Size Selective Air Sampling in the Workplace: ***Respirable***

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Brussels, june 2014

Introduction : Respirable Dust Definition & Sampling Convention

- In 1952, the British Medical Research Council (BMRC) adopted a definition of respirable dust as that fraction reaching the alveolar region of the lung
- The BMRC defined respirable dust samplers as having a 50% cut-point of **5 microns**
- In 1959, the BMRC definition was adopted by the Johannesburgh Conference on Pneumoconiosis

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USA

- In 1968, the American Conference of Governmental Industrial Hygienists (ACGIH) defined respirable dust samplers as having a 50% cut-point of **3.5 µm**

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At this moment

In the early 1990's, a new international definition was developed to achieve worldwide consensus. Respirable samplers were defined as having a 50% cut-point of **4 microns**

1993, revisions to Appendix D of the ACGIH TLV/BEI ® booklet, "Particle Size-Selective Sampling Criteria for Airborne Particulate Matter"

Respirable Particulate Mass

Those materials that are hazardous when deposited in the gas-exchange region including the respiratory bronchioles and alveoli. A significant change from previous definitions, the 1993 recommendation increased the 50% cut-point for respirable dust samplers from 3.5 to 4.0 microns.

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Sampling convention

Penetration in the alveolar zone

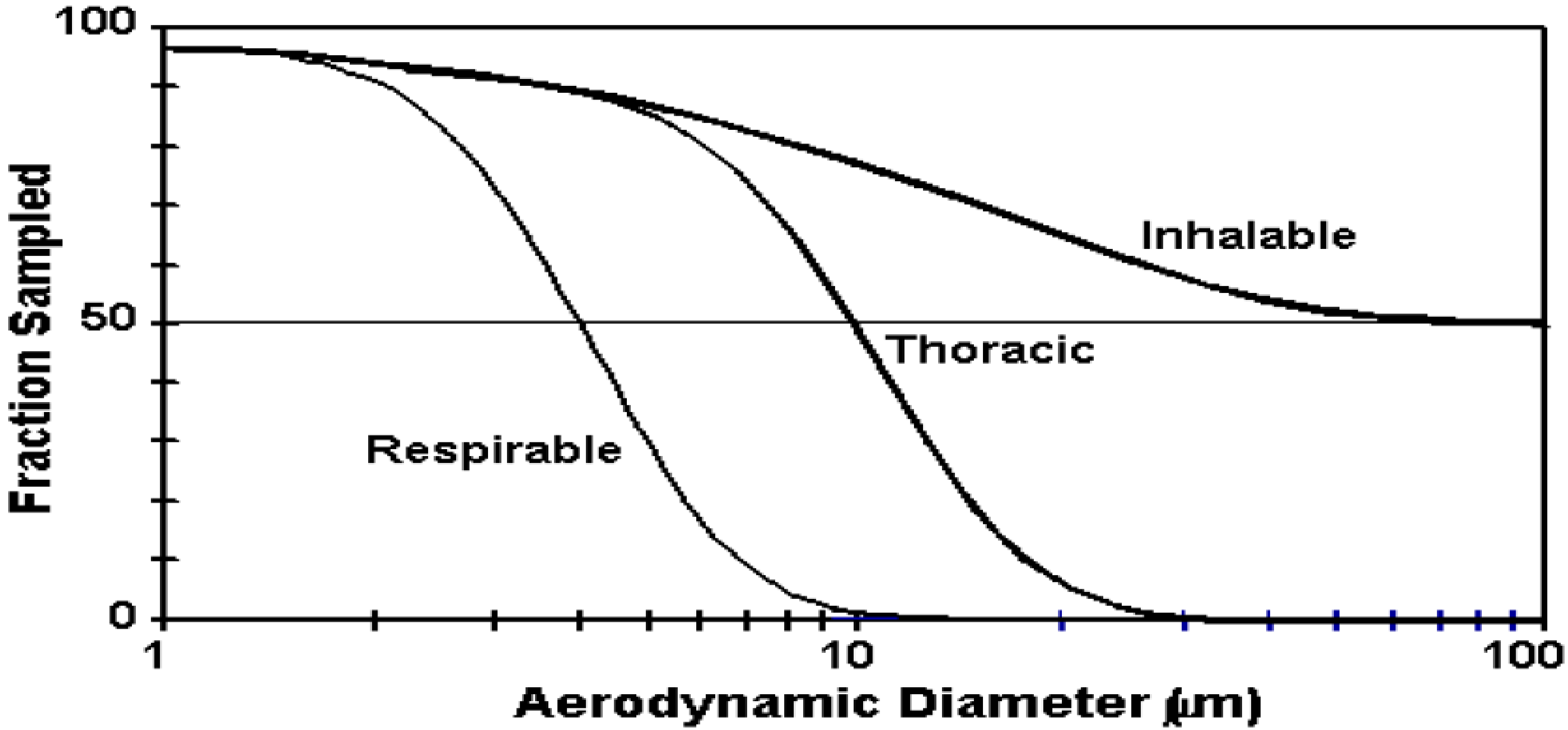


Figure 1. ISO/ACGIH/CEN sampling conventions. An ideal sampler should have a sampling efficiency curve that matches one of these curves as closely as possible under all wind directions and velocities. The 50% cutpoints for the respirable and thoracic conventions are 4 and 10 μm respectively.

Behaviour of aerosols in the Airways

- Deposition of Aerosols in the Airways
  - 5 Mechanisms
    - Inertion Impaction
    - Sedimentation
    - Diffusion
    - Electrostatic precipitation
    - Interception

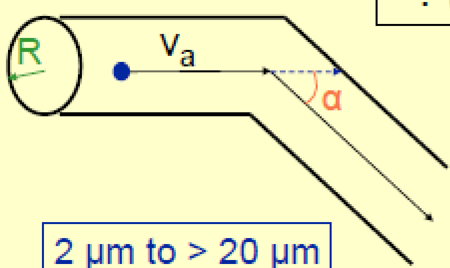
Mechanism N°1

Deposition of particles

1. Inertial impaction

I = probability of inertial deposition

÷ $(v_a\ v_t\ \sin\alpha)\ /\ g\ R$



2 µm to > 20 µm

v_a = air velocity

v_t = settling velocity

$v_t = (\rho - \sigma)\ g\ d^2\ /\ 18\gamma$

d = particle diameter

ρ = particle density

σ = air density

γ = air viscosity

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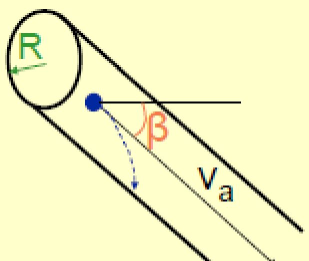
N°2

Deposition of particles

2. Sedimentation



≤ 2 µm

S = probability of deposition

$\div\ 1-e^{(-0.8\ t\ v_t \cos\beta)\ /\ R}$

t = time of travel ($\div\ 1/v_a$)

v_t = settling velocity

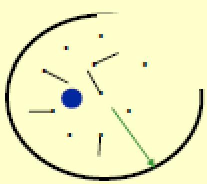
$v_t = (\rho - \sigma)\ g\ d^2\ /\ 18\gamma$

- d = particle diameter
- ρ = particle density
- σ = air density
- γ = air viscosity

N°3

Deposition of particles

3. Diffusion



$\leq 0.2\ \mu m$

D = probability of deposition

$\div\ 1-e^{-0.58\ \Lambda\ /\ R}$

Λ= thermal (Brownian) motion ⁄

$\div$ 1/d

$\div$ t = residence time ($\div$ $1/v_a$)

N°4 and 5

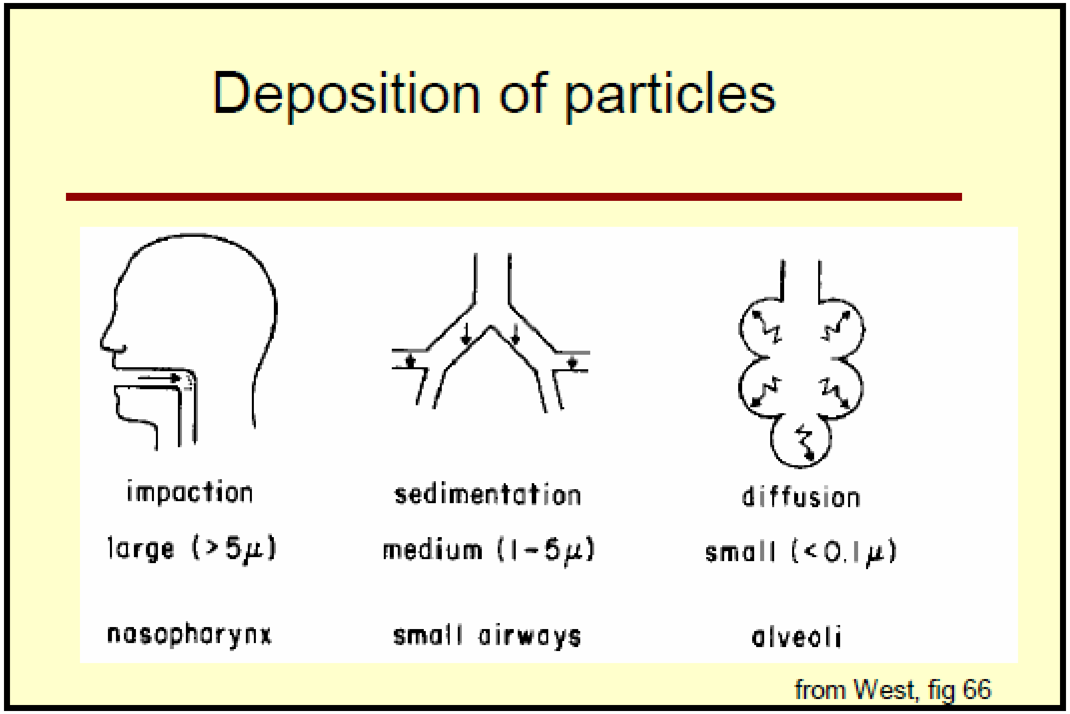
Deposition of particles

4. Electrostatic precipitation

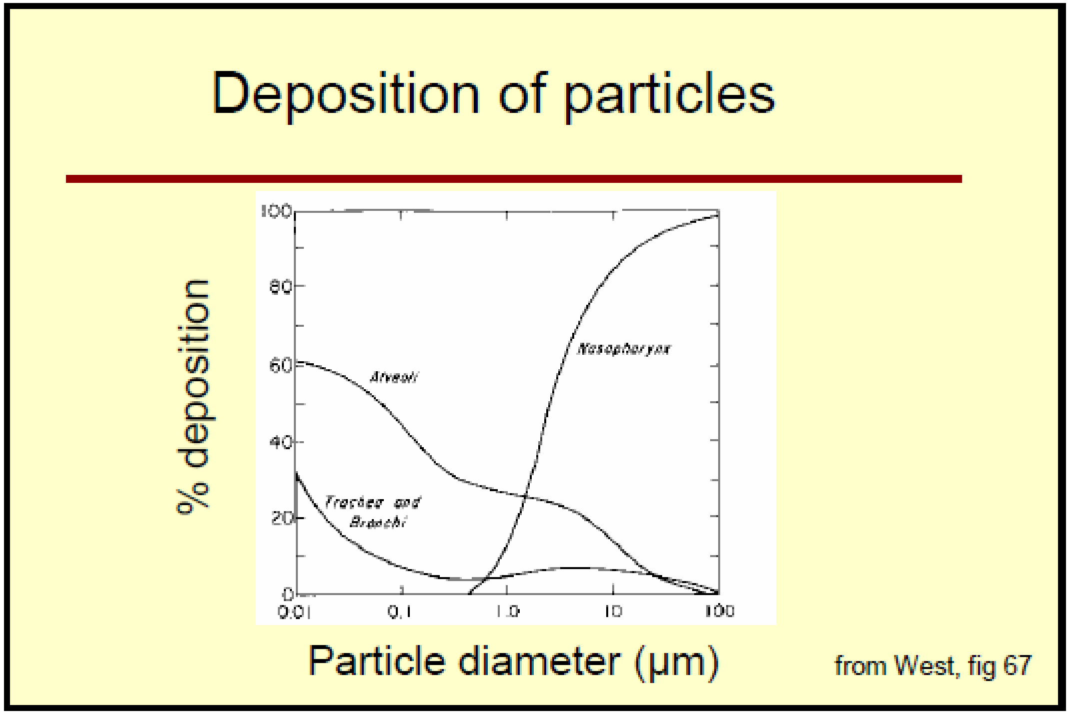
+ -

5. Interception

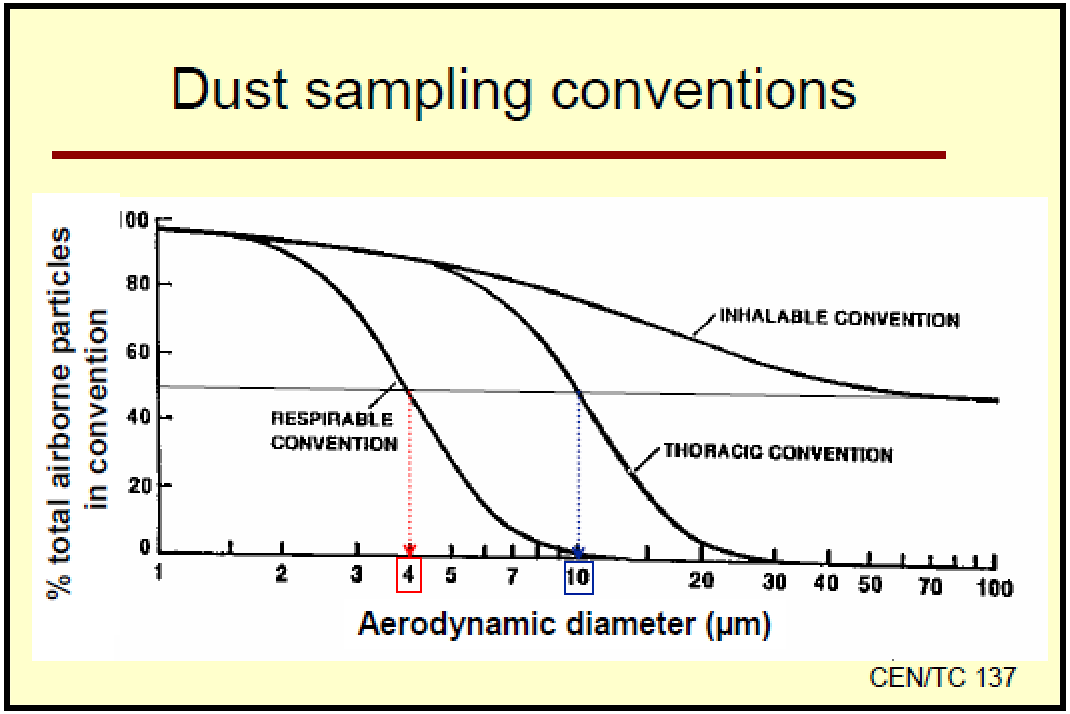
Deposition of particles 1



Deposition of inhaled particles 2



Dust sampling conventions



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Deposition: Host factors

Deposition of particles - host factors

- Flow characteristics
  - tidal volume (exercise > rest)
  - nasal *vs* mouth breathing (exercise)
- Individual factors
  - anatomy of airways (branching angles)
  - airway narrowing (reflex, asthma)
  - chronic lung disease (bronchitis, emphysema)
- Presence of other factors (irritants, smoking)

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Clearance of particles 1

Clearance of particles

- Soluble particles:
  - dissolved in lining fluid
  - ! potential for irritation & local damage, but no persistence
  - ! potential for systemic absorption via nasal / bronchial / pulmonary circulation

Clearance of particles 2

Clearance of particles

- Insoluble particles
  - if deposition in trachea - terminal bronchioli
  - mucociliary escalator: rapid process: $t_{1/2}$ = 1h-15d
    - ! individual differences
      - effects of smoking and irritants
      - effects of disease (acute/chronic bronchitis, CF, …)
    - ! potential for systemic absorption via gut

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Clearance of particles 3

Clearance of particles

- Insoluble particles
  - if deposition beyond terminal bronchioli

    phagocytosis by alveolar macrophages:

    slow process: $t_{½}$ = 60 - 300 d
    - mucociliary escalator
    - lymphatic clearance → mediastinal lymph nodes
      → pleural space

    ! toxicity for macrophages → inflammation

    ! "biopersistence" in lung tissue

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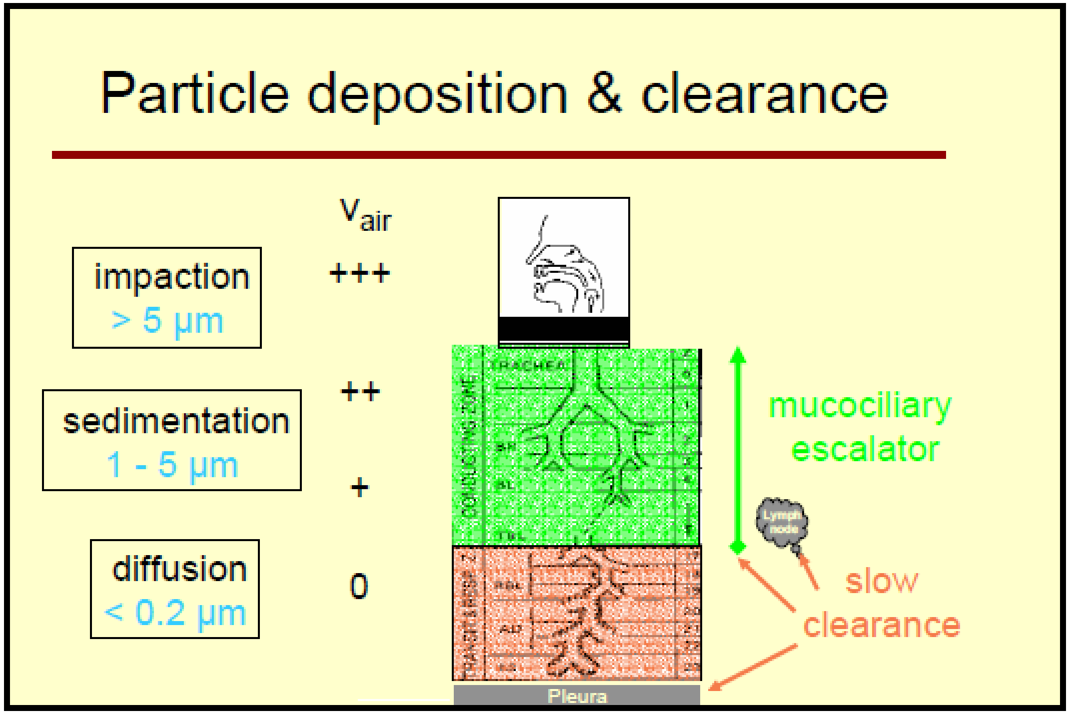
Deposition and Clearance



Toxical importance of Respirable Particles

- They reach the gas exchange zone: respiratory bronchioli and alveoli
- Very slow clearance; long biopersistence in lungtissue
- Clearance into the body: no mucociliary escalator
  - to bloodstream: soluble particles
  - to macrophages: non soluble

- High bio-reactive surface/ weight unit

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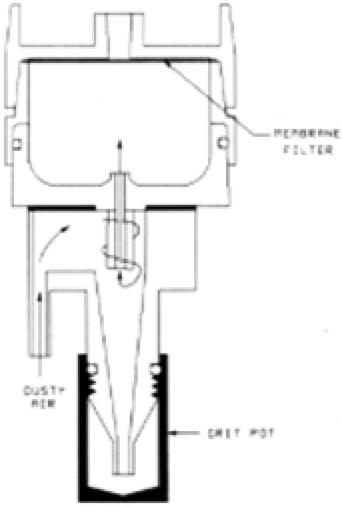
Practical: Airsampling of Respirable aerosols

- Equipment
  - Sampler Pump
  - Filter (Sampler) head and Filters
  - Calibrator
  - Maintenance
- Preparation of the Measurements
- The Air Sampling & Lab Analysis
- Results

Pump: Personal Sampler

Sampler Heads for respirable aerosols (to meet the convention 50%-4µm)

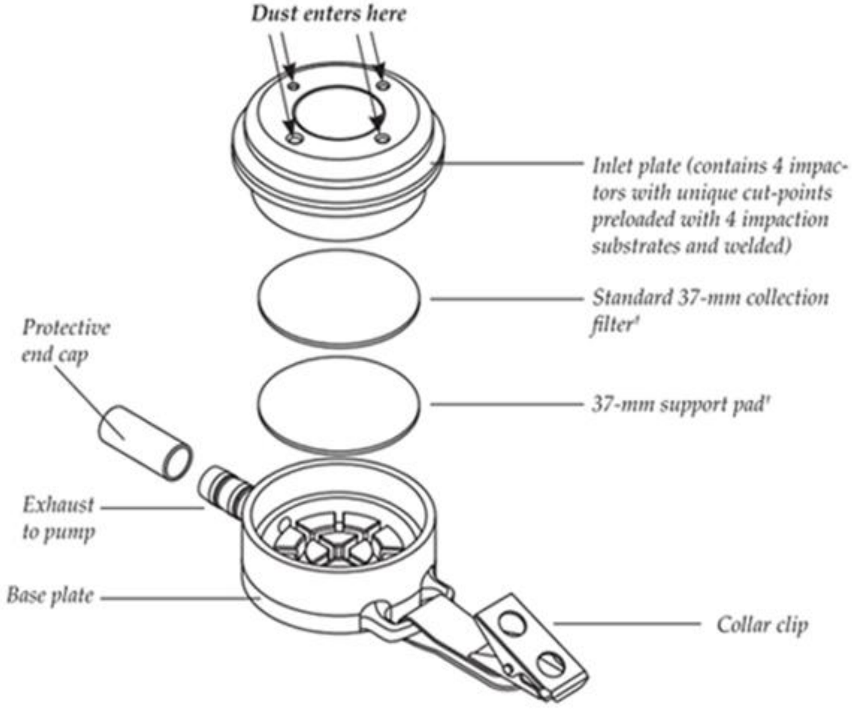
1. Cyclones



Nylon	**Higgins-Dewell**	Aluminum
1,7 l/mn	**2,2 l/mn**	2,5 l/mn

2. Parallel Particle Impactors (PPIs)

2 l/mn



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Why use a cyclone?

Table 6 Main advantages and disadvantages of inhalable and respirable samplers

	IOM inhalable head	IOM dual head	CIS/GSP	Respicon	Cyclone
Aerosol fractions sampled?	I	I, R	I, R	I, T, R	R
Deviations from the ACGIH/CEN/ISO criteria with variations in flow-rate	N	N	Y	Y	Y
Deviations from the ACGIH/CEN/ISO criteria at low wind speeds (< 0.24 m s^{-1})	Y	Y	Y	NA	N
Deviations from the ACGIH/CEN/ISO criteria with large particles (> 100 µm)	Y	Y	N	NA	N
Particle deposits in cassette wall	Y	Y	N	N	N
Cost (comparison includes cassettes and sampling mediums)	Low	Low	Low	Expensive	Low (plastic cyclones)

I= Inhalable, R = respirable, T=thoracic

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Important!!!

- Each cyclone has different operating specifications and performance criteria.
- Be sure you know the **flow rate** specified to achieve the desired cut-point before using a cyclone
- Right place of the Filterhead in the 'Breathing Zone'

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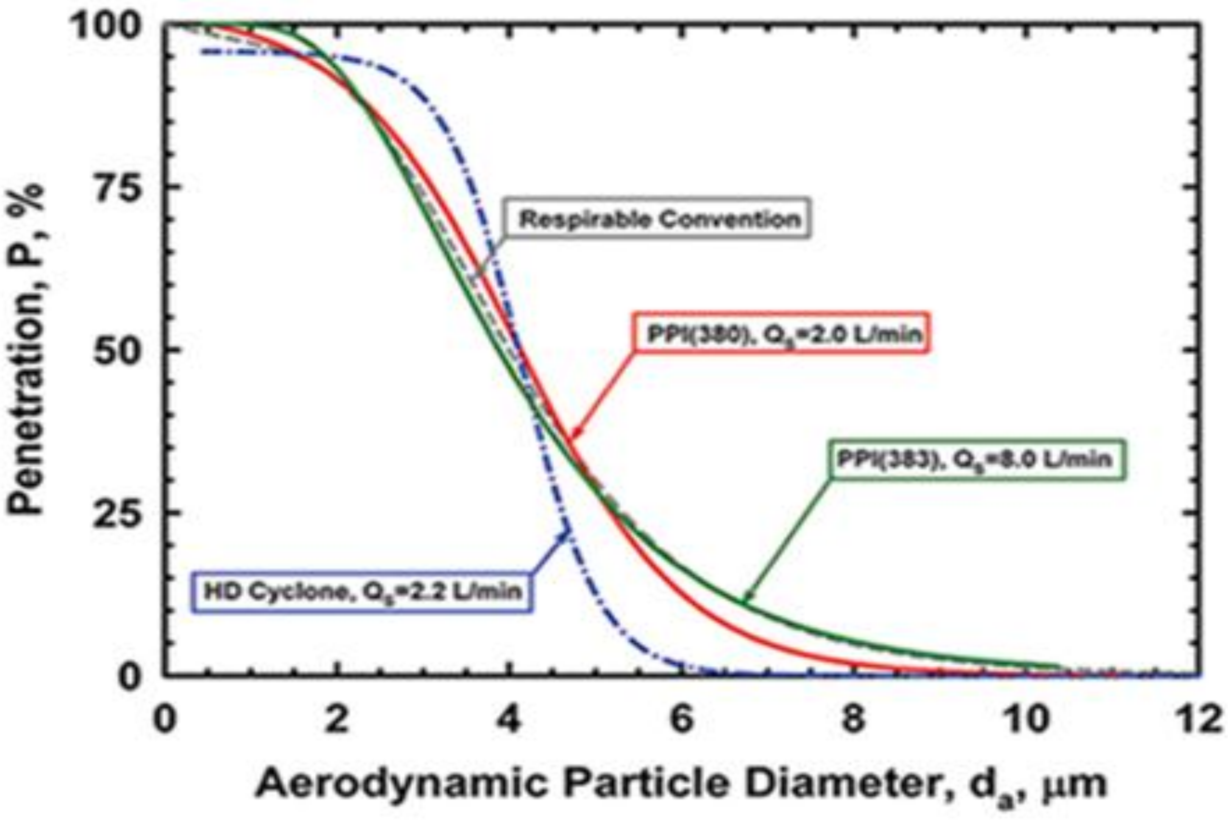
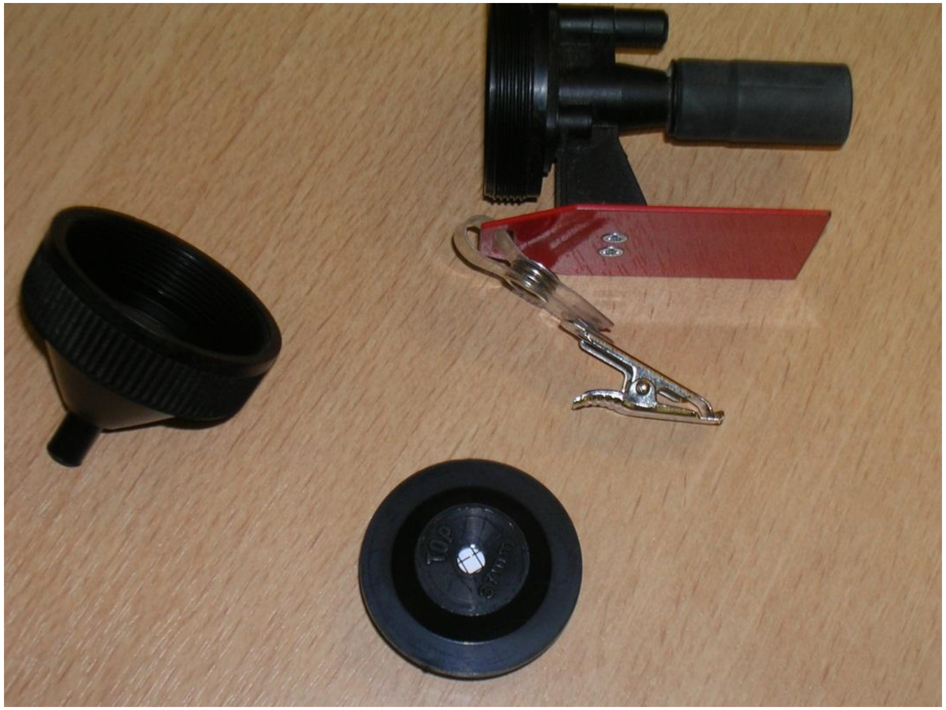
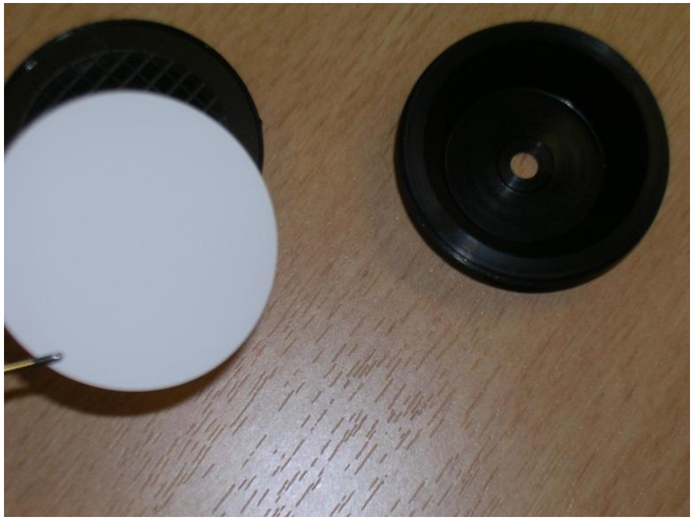
Compliance with Convention?



Composition of the Filter Head





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Place of the Filter Head

Type of Filter

- For Cadmium use the MCEF-filter
  - Mixed Cellulose Ester Filter
  - 0,8 µm pores
  - Assembling in clean area
  - Clean storage of filters
  - Do not touch with fingers
  - Use clean forceps
  - Clean transport to Lab

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Calibrator: Soap Bubble

Important: Also Yearly Calibration!!

Dayly Calibration of the Pump

- Before and After the sampling
- Difference flow Before & After <u>**< 5%**</u>

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Maintenance

- AirSampler (pump)
  - Clean storage
  - Replace filter when dirty
  - Full charge of the battery before sampling
- Calibrator
  - Yearly calibration at manufacturer

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Preparation of the measurements

- Definition of a **SEG**: Similar Exposure Group
  - group of workers having the same general exposure profile for the environmental agent being assessed because of the similarity and frequency of the tasks they perform, the materials and processes with which they work, and the similarity of the way they perform the tasks

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- Number of samples per SEG
  - Minimum 3 samples/SEG
  - Put in statistical Programm '**IHSTAT**'
    - When big spread, take 3 samples more
    - LogNormal distribution?
    - Wrong definition of the SEG??

Literature:

- (NBN) EN 689 (1996)
- BOHS (2011):'Testing Compliance with Occup. Exposure limits for airborne substances'

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Duration of a sample

- Normaly > 2h (EN 689)
- Nyrstar: we are sampling a whole shift
  - Error gets smaller

Required samples per shift (EN 689)

monsternemingsduur	minimum aantal monsters per werkperiode
10 s	30
1 min	20
15 min	4
30 min	3
1 u	2
≥ 2 u	1

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Frequency of testing (EN 689)

GM: Geometric Mean

%>OEL: OEL Exceedance Probability

Chemical risks		Frekwentie (Wkn)
GM < 10% OEL and %>OEL < 0,1%	Unsignificant risk	124
GM > 10% OEL but < 25% OEL and %>OEL < 5%	Acceptable risk	62
GM > 25% OEL but < 50% OEL and %>OEL < 5%	Significant risk	32
GM > 50% OEL and/or %>OEL > 5%	Imm Action Req	16

Lab Analysis

- 2 possible ways to analyse
  - Gravimetric: not specific
  - Analytical: specific

We do the **Analytical** one, because we only want to know how much Cd is on the filter (and in the air)

Our Lab uses ICP-MS: 'Inductive Coupled Plasma Mass Spectrometry'

Det.Limit: 0,02 µg for Cd

!!!Always send 1 BLANC Filter !!!

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Results

- You receive the results of the lab
  - Absolute values in µg = amount of Cd on the filter
  - You know the <u>flowrate</u> and <u>duration</u> of the sampling
  - So you can calculate the concentration in the ambient air in µg/m³

<u>Remark</u>: we don't make a correction for temperature and airpressure,
but you can do if you want

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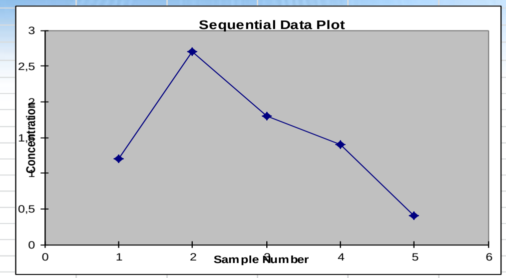
IHSTAT (free download from www)

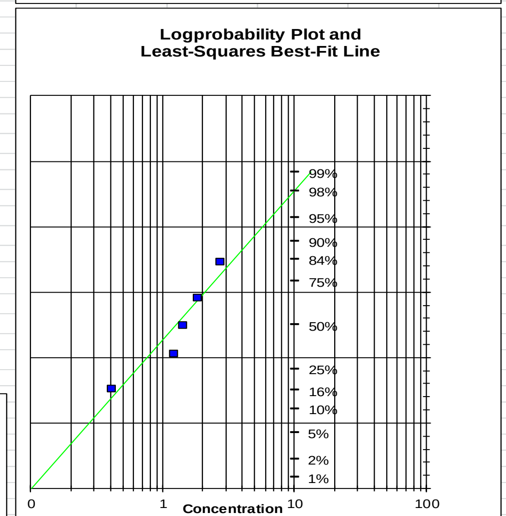
Industrial Hygiene Statistics

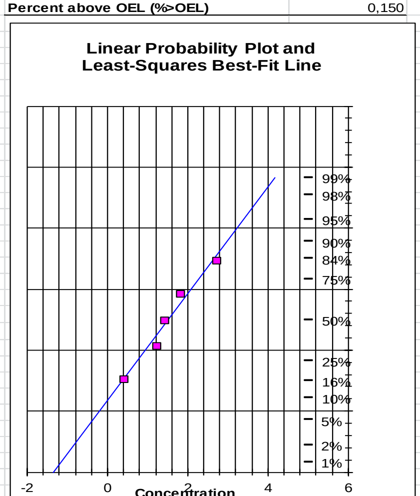
Data Description:		**Name of the SEG:**	ERTSENPLEIN LOSSEN TREIN
Cd	dec 2011		
OEL	mei 2013		
4			

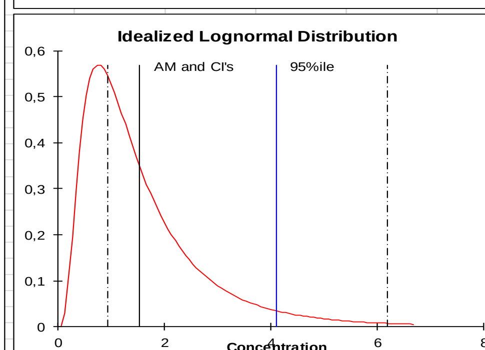
Sample Data (max n = 50) No less-than (<) or greater-than (>)
1,2
2,7
1,8
1,4
0,4

DESCRIPTIVE STATISTICS	
Number of samples (n)	5
Maximum (max)	2,7
Minimum (min)	0,4
Range	2,3
Percent above OEL (%>OEL)	0,000
Mean	1,500
Median	1,400
Standard deviation (s)	0,843
Mean of logtransformed data (LN)	0,237
Std. deviation of logtransformed data (LN)	0,714
Geometric mean (GM)	1,267
Geometric standard deviation (GSD)	2,042
TEST FOR DISTRIBUTION FIT	
W-test of logtransformed data (LN)	0,917
Lognormal (a = 0.05)?	Yes
W-test of data	0,986
Normal (a = 0.05)?	Yes
LOGNORMAL PARAMETRIC STATISTICS	
Estimated Arithmetic Mean - MVUE	1,543
$LCL_{1,95\%}$ - Land's "Exact"	0,941
$UCL_{1,95\%}$ - Land's "Exact"	6,187
95th Percentile	4,100
$UTL_{95\%,95\%}$	25,432
Percent above OEL (%>OEL)	5,364
$LCL_{1,95\%}$ %>OEL	0,323
$UCL_{1,95\%}$ %>OEL	34,856
NORMAL PARAMETRIC STATISTICS	
Mean	1,500
$LCL_{1,95\%}$ - t statistics	0,697
$UCL_{1,95\%}$ - t statistics	2,303
95th Percentile - Z	2,886
$UTL_{95\%,95\%}$	5,04
Percent above OEL (%>OEL)	0,150









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Possible other methods:'Gestis' database

IFA
Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung

DGUV Homep

News | Research | Technical information | Databases hazardous substances | Practical solutions | Testing/Certification | Publicatio

Home

- GESTIS-database on hazardous substances
- ISi information system for safety data sheets
- GESTIS - Analytical methods
- GESTIS - International limit values for chemical agents
- GESTIS DNEL database
- GESTIS - Scientific criteria documents
- GESTIS-DUST-EX
- Exposure database MEGA
- International Chemical Safety Cards (ICSC)

Databases hazardous substances > GESTIS - Analytical methods

Laboratory equipment, Source: IFA

Contact

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Division 2: Chemical and biological hazards

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E-mail

GESTIS - Analytical methods

Open database

Contents

This database contains validated lists of methods from various EU member states described as suitable for the analysis of chemical agents at workplaces. The priority of substances covered here was defined in line with their relevance to workplace health.

The database represents the outcome of the European project BC/CEN/ENTR/000/2002-16 "Analytical methods for chemical agents". Article 3 (10) of the Chemical Agents directive 98/24/EC (PDF, 70 KB) called for suitable analytical methods for hazardous substances in the workplace atmosphere.

Lists of analytical methods were compiled for 123 substances. The analytical methods have been indicatively rated considering the requirements of European standards. As a consequence, the methods in best agreement with these requirements were selected for detailed

List No.	Substance	CAS-No.	EINECS-No.
81	**Cadmium and Cd compounds except CdO fume and CdS pigments (as Cd)**	**7440-43-9**	**231-152-8**

No.	Source and method name	Language	Year of publication	Principle of the method	Flow rate/ Recommended air volume	LOQ/ Validated working range	Indicative rating	Remarks
1	ISO 11174 Workplace air — Determination of particulate cadmium and cadmium compounds	English French	1996	Particulates trapped on a filter mounted in an inhalable sampler. Hotplate dissolution with HNO_3 and, if quartz or glass fibre are used, HF. Analysis by FAAS or ETAAS.	Flow rate: Sampler–dependent Recommended sampling time: 15 min–8 h	LOQ: ETAAS: 0,0008 mg/m^3 30 l FAAS: 0,004 mg/m^3 30 l	A	
2	ISO 15202 Workplace air — Determination of metals and metalloids in airborne particulate matter by Inductively Coupled Plasma Atomic Emission Spectrometry Part 1: Sampling. Part 2: Sample preparation Part 3:Analysis	English French	Part 1: 2000 Part 2: 2001 Part 3: 2004	Particulates trapped on a suitable filter in an inhalable sampler. Hotplate dissolution with 1+1 HNO_3 and HCl; or 1+1 H_2SO_4, H_2O_2 and HCl; or HNO_3, $HClO_4$ and, if silicates are present, HF. Ultrasonic dissolution with HF and HNO_3. Microwave dissolution with HNO_3 and HF; or HNO_3, $HClO_4$ and HF; or HNO_3 and $HClO_4$. Analysis by ICP-AES.	Flow rate: Sampler–dependent Recommended sampling time: 15 min–8 h	LOQ: 0,0005 mg/m^3 480 l	A	
3	MDHS 10/2 Cadmium and inorganic compounds of cadmium in air	English	1994	Particulates trapped on an MCE or other suitable filter mounted in an inhalable sampler. Hotplate dissolution with HNO_3. Analysis by FAAS or ETAAS.	2 l/min	LOQ: ETAAS: 0,00008 mg/m^3 30 l	A	Similar method described in ISO 11174

81-2 (2004)	Cadmium and inorganic compounds (as Cd)
CAS Nº: 7440-43-9	EINECS Nº: 231-152-8
EC-LV (8 h): - Lowest European LV (8 h): 0,005 mg/m³ Highest European LV (8 h): 0,15 mg/m³	EC-STLV: - Lowest European STLV: 0,01 mg/m³ Highest European STLV: 0,6 mg/m³

SUMMARY OF THE METHOD

Language:	Reference:
English, French	**Workplace air - Determination of metals and metalloids in airborne particulate matter by Inductively Coupled Plasma Atomic Emission Spectrometry:** ISO 15202-1:2000 (Sampling), ISO 15202-2:2001 (Sample preparation), and ISO 15202-3:2004 (Analysis): ISO (2000 - 2004).

Summary: Air is drawn through a suitable filter mounted in a respirable or an inhalable sampler. The sample is then subjected to hotplate dissolution or microwave digestion with one of a number of different mixtures of inorganic acids and the sample solution is analysed by ICP-AES.

SAMPLING

Presentation of the results

PERSONAL SAMPLING

DEFINITION of the SEG

Name of the company:
Plant:
SEG: *name:* *N° of workers:*

SPECIFICATIONS of SAMPLING

Pump (Manufactor & type):
Sampler head:
Used filter (type, µm, manufactor):
Aspiration flow: *l/min*
Flow calibration(before and after) deviation required: *< %*
Lab analysis by (Certified for the analysis?)
Used analysis method:
Detection limit:
Analysed fraction: *Respirable*

RESULTS

Sample n°	date	element µg/m³							
		Cd							
	DNEL	4							
							Duration (min)	Sample volume	Δ Calibration %
1									
2									
3									
4									
5									
6									
Blanc									

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The End

Addendum

Aerodynamic Equivalent Diameter

The *Aerodynamic Equivalent Diameter (AED)* of a particle is the diameter of a unit density sphere that would have the identical settling velocity as the particle

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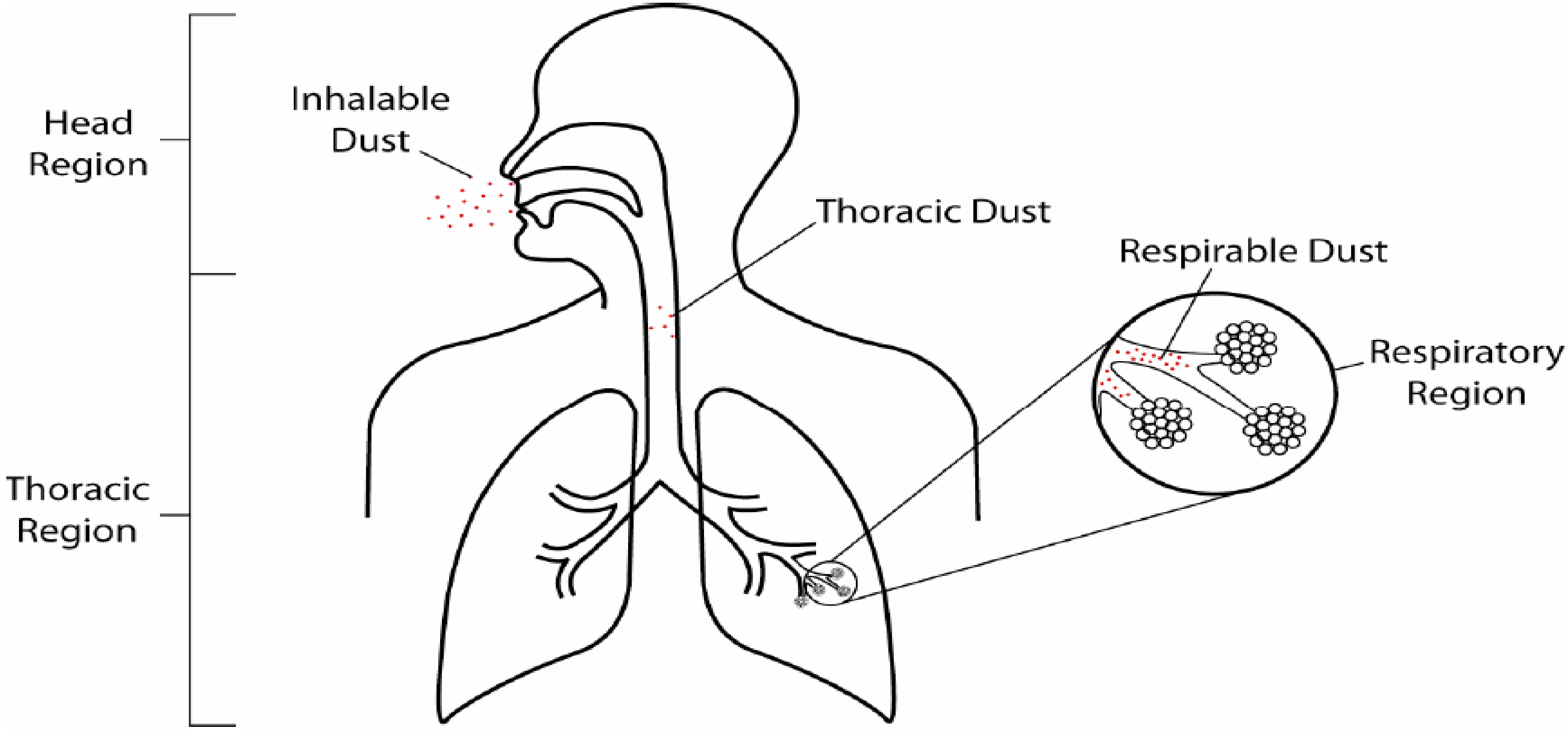
Regional Particle Deposition



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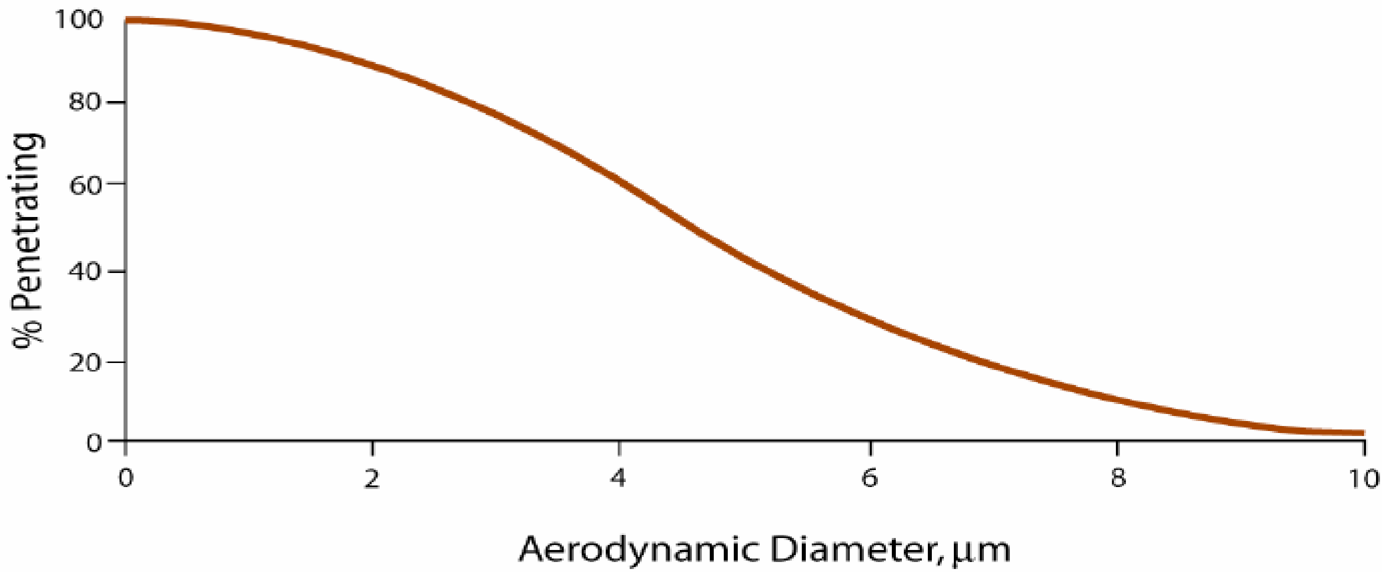
Respirable Dust Definition

AED, µm	% Penetrating
0	100
2	91
4	50
6	17
8	5
10	1



New Particle-Size Conventions

- Inhalable fraction (<100 μm AED)
  - Can be breathed into nose or mouth
- Thoracic fraction (<25 μm AED)
  - Can penetrate head airways and enter lung airways
- Respirable fraction (<10 μm AED)
  - Can penetrate beyond terminal bronchioles to gas exchange region

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Penetration to the alveolar zone

Aerodynamic diameter (µm)	Respirable fraction (%)
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

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Cyclone: How does it work?

Cyclones

Cyclones use centrifugal force to remove dust. A particle in a rotating air stream is subjected to a centrifugal force that accelerates it towards a surface where it will impact and lose momentum, thus being removed from the air stream. These cyclones are usually of small sizes, from 10 mm to no more than 50 mm in diameter. They have been widely used since the 1960s to collect the respirable fraction. In a typical cyclone pre-collector, the air enters tangentially at its side and swirls around inside. Particles above a certain size are thrown to the cyclone walls and collected at its base ("grit-pot"). The air containing the respirable dust leaves through the central exit in the top of the cyclone, and the air is filtered to collect the dust.

Because of the complexity of fluid behaviour in cyclones, it is difficult to predict mathematically their collection characteristics and they are based on empirical design. To achieve the proper size selection, however, the air sampling pump must be calibrated to provide the appropriate flow throughout the cyclone opening, within a specified variability, and the flow must be smooth. If the pump is not calibrated correctly, the selection will be shifted, either to larger (for low flow) or smaller (for high flow) aerodynamic diameters. Once calibrated, cyclones can be used for all particles, but are not generally used for fibres. The cyclones available on the market to be used as pre-collectors in two-stage samplers are usually made of nylon or aluminium. Different cyclone designs and manufacturers each have their own specific operational flow rates and filter cassette configuration (2-piece or 3-piece).

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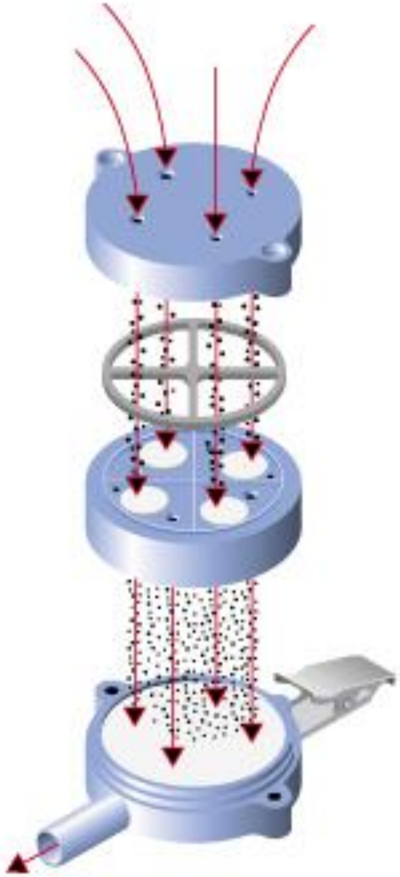
Cyclone anatomy

Impactor



Guidance documents

Table 4 Guidance documents for sampling of inhalable and respirable particles

Institution	Standard	Title	Link
ISO	15202-1	Workplace air – Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry – Part 1: Sampling.	http://www.iso.org/iso/search.htm?qt=15202&sort=rel&type=simple&published=on
CEN EU	15230:2005	Workplace atmospheres. Guidance for sampling of inhalable, thoracic and respirable aerosol fractions.	http://shop.bsigroup.com/ProductDetail/?pid=000000000030133932
NIOSH US	0600	Particles not otherwise regulated, respirable.	Appendix 1 http://www.cdc.gov/niosh/docs/81-123/pdfs/0600.pdf
HSE UK	MDHS 14/3	General methods for sampling and gravimetric analysis of respirable and inhalable dust.	Appendix 2 http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-3.pdf

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Table 5 Guidance document for measuring metals and metalloids

Institution	Standard	Title	Link
ISO	15202-2 and 15202-3	Workplace air- Determination of Metals and Mealloids in Airborne Particculate Matter by ICP-AES. Part: 2 (sample preparation and part 3: analysis).	http://www.iso.org/iso/search.htm?qt=15202&sort=rel&type=simple&published=on
CEN EU	BS EN 13890:2009	Workplace exposure. Procedures for measuring metals and metalloids in airborne particles. Requirements and test methods.	http://shop.bsigroup.com/ProductDetail/?pid=000000000030163840

Why use a cyclone?

Table 6 Main advantages and disadvantages of inhalable and respirable samplers

	IOM inhalable head	IOM dual head	CIS/GSP	Respicon	Cyclone
Aerosol fractions sampled?	I	I, R	I, R	I, T, R	R
Deviations from the ACGIH/CEN/ISO criteria with variations in flow-rate	N	N	Y	Y	Y
Deviations from the ACGIH/CEN/ISO criteria at low wind speeds (< 0.24 m s^{-1})	Y	Y	Y	NA	N
Deviations from the ACGIH/CEN/ISO criteria with large particles (> 100 µm)	Y	Y	N	NA	N
Particle deposits in cassette wall	Y	Y	N	N	N
Cost (comparison includes cassettes and sampling mediums)	Low	Low	Low	Expensive	Low (plastic cyclones)

I= Inhalable, R = respirable, T=thoracic

nyrstar

Title slide

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