatic shut down limit. Set to operate at a maximum of 2.0 times the WEL.

Where flammable or explosive gases are being monitored, alarm levels are recommended to be set at a maximum of 10% of the Lower Explosive Limit for warning limits, and at 20% LEL for the evacuation and shut down alarm.

3.3.3 Planning and Installation

Careful consideration must be given to the deployment of multipoint continuous monitoring Instruments. Vulnerable areas, such as gas cabinets or gas manifolds will require a more frequent monitoring cycle.

The following considerations should be borne in mind when installing or running a continuous automatic static monitoring system (these are in line with the general guidance given in section

(a) Continuous monitoring systems should provide both-audible and visible alarms. Provision should be made so that unauthorised persons cannot shut off these alarms.

(b) Where practical, alarms should be linked to automatic process gas shut-off.

(c) Instruments should be capable of responding specifically to the gas being sampled and should be subject to minimal interference from other chemicals including resistance to poisoning by other chemicals that could be present in the area.

(d) Systems must be capable of providing a retrievable record of events, e.g. date, time, sample point, concentration. These records should be kept for a minimum of five years where there are people operating in the work area.

(e) Where appropriate equipment is available the detector system should fail to safety, i.e. if the detector breaks down a fault alarm should activate. The system should provide both audio and visual alarms to warn personnel so that appropriate emergency/corrective action can be taken prior to a dangerous situation being reached.

(f) For each instrument there must be introduced both regular calibration and maintenance in accordance with the manufacturer's instructions. A record is to be kept of such calibrations and maintenance for a minimum period of 5 years to assist in interpreting exposure data and in diagnosing regular faults.

(g) Maintenance of monitoring systems should be based on risk assessment and manufacturers recommendations. This may vary from site to site however techniques may include the use of a permit to-work system and providing alternative arrangements for monitoring during the maintenance period. Similar provision for back-up arrangements should be made where a detector or other equipment breaks down.

(h) Consideration should be given to provision of battery/generator backup in case of general power failure. This will assist in determining hazard areas during the emergency.

(i) The monitoring system should be designed to avoid nuisance alarms. If nuisance alarms tend to occur then every effort should be made to suppress them. Frequent nuisance alarms are wasteful and generate a mistrust of the monitoring equipment, which could lead to an alarm being ignored in a real hazard situation.

(j) Before re-entering an area which has been evacuated on account of a toxic or flammable hazard warning, tests shall be conducted to confirm that it is safe to do so. Also, the monitoring system should be checked to determine whether it is still in operation.

3.4 MONITORING POINT LOCATION

Where a fixed monitoring system for hazardous gases is employed, sample probes may be situated at the following positions:

3.4.1 In Gas Cylinder Cabinets and Valve Manifold Boxes

The most satisfactory site is normally in the entry to the extract duct. - This is usually at the top of the cabinet but for gases very much denser than air location at the bottom should be considered. Because of the dilution effect of the high air flow rate, small leaks may not be detected and auxiliary tests with a hand held instrument are advised when access is required to the cabinet, for example when changing a gas cylinder.

3.4.2 In Gas Supply Areas

In close proximity to vulnerable areas such as gas cylinder connection points and pigtails. Exact location will depend upon the density of the gas/vapour and air movement within the room. The use of smoke tubes will assist in determining air movement and sample point location.

3.4.3 At Gas Point of Use.

Monitoring should be considered at user points in fabrication areas with a view to protecting both personnel and equipment. Consideration should also be given to sighting monitoring probes at user points in fabrication areas, and in the principal working areas where highly toxic gases are used or handled. The same positions should be used where monitoring for other toxic gases is deemed necessary. Separate, but similar, considerations should be given to positioning of sample probes where flammable gases or process chemicals are used or stored.

3.4.3.1 Monitoring of "Ballroom" Style Clean Rooms

Recent Clean Room design has produced open plan areas, with no partitioning or service chases. This makes locating of sensors more difficult. In order to effect the best detection strategies, the following should be borne in mind:

- Direction of Airflow
- Effects of equipment location
- Vapour air density of gas table monitored
- Normal operator positions
- Locations of gas lines into tool
- Tool maintenance areas.

To provide room area/working environment monitoring as opposed to equipment monitoring, looking at the above and adapting systems as necessary is essential. Generally attaching sensors or sample lines to the tool itself is the best policy for good coverage.

3.5 SYSTEM INTEGRATION

In order to achieve greater control and information gathering, the integration of fixed monitoring systems is desirable. Systems can be integrated in a number of ways:

(a) Via digital input/outputs into computer packages by the use of relays or switched contacts. This gives fairly limited information and generally means a "Yes' or "No" signal.

(b) Via analogue signals into a computer. These signals are generally 4 to 20 mA current signals or-0-5V/Q-lV voltage signals input to an A/D converter and then fed to the computer. This gives a good deal of information on the status of all devices so connected, but is unidirectional. That is, the computer can only receive the data.

(c) Via Bus or Highway digital communications into a computer. These signals can be from a multitude of formats (FieldBus, MODBus, ProfiBus, LONworks. etc.). The data is taken into the computer and signals can be returned to the device to perform relevant actions.

There are numerous software and control packages available, often designed for system management. The type chosen will reflect the needs of the user. For example, alarm inputs from monitoring devices within a semiconductor processing facility can be displayed on mimic diagrams on the computer monitor to show their location. Accumulated data from these devices can be displayed graphically as trend plots. Self-test and calibration procedures for each monitoring system can be included. Consideration should be given to the following when selecting the package:

(a) The number of inputs the system can accept.

(b) The types of interfaces available.

(c) The graphics capability

(d) The speed of the system when fully loaded

(e) Bi-directional communication

(f) Ease of use, user friendliness and ease of upgrade

The use of data management software in system integration *is* becoming increasingly widespread in the Microelectronics Industry. - Fully integrated systems are often referred to as "Life Safety Systems", and generally combine Gas Monitoring, Gas Cabinet/VMB Control, Fire Detection Alarm Sounders, Alarm Beacons and Evacuation Systems.

3.6 FAIL-SAFE CONSIDERATIONS

In an integrated system, each monitoring device should be independently capable of carrying out its designed safety function. (For example, if a gas-monitoring device is intended to cut off gas supply at source in the event of an alarm level being detected, it should do so whether or not the system is operational).

In the interests of safety, consideration can also be given to the use of Programmable Logic Controllers (PLCs) as part of the network. PLCs can be operated with a second hot CPU to provide failsafe operation. Also, PLCs work on sequences of instructions, so programming faults can be found more easily.

4. Other Monitoring Of Airborne Hazards

Other regimes may be used for the monitoring of airborne hazards and can be applied to gases, vapour, particulates and noise. Direct instrumental techniques are available in some cases and are frequently applied. Monitoring may involve a choice of techniques for collection and subsequent analysis of the collected material. The Code of Practice CP18 "The Safe Storage, Handling and Use of Gases in the Microelectronics Industry" gives information on control measures appropriate to the use of compressed gases and relates closely to the present document. For particulates, monitoring usually involves filtration with subsequent analysis of the collected material.

The HSE publication HS(G) 173 "Monitoring Strategies for Toxic Substances" gives further useful information.

4.1 SHORT TERM OR GRAB SAMPLES

Short term or "grab" samples are used for checking local situations or operations for toxicity flammability, asphyxiation or nuisance hazards.

Short term or grab samples are samples collected over a few seconds up to a few minutes. Measurement methods include suitable gas or vapour indicator tubes operated by a hand bellows or battery operated pump. A number of portable battery operated instruments are available which provide a visual indication of emission level and/or pre-set limit.

This type of monitoring is used to detect leakage and point source emissions e.g. gas container connections, or as a preliminary check on the effectiveness of engineering controls, or before commencing maintenance operations where accumulations of toxic gases and chemical vapours exist. Short term monitoring by itself is not appropriate for measuring compliance with occupational exposure limits, although it may assist with the assessment of the risk. In general, point source samples are not likely to be affected by interference from other gases.

Short-term samples can be used in the following instances:

(a) At each gas container cap, when delivery is made to the manufacturing facility.

(b) Suitable and appropriate monitoring checks should also be made whenever a container is connected to or disconnected from a supply system, or a supply is connected to process

(c) During fixed monitoring systems maintenance as a back up to check that engineering controls are working properly.

(d) When highly toxic gas lines are being pressurised. Helium leak checking procedures will give a good indication of the tightness of the gas lines but short-term samples will support the effectiveness of this technique.

(e) In the workplace, to check that engineering and operational controls are functioning correctly.

4.2 PERSONAL MONITORING

This monitoring method implies direct measurement of the exposure of a person to a toxic substance using a monitoring device worn by the person, usually near the breathing zone. A number of different personal monitoring techniques exists which need to be carefully selected.

Monitoring techniques include the use of long-term gas or vapour indicator tubes, adsorption tubes, bubblers or filters through which an air flow is drawn by a battery operated pump, and small direct reading instruments. Diffusion monitoring techniques are available for some substances and do not require the use of personal sampling pumps.

Personal monitoring may be used as a back-up during maintenance operations. For example, the out gassing of arsine or phosphine or formation of arsenic particulate from vacuum pumps or reactor walls where these materials have been used. Normal maintenance procedures should take account of these possibilities, but a personal monitor incorporating a pre-set alarm may be used to highlight unforeseen dangers.

However, personal monitoring is invaluable to provide information on employee exposure and as a controller instrument monitoring systems. Where personal monitoring is undertaken records must be kept for a period of 40 years

4.3 EXPOSURE MONITORING

Although many operating procedures in Semiconductor Fabrication are associated with minimal or negligible personal exposure to chemical agents and other hazards, these procedures, like any other control measures will require a degree of monitoring. A planned strategy for personal exposure monitoring for specific hazards by a competent Occupational

Hygienist is recommended. Periodic studies of exposure to solvent vapours during photolithography will confirm that exposures are adequately controlled and provide operators with reassurance of a safe working environment.

4.4 SURFACE CONTAMINATION

Monitoring for surface contaminants is appropriate in the event of suspected surface contaminants which are of low volatility but which may be absorbed through skin contact or accidental ingestion. Hence it is of relevance to solids and liquids of low volatility.

It is difficult to be quantitative in an absolute sense, and local procedures must be standardised as far as possible to provide data, which are comparable from one sampling to another. Direct wiping (with or without a fluid to assist collection) is usual.

An alternative approach is to leave defined specimen surfaces (e.g. filter papers or glass slides) in fixed positions where they will not be disturbed but will collect contamination in a representative manner. All samples need to be chemically analysed to determine the extent of the surface contamination. Methods for sampling and analysis are described in the HSE series Methods for the Determination of Hazardous Substances (MDHS).

4.5 ASPHYXIANT CONDITIONS

Confined spaces, such as storage tanks and underground service chases, may be areas where there is a low concentration of oxygen due to displacement of air by other gases. Safety procedures (such as permits to work following a check on the space) are essential to minimise the risk to employees. Advice is given in HSE Guidance Note INDG258 Safe Work in Confined Spaces. Under the Confined Spaces Regulations work in confined spaces should be avoided, but where it necessary, a safe system of work is required with adequate measures for rescue in emergency.

Instruments are available to sample the air for the concentration of oxygen and presence of other chemical compounds. A check must be made before personnel enter such an area, or compressed air or other air-supply breathing equipment must be worn. For extended working without air-supply breathing equipment continuous or frequent monitoring should be used. Portable or belt worn monitoring units are available for this purpose.

Asphyxiant conditions may arise in a work area as a result of the release of asphyxiant gases or cryogenic liquids in sufficient quantity to displace air and hence reduce the oxygen concentration. Liquid Nitrogen, for example, expands to several hundred times its volume on reaching temperatures approaching ambient. In a small room with limited ventilation, a few litres per minute of liquid nitrogen evaporating into the room can quickly reduce the oxygen content to dangerous levels. The hazardous nature of the leakage may not be fully appreciated by the occupants until it is too late, as little physiological alarm warning is given in these conditions. Continuous monitoring equipment can be used to warn of any significant reduction in oxygen content, and should be installed where a risk assessment indicates the possibility of oxygen levels being reduced to 18% or lower.

4.6 EMERGENCY RESPONSE MONITORING

Following an incident response, it should be borne in mind that, dependent upon the type of incident that has occurred, there will be a need to monitor the work area environment and work area surfaces in order to ascertain whether or not it is safe for employees to return to their workstations.
Work area environment would be checked using the 'grab sample' techniques referred to in section 4.1.
It may not be sufficient to rely on the in-house monitoring systems for a post-incident check as the sensors may not be positioned in a representative position adjacent to the incident area. Therefore portable monitoring equipment will be essential in order to carry out monitoring at the operator positions in the incident area.

It must also be noted that vapours emanating from an incident may not just be the results of a gas leak or equipment breakdown, but may be the results of interactions with other materials or chemical substances, or liquids in the incident zone. Risk analysis data of the possibility of such interactions should be available from relevant COSHH studies appropriate to the operation being carried out. Any unusual by-products should then signal the requirement for appropriate detection equipment in the event of a emergency.

Surface contamination is almost certainly a post-incident by-product. Section 4.4 highlights the necessity for appropriate monitoring and this should be applied bearing in mind that the surface contamination from reaction by-products may be just as hazardous as the original product.

Whilst not strictly under the heading of 'Monitoring of Hazards' it is most important that an essential part of emergency response is the regular monitoring of Emergency Response Equipment, status and serviceability. This not only applies to safety gear that is worn - there are other Regulations which cover that aspect - but also applies to the availability of monitoring equipment which is 'in date' i.e. batteries charged or replenished, sensors within expiry date, etc. Check sheets should be generated which highlight those items, which need to be regularly maintained and serviced.

5. Fire Alarm Detection

It is not the intention of this document to cover monitoring for fire detection as this is not something which is specific to the microelectronics industry.

Many standards and guidelines exist which cover this in great detail, an example of some of them are outlined below :

- NFPA 318 Standard for the Protection of Cleanrooms
- FM Global Property Loss Prevention Data Sheet 7-7
- BS5839 Fire Detection and Fire Alarm Systems for Buildings

6. Monitoring of Other Hazards

To maintain the safe operation of a microelectronics semiconductor facility, monitoring of hazards other than chemical must also be considered.

The physical hazards that may be include ionising and non-ionising radiation, noise and vibration, mechanical, and electrical, as well as the human environmental factors such as lighting, heating and ergonomics.

6.1 IONISING RADIATION

Ionising radiations, which include X-rays, gamma-rays, and beta-rays, are known to cause harm to people. Such radiation is generated by certain equipment used in the industry e.g. beta backscatter gauges, radiography units, scanning electron microscopes, static elimination devices, and ion implantation units.
There is detailed legislation and attendant guidance on the control measures to be used with ionising radiation. The items of general relevance are:-

- The Ionising Radiations Regulations
- The Approved Code of Practice "The protection of persons against ionising radiation arising from any work activity (ACOP5)."

The generation of X-rays in ion implanters is normally sufficiently contained that the work area is not classified under the Ionising Radiations Regulations. However routing checks, especially after maintenance procedures involving the beam line, are essential to ensure that the re-assembly of the relevant shielding has been properly carried out. Under normal circumstances it should not be possible to generate an ion beam without all safety interlocks in place and functioning properly. Built-in shielding should also ensure that radiation from beam-line components is sufficiently contained. Measurements must be carried out using properly calibrated dose-rate meters after maintenance and before the implanter is release back into normal service. Each check must be logged in an appropriate record sheet and the results kept for two years.

Where radioactive sources of radiation are used, as opposed to radiation from an X-ray generator, the Environmental Permitting Regulations 2010 (as amended) Section 23 also applies. All such sources must be registered with the relevant enforcing authority eg : EA, SEPA. All holding & disposal of such sources must also be done in conjunction with these authorities

In the microelectronics industry there is an almost complete reliance on controlling hazards by shielding, usually containment with interlocks. Control of exposure by use of distance or limitation of received dose although possible should not be necessary in this industry.

By adopting full shielding (containment), classifying workers involved is unnecessary.

Requirements for instrumental and other checks on radiation levels are set out in the relevant regulations. Checks can relate to general or background levels, to localised beams, or to individual exposures (film badges). Adoption of a containment policy reduces but does not entirely eliminate the need for monitoring and for alarm arrangements to warn of high levels should they occur.

6.2 NON-IONISING RADIATIONS

Ultraviolet (UV), visible, infra-red (IR), radio frequency and microwave radiations can each be harmful if the intensity is sufficient. Containment of the radiation is the main control.

Monitoring by carrying out regular instrumental checks on intensities are advised where it is not possible to contain the radiation fully and the source intensity is sufficient to pose a risk if exposure occurs.
Further information is given in the HSE publication “Guidance for Employers on the Control of Artificial Optical Radiation at Work Regulations (AOR) 2010” and the National Register of Rf Workers

6.3 NOISE AND VIBRATION

High levels of either can constitute a direct hazard, particularly in confined work spaces, and they can also be irritating and hence be a cause of accidents. The aim should be to reduce noise levels by engineering means or by use of different equipment which avoids the problem. In some cases enclosure of the source May be necessary. Information is given in the

HSE guidance document associated with the Control of Noise at Work Regulations for reducing the exposure of persons to noise.

Measurements of intensity of sound and vibration should be undertaken to ensure that safe levels are set and maintained. To be effective these measurements should be carried out and interpreted by a suitably qualified and skilled person.
Further information is given in the HSE publication “The Control of Vibration at Work Regulations”

6.4 WORKPLACE ENVIRONMENT

Included in this category are poor ventilation and lighting, high or low working humidity and temperatures, and un-ergonomic working arrangements. These may not in themselves be direct hazards but they can all cause accidents.

Workplace Environmental hazards are controlled by improved arrangements or engineering. Regular checking of temperatures humidity and lighting and ventilation levels is simple and effective. Control of ergonomic working conditions call for vigilance and routine risk assessment. A suitably trained workforce will recognise problems linked to upper-limb disorders and should be encouraged to report these problems at the earliest opportunity.

6.5 BIOLOGICAL HAZARDS

6.5.1 Legionella in Cooling Towers and Other Water Systems

If the measures taken to minimise the risk of infection from Legionella are to remain effective the condition and performance of the water system will need to be monitored, and water quality routinely tested. Where the system is treated by chlorination, residual chlorine must remain in the system. Free residual chlorine and pH should be measured. Where other control measures are used it may be necessary to monitor microbiological activity. Routine inspection of the condition of the water system, and checks on its performance are also important monitoring procedures.

Further information is included in the HSE Guidance Document L8 “The Control of Legionella Bacteria in Water Systems ACOP”.

7. Health Surveillance

The COSHH regulations require that employers provide suitable health surveillance in certain circumstance, notably were exposure to a substance is associated with specific disease, such as, for example, carcinogens. Health Surveillance may include medical examination and completion of health questionnaires. Routine skin examinations are recommended for those working with known skin sensitisers. Lung function tests may be appropriate for those exposed to respiratory sensitisers. Further information may be found in HS(G)61 Surveillance of people with health risks at work.

Where there is a requirement for Health Surveillance, as defined by COSHH assessments health records must be kept for at least 40 years.

Health Surveillance may include Biological monitoring, where necessary

Where there is a statutory requirement for Health Surveillance it must be carried out by a suitably qualified OH professional

7.1 BIOLOGICAL MONITORING

Biological monitoring has a role to play in the control of toxic hazards, where risk assessment identifies it is required, and may be used to complement measures of exposure by air sampling methods.

Biological Monitoring can be defined as a regular activity where selected, validated indicators of the uptake of toxic substances are determined in order to prevent health impairment. It should not be confused with the early detection of health impairment, a wider concept encompassing several aspects of health screening and early diagnosis.

Biological Uptake Monitoring is a technique which measures the extent of intake of a substance inside the body in the form of the quantity of the substance or it's metabolise. It need not necessarily cause an effect on the body but is indicative of exposure.

Biological Effect Monitoring is a technique that can be used to assess the effect of exposure of a worker to a chemical. It may also be used to assess pre-clinical effects, for example by measurement of reaction times or actual physical harm to the tissues. Biological Effect Monitoring may also include the measurement of reversible biochemical changes, e.g. plasma cholinesterase analysis to determine organ phosphorus exposure.

Examples of measurements, which can be used for semiconductor chemicals include, arsenic in urine tests, fluoride-in-urine tests, and metabolise tests for workers exposed to solvents.

The results of biological monitoring tests can be related to recommended or legal standards.

The potential advantages of Biological Monitoring are :

- It measures the toxic dose from all routes.
- It can identify unacceptable uptake.
- It can identity susceptible individuals.
- It can identify failure of control strategy.

Biological samples most frequently used for analysis are urine, blood and alveolar air. Others less frequently utilised include: fat, saliva, hair, nails, teeth and placenta.

If a biological monitoring programme is being considered but there is not appropriate expertise in-house, help should be sought from an organisation, which does have relevant expertise and specialises in providing a biological monitoring service.

7.2 ESTABLISHING PROCEDURES FOR FEEDBACK

Inform the employees being monitored of their own results and what they mean. This needs to be done by someone who understands the results and can explain what they mean.

8. Calibration and Record Keeping

8.1 CALIBRATION AND TESTING

All instruments which measure chemical or physical agents will require calibration.

The type and regularity of calibration will depend on the instrument. Where possible, this should be carried out by the manufacturer and a certificate of such calibration should be supplied with the instrument on purchase. Where this is not the situation, recommendations should be sought from the manufacturer on the procedure to use. Procedures used for calibration should be checked against a reliable reference method and any equipment involved should itself be regularly checked against recognised standards.

The frequency of instrument calibration depends on the equipment but should be at least every six months. It is recommended that there be an annual check for correct operation and ~ calibration by the manufacturer. Records relating to calibrations should be kept for a minimum of five years.

8.2 RECORD KEEPING

For monitoring to be effective it is essential that the results are recorded in such a manner that the information can be examined and correlated with other results such as plant maintenance records or health surveillance data.

COSHH provides requirements for hazardous substances and the principles set out can be applied to non-chemical monitoring. Two record keeping periods are defined under COSHH:

(a) At least 40 years. This applies to personal exposures and to health records, where the period is from the last entry.

(b) At least 5 years. This period applies to records of maintenance and repair on engineering control measures, e.g. ventilation plant, and to all records of monitoring other than personal monitoring (where the period is 30 years).

8.2.1 Requirements under the Ionising Radiation Regulations

Where full containment of radiation sources is achieved there need be no classification of workers and no medical records are required or records of personal exposures. If there is an accidental exposure, an investigation is required and the- degree-of exposure assessed. Records must be kept as per the Regulations

With radioactive sources there is a requirement that all sources be registered with the relevant enforcing authority and that the location of each source be recorded on a regular (usually daily) basis. These records must be kept as per the Regulations

9. Environmental Monitoring

It is not the intention of this document to cover environmental monitoring as a comprehensive overview of this can be found in the following publications :

- UKMEAC Environmental Code of Practice for the Microelectronics Industry (Rev 3)
- UKMEAC Guidance Note on Extract Stack Monitoring for the Microelectronics Industry

Appendix 1 Gas Detection Techniques

ELECTROCHEMICAL

Operation of an electrochemical sensor depends upon electrical changes at the electrodes (in contact with a liquid electrolyte) due to redox reactions of the gas or vapour on the surface of the electrodes. Gas diffuses to the sensing electrode and is either oxidised or reduced. Only small quantities of gas or vapour can be consumed therefore electrodes and electrolyte are usually confined in a semi-permeable membranes to prevent overloading.

Typical measurement tasks

Suitable for a wide range of measurement tasks including continuous monitoring, personal exposure monitoring, emissions monitoring

Typical measurement range

From ppb to thousands of ppm

Time of response

Response and recovery time usually not less than 30 sec.

Selectivity

Some selectively, other oxidising or reducing gases and vapours may interfere.

Typical calibration frequency

Depends on gas or vapour, but typically 6 - 12 months.

Limitations

(a) restricted temperature range due to properties of the electrolyte, e.g. to +40°C; -10°C.

(b) Slow recovery after high exposure

(c) Slow response to small step changes

Semiconductor Industry Gases Measured

Most toxic and flammable, e.g.: Hydrides, Acid Gases and Hydrogen. Also O_2 measurement.

SEMICONDUCTOR DEVICES

Operating principle

The sensor is based on electrical conductivity effects associated with chemisorption of gases on a semiconductor surface, i.e. gas sensitive resistors. The gas concentration is monitored by measuring changes in the to gases or vapours other than air.

Typical Measurement Tasks

(a) suitable for a wide range of measurement tasks, particularly in alarm-only apparatus and emission source measurements.

(b) used to measure a wide range of gases and vapours.

Typical Measurement Range

Sensors are used for the detection of gases and vapours in any concentration but usually in the ppm range, e.g. 1 to 1000 ppm. However, they tend to have a non-linear response.

Time of response

Depends on gas or vapour.

Selectivity

Generally non-specific and very susceptible to interference.

Typical Calibration Frequency

Frequent calibration necessary.

Limitations

(a) wide range of sensitivity to different gases and vapours;

(b) after exposure to high gas concentrations the sensor may need a recovery time of several hours and may have irreversible changes to its zero gas reading and sensitivity;

(c) exposure to basic or acidic compounds, silicones, organo-lead, sulphur compounds and halogenated compounds may have a significant effect on the sensitivity;

(d) oxygen concentration may have a significant effect on sensitivity.

(e) unable to measure in ppb range.

Semiconductor Industry gas measured
Most toxic and flammable but levels of detection variable.

PAPER TAPE

Operating principle
Gas adsorbs and reacts with a supported chemical reagent, usually in the form of a paper tape or badge, resulting in a colour change of the reagent. The resulting stain is monitored electronically commonly using a light reflectance technique (usually based on LED + photodiode/transistor). The reaction may be irreversible or reversible.

Typical measurement tasks
Suitable for a wide range of measurement tasks' but not for personal exposure monitoring because of the size/weight of the apparatus. Often used to monitor isocyanates.

Typical measurement range
ppb to low ppm.

Time of response
Of the order of minutes for some gases.

Selectivity
Depends on the gas or vapour but can be reasonably selective

Typical calibration frequency
Instrument - of the order of weeks.

Limitations

(a) chemical cassettes for paper tape systems are consumable items;

(b) usually paper tapes have a short shelf-life (typically 3 months);

(c) bleaching agents may inhibit reaction with the chemical reagent.

(d) mechanical based systems need higher maintenance.

(e) sample based systems can lead to losses of sample in tubing/valves etc.

Semiconductor Industry gas measured
Most toxics, unsuitable for flammable gases or O_2 measurement.

CATALYTIC (PELLISTOR)

Operating principle

Oxidation of flammable gas occurs at the surface of an electrically heated catalytic element. Sensors are normally constructed as an electrical bridge with two electrically similar elements (beads) mounted close to one another. The elements typically consist of a platinum coil embedded in a ceramic, one (the sensing element) is additionally covered with the catalyst usually a platinum group metal. The heater maintains the ceramic at a sufficiently high temperature (400°C - 600°C) to ensure combustion of flammable gas. The gas concentration is monitored by measuring the relative change in the resistance of the elements resulting from a temperature increase produced by combustion (Wheatstone Bridge Principle.)

Typical measurement tasks

The measurement of a wide variety of flammable gases and vapours at concentrations up to the lower explosion limit (LEL).

Typical measurement range

to 5% V/V or 0-100% LEL NB: Most WELs for gases and vapours fall well below this measurement range. Alarms below 10'% LEL not normally practical.

Time of response

Depends on gas or vapour. but reacts faster to smaller molecules e.g. H_2 or CH_4.

Selectivity

The sensor response is generally not selective.

Typical calibration frequency

Will depend on exposure and can vary between weeks and months.

Limitations

(a) not recommended for the measurement of flammable mixtures above the LEL

(b) for the reliable operation of the sensor about 10% v/v of oxygen is required in the measured gas mixture

(c) may give false readings in high flammable gas concentrations;

(d) will detect all other flammable gases and vapours;

(e) exposure to vapours such as silicones, organo-lead, sulphur compounds, halogenated hydrocarbons and phosphate esters will cause inhibition or poisoning of the sensor.

Semiconductor Industry gas measured

Most flammable. No toxics.

INFRA-RED SPECTROMETRY

Operating principle

Infrared radiation (from a bulb lamp or LED and usually modulated in intensity) is passed through a sample cell and is absorbed by the target gas. The optical path can have a length of up to 20 metres but uses multiple reflection. Thermal, quantum or photoacoustic detectors measure the absorption. Comparing a sample and reference in a single or a double beam apparatus to compensate for changes in beam intensity usually measures the concentration of gas. Non-dispersive (e.g. interference filters) and sometimes dispersive technique are used to select the appropriate infrared wavelength. Many gases and vapours absorb in the infrared region (2-14 micron)

Typical measurement tasks

Suitable for a wide range of measurement tasks but not for personal exposure monitoring
because of the size/weight of the apparatus.

Typical measurement range

ppm to 100% v/v.

Time of response
Seconds. Limited by cell volume and pump speed in aspirated systems. Filters and weather protection will increase the time of response.

Selectivity
Depends on gas or vapour and selection of wavelength.

Typical calibration frequency
Weeks to months.

Limitations
(a) exposure to high concentration may saturate the instrument for a finite time
(b) cannot detect monatomic and diatomic homonuclear molecules, e g. Hg, Cl_2 and other
(c) high maintenance system because of need for clean optics at lowest ranges.

Semiconductor Industry gas measured
Some toxic and flammable but generally associated with solvent vapours.

MASS SPECTROMETRY

Operating principle
Gases and vapours are injected or continuously aspirated into an ionisation chamber where they undergo ionisation and fragmentation. Fragment ions are separated according to their mass-to-charge ratio and detected by a Faraday cup or an electron multiplier. Relative intensities of the tons generated from a specific compound are constant under steady operating conditions. The whole system is under high vacuum.

Typical measurement tasks
Measurement of a wide range of gases and vapours. Simultaneous multi-component identification and measurement.

Typical measurement range
Usually from ppb to ppm (depending on the gas or vapour and interferents)

Time of response
Very short time of response and recovery time for directly aspirated apparatus. Slow response if coupled to a gas chromatograph.

Selectivity
High selectivity

Typical calibration frequency
Daily calibration is usually required.

Limitations
(a) bulky and complex apparatus - although not laboratory-sized
(b) extensive operator training required;
(c) high concentrations may saturate the detector and produce memory effects impairing measurements of very low concentrations.
(d) very high maintenance requirements.

Semiconductor Industry gas measured
Most toxic and flammable but not in much practical uses expect for background checking with long cycle times.

FLAME EMISSION SPECTROMETRY

Operating principle
The target gas is mixed with hydrogen and combusted at high temperature, which causes the gas molecules to enter excited states. On returning to the stable state, light of characteristic wavelengths is emitted and measured using a wavelength filter and photometer.

Typical measurement tasks
Suitable for a wide range of measurement tasks but not for personal exposure monitoring because of the size/weight of the apparatus.

Typical measurement range
ppb or ppm generally

Time of response
Typically can be as fast as 1-2 seconds after gas arrives at sensor.

Selectivity
Highly selective.

Typical calibration frequency
Most instruments have a calibration period of weeks.

Limitations
(a) external gases (hydrogen and clean air) are required for the flame.
(b) high maintenance system requires regular checking
(c) requires H_2 detector to monitor fuel gas for flame

Semiconductor Industry gas measured
Most toxic gases.

PHOTO IONISATION

Operating principle
The detection principle is based on ionisation of gaseous compounds by ultraviolet radiation. The gas is Irradiated by a UV source, usually a hydrogen lamp with a maximum emission energy of around 10.6 eV. Molecules are photo-ionised and the resulting ion current is measured across an applied electric field. Molecules having an ionisation potential lower than the excitation energy of the lamp are detected. In principle, as the measurements are performed in air, all substances having an ionisation potential higher than oxygen (12.1 eV) cannot be detected. The sensor has a linear response over a wide concentration range.

Typical measurement tasks
Suitable for a wide range of measurement tasks

Typical measurement range
Ppb to thousands of ppm.

Time of response
Fast response, depends on detector volume and pump speed.

Selectivity
Non-selective. Can be selective if used in conjunction with gas chromatograph.

Typical calibration frequency
Most instruments have a short calibration period, typically a day

Limitations
(a) The lamp used as a source of UV radiation has a limited lifetime, especially higher energy (>10.6eV) cannot be detected with commonly available detectors and vapours such as ethanol and ethylene give a low response with a 10.6eV lamp
(b) water vapour may interfere

(c) high levels of methane in the presence of the target gas reduce sensitivity by inhibiting

Semiconductor Industry gas measured
Most toxic but generally used for solvent monitoring.

DETECTOR TUBES

Operating principle
A detector tube consists of a sealed gas tube containing a precise amount of the appropriate regent on a solid matrix. They can be used in pumped systems (using pump or bellows) to indicated concentration (short term tubes) or sample diffusively for measurement of a dose from which the TWA can be calculated knowing the exposure time (long term tubes). The end(s) of the tube are broken off and the sample is drawn through the tube where it reacts and the colour of the reagent. There are two types of end point – stain length, where the length of the stain gives an indication of concentration or dose, and colour comparison where the number of strokes of the pump to produce a particular colour is an indication of the concentration.

Typical measurement tasks
Short-term tubes mainly used for spot tests. Long-term tubes used for personal monitoring.

Typical measurement range
From sub-ppm to % levels.

Time of response
Depends on pump and reagent.

Selectivity
Tubes are cross sensitive to similarly reacting chemical species.

Typical calibration frequency
Tubes are pre-calibrated by manufacturer.

Limitations
(a) tubes can only be used once.
(b) need to dispose of glass tubes after use.
(c) need several readings to get best accuracy.
(d) need dedicated pump for each brand of tube.

Semiconductor Industry gas measured
Most toxic and some flammable gases, also O_2.