Aerosol Photometers:
The Gold Standard in HEPA Filtration Testing气溶胶光度计：在HEPA测试中的黄金标准

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Introductions

Agenda 主题

- History of Photometry 光度测定法历史
- Science of Photometry光度测定法科学
- Applications of Photometry光度测定法应用

History of Photometers & HEPA Filters 光度计和HEPA历史

History of Photometers & HEPA Filters

“You can’t have one without the other”

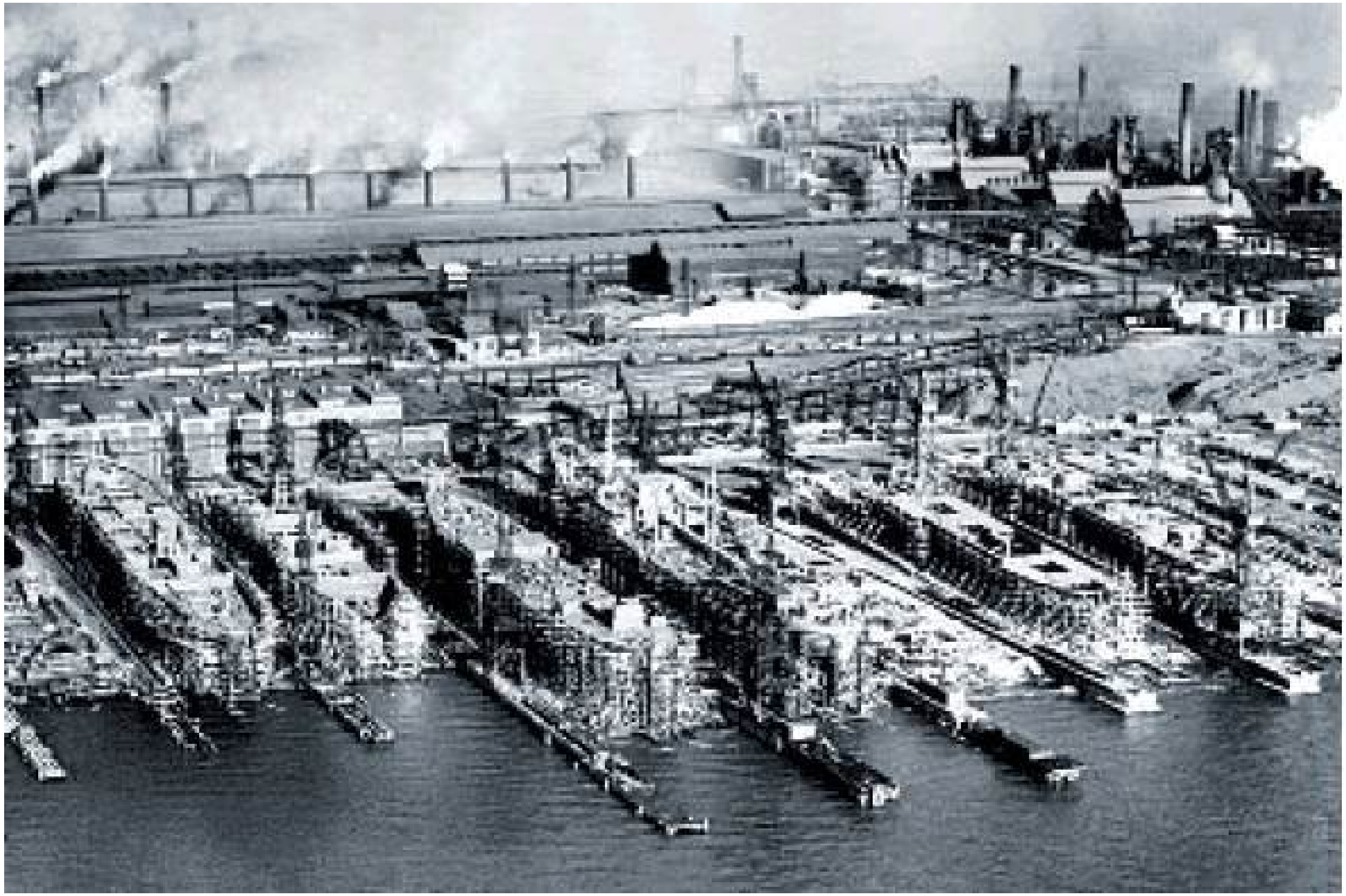
The photometer was first since there was a <u>need</u>

David Sinclair, Ph.D.

(Nephelometer 浊度计)

(Not portable and had logarithmic display不是便携式的且是对数显示)

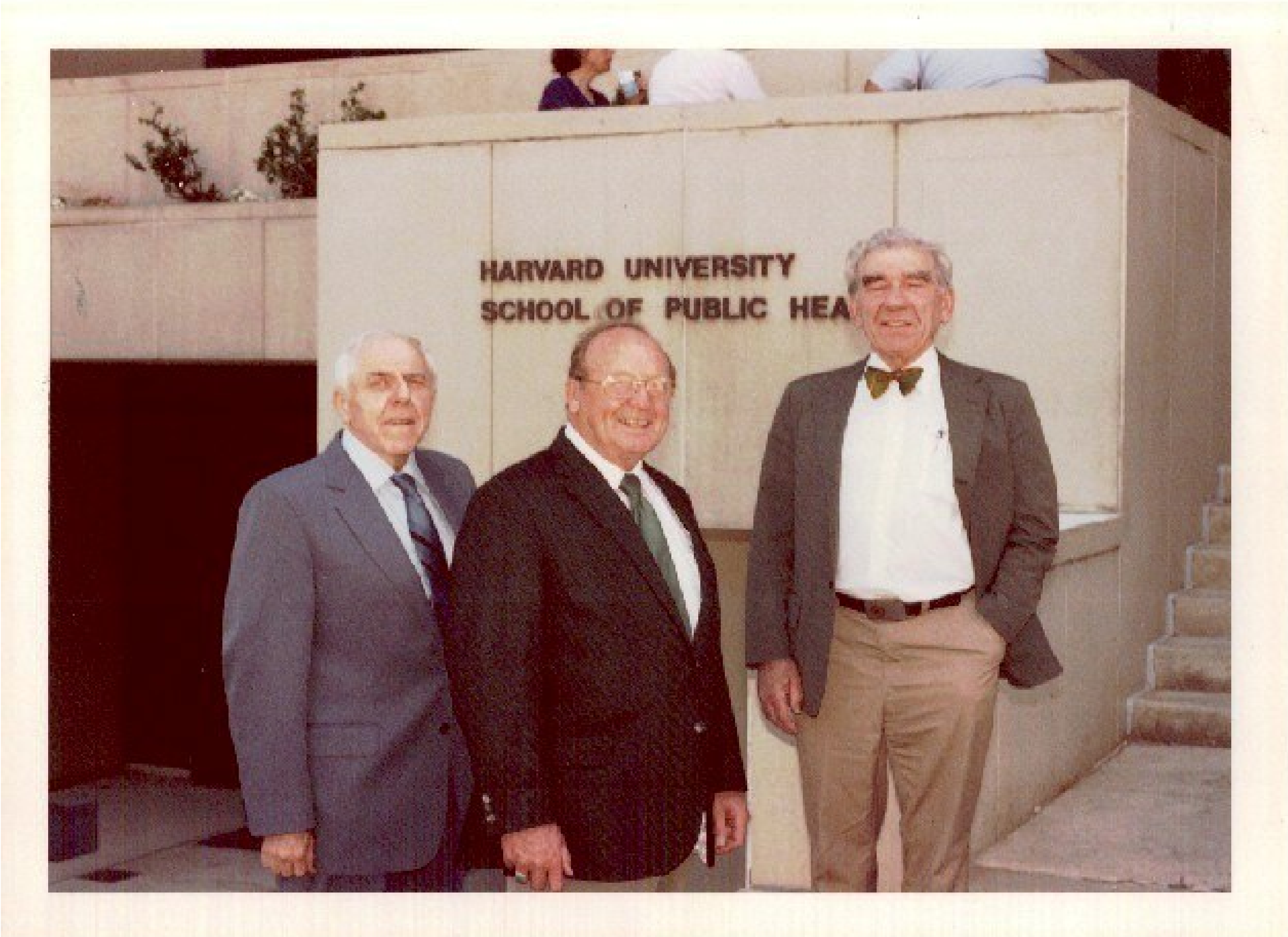
Air Pollution Research 1933
自1933年来的空气污染研究



WW II generated a high priority need二战后产生了一个高优先性需求

It all started in 1942

Some Key Players主要的玩家



Wendell Anderson, Humphrey Gilbert, Dr. Melvin First

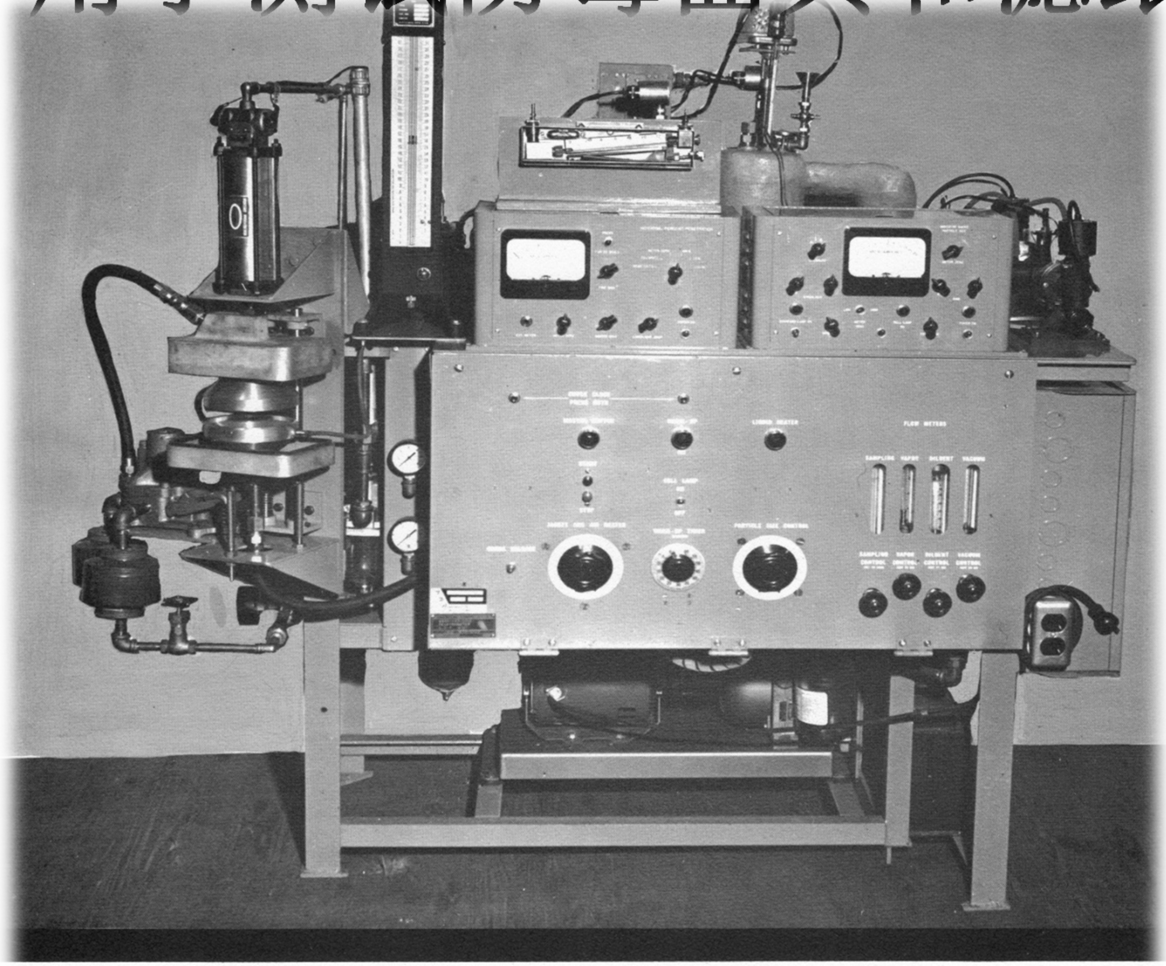
Captured WW II German Gas Masks德国的防毒面具获得

- **The US had performed no gas mask development since WW 1**在**1**战时，美国没有防毒面具
- **German masks used cellulose asbestos media patented by Dräger Werke in 1933** 在二战中德国用德尔格专利的石棉纤维纸作防毒面具的滤材
- **Wendell Anderson working with H&V developed media comparable to the German sample Wendell Anderson** 和哈佛发展能够和德国滤材相比较的滤材。

M10A1 Canister M10A1濾毒罐

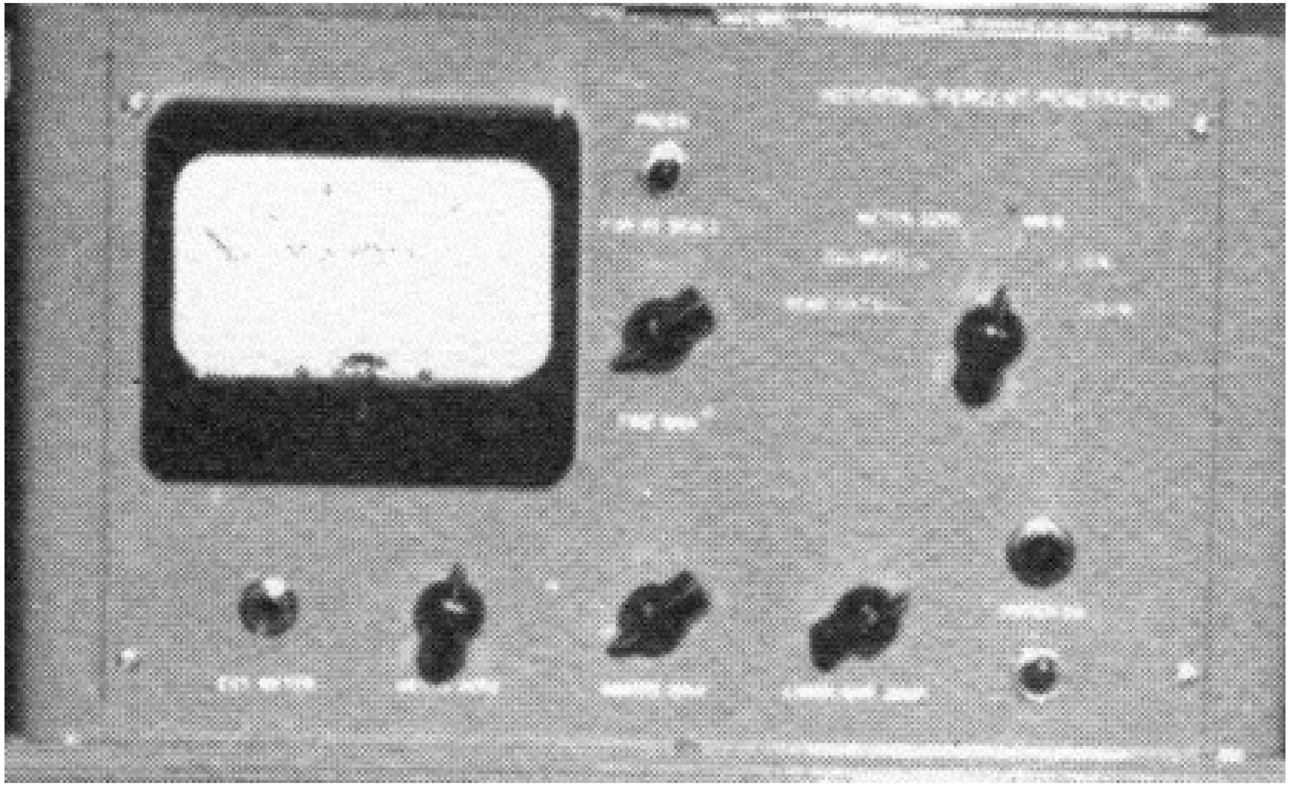
Tank & APC M-25 Mask坦克&APC M-25防毒面具

Smoke Penetrometer to test the gas mask paper & filters烟雾光度计用于测试防毒面具和滤纸



D O P SMOKE PENETROMETER, Q127

First Linear Photometer第一个线性光度计

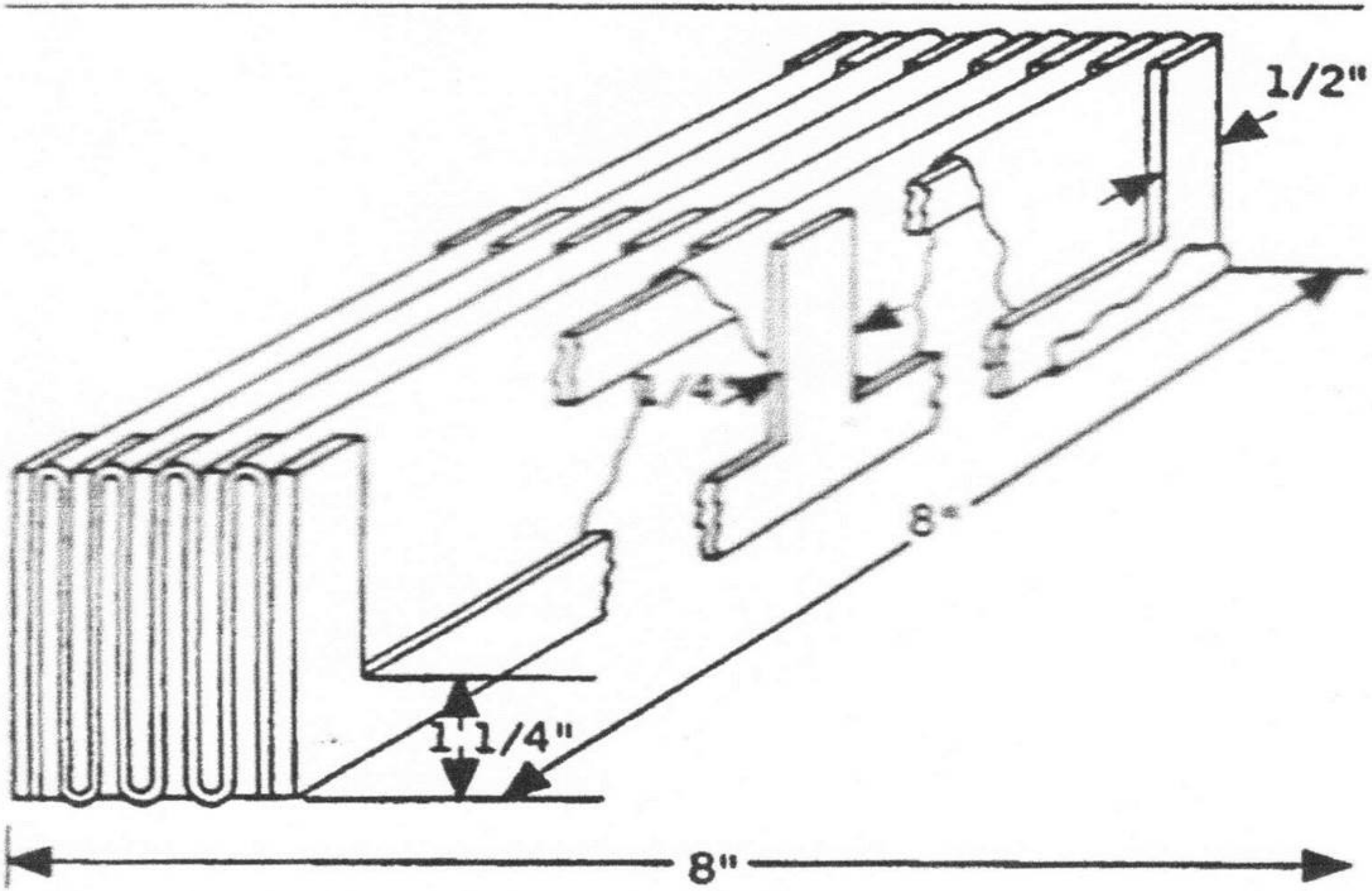


Space Filter空间过滤器

- **US military needed filtration of room areas for people and used gas mask media for a pleated filter for larger air flow (1943-1948)** 美国军方需要过滤人工作的房间区域，把防毒面具的滤材用到一个褶叠过滤器上，可提供大的气流。
- **Know as “Collective Protection”**被认为是一个集体性的保护
- **Used cardboard spacers between pleats, which had high air flow resistance**在摺之间用纸板作为间隔，这种结构会产生高的气流阻力

Cardboard Pleat纸板与摺

Straight Pleat Filter with Cardboard Dividers



From "History of Research and Development of the Chemical Warfare Service through 1945 – Antigas Collective Protection Equipment," December 1969.

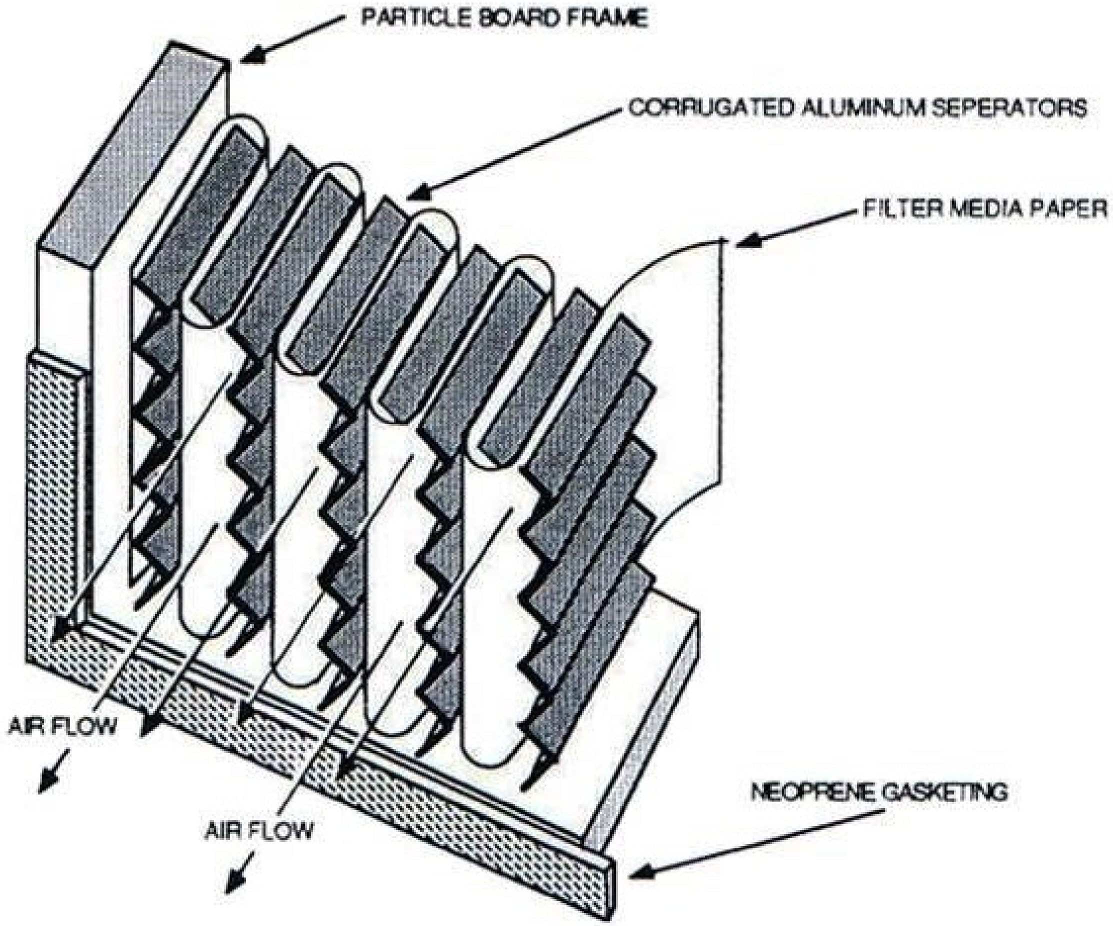
Manhattan Project曼哈顿工程

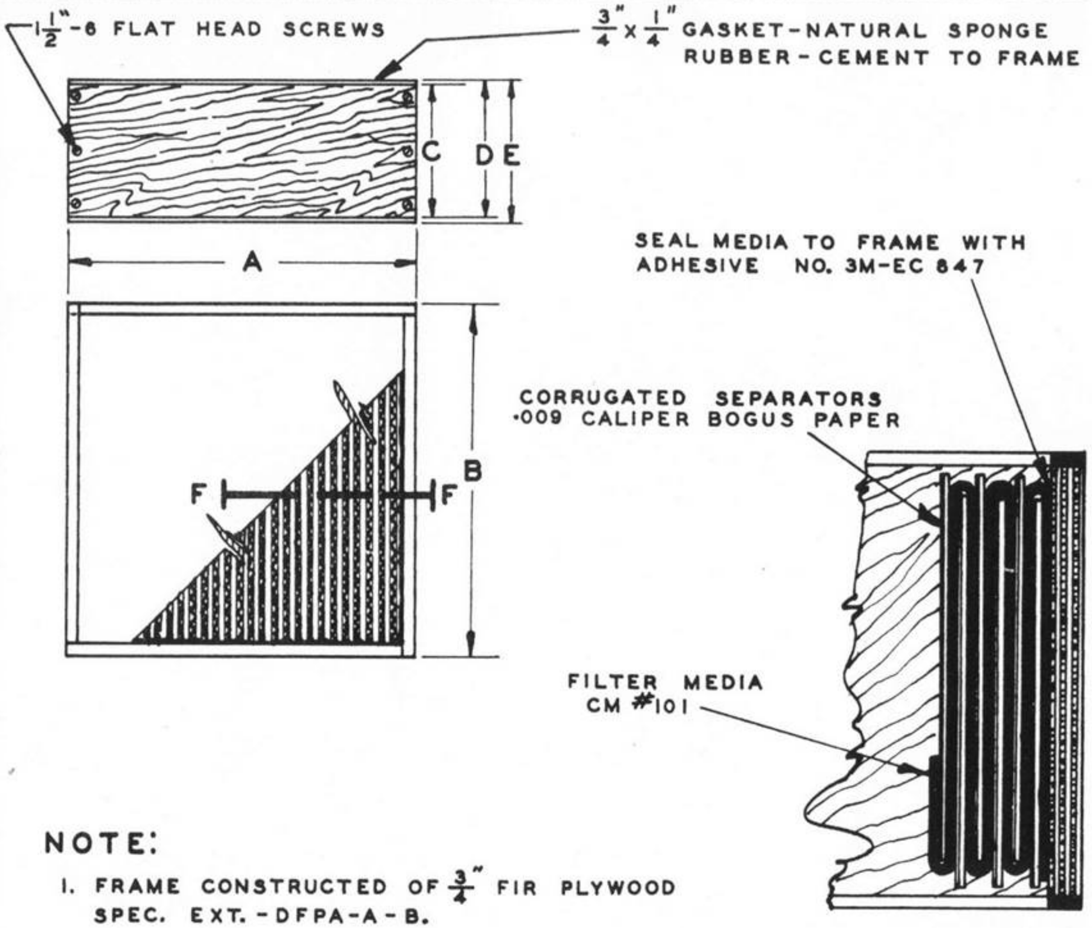
- **Humphrey Gilbert safety engineer at Los Alamos was sent to Oak Ridge**
- **Filters used in Manhattan Project were very thick with extremely high pressure drop**用在曼哈顿工程上的过滤器特别薄，很高的压力降
- **Foresaw need for high efficiency air filters in HVAC systems**预测在**HVAC**暖通系统中有高效空气过滤器需求

Absolute Air Filter完全的空气过滤器

- **Gilbert (now with AEC) unhappy with Army Space filter and its limitationsGilbert（AEC)**对空间过滤器和它的限制性很不高兴
- **AEC in 1948 gives Author D. Little a contract to redesign filter and find a supplier AEC**在**1948**年**AEC**给**D. Little** 一个合同用于重新设计过滤器并找到供应商
- **Walter Smith Ph.D. comes up with corrugated cardboard separator idea**
- **Walter Smith Ph.D**提出使纸板分隔器起邹摺

Improved Pleated Filter Design改良后的起邹褶的过滤器





SECTION "F-F"

MODEL	RATED CFM AT 1" W.G.	DIMENSIONS A	B	C	D	E
IA-25-0	30	8	8	$3\frac{1}{16}$	IA-25-1 $3\frac{5}{16}$	IA-25-2 $3\frac{9}{16}$
IA-50-0	50	8	8	$5\frac{7}{8}$	IA-50-1 $6\frac{1}{8}$	IA-50-2 $6\frac{3}{8}$
IA-250-0	250	24	24	$3\frac{1}{16}$	IA-250-1 $3\frac{5}{16}$	IA-250-2 $3\frac{9}{16}$
IA-600-0	550	24	24	$5\frac{7}{8}$	IA-600-1 $6\frac{1}{8}$	IA-600-2 $6\frac{3}{8}$
IA-1000-0	1000	24	24	$11\frac{1}{2}$	IA-1000-1 $11\frac{3}{4}$	IA-1000-2 12
IA-1250-0	1250	24	30	$11\frac{1}{2}$	IA-1250-1 $11\frac{3}{4}$	IA-1250-2 12
					DIMENSIONS & MODEL NO. 1 GASKET	DIMENSIONS & MODEL NO. 2-GASKETS

NOTE:

1. FRAME CONSTRUCTED OF $\frac{3}{4}$" FIR PLYWOOD SPEC. EXT.-DFPA-A-B.
2. TOLERANCES: $\frac{1}{16}$"$\pm$ ON OVERALL DIMENSIONS.
3. MAX. DEVIATION FROM THE SQUARE NOT MORE THAN $\frac{1}{8}$" AT ANY CORNER.

TITLE: TABULATED DIMENSIONS IA-SERIES CAMBRIDGE ABSOLUTE FILTER

CAUTION: ALL DIMENSIONS GIVEN IN INCHES DO NOT SCALE DRAWING

DR.	F. R.J. DUHAMEL	12 SEP '55	SCALE:
CH.	W. W. BALDWIN	12 SEP '55	NONE
DWG. NO	PI/GEN-022-1-A		

HEPA Filter DevelopmentHEPA过滤器发展

- **First Air Cleaning Seminar for AEC personnel held June 1951 at Harvard Air Cleaning Laboratory1951**年**6**月在哈佛空间洁净实验室举办了第一个空气洁净研讨会
- **First Handbook on Air Cleaning distributed at meeting**在会上发行了一个有关空气洁净的手册。
- **Fires at several weapons plants made need for high temperature and water resistance necessary**几个武器工厂的起火造成了对高温和防水性守滤器需求。

Second Air Cleaning Conference held in Ames, IA 1952

Melvin W. First Ph.D. Presented four research papers

1952

TABLE OF CONTENTS

Military develops procedures and

Apparatus to test High Efficiency filters and related products

Penetrometers

Q-127 Low Flow

Q-76 Med. Flow

Q-107 High Flow

Rough Handling

Water Repellency

etc.

MIL-STD-282
28 May 1956

SUPERSEDING
MIL–F–10462A (Cm1C)
30 October 1952

MILITARY STANDARD

FILTER UNITS, PROTECTIVE CLOTHING, GAS-MASK COMPONENTS AND RELATED PRODUCTS: PERFORMANCE-TEST METHODS

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON

HEPA Development for Fire & Water Resistance (1953)

DEVELOPMENT OF A

HIGH TEMPERATURE - HIGH EFFICIENCY

AIR FILTER

Summary Report
to
Division of Engineering
U. S. Atomic Energy Commission

Issued: August 18, 1953
Under Contract AT(30-1)-1013
C-58197

Arthur D. Little, Inc.
Cambridge 42, Massachusetts

First HEPA Guide (1961)

HEALTH AND SAFETY

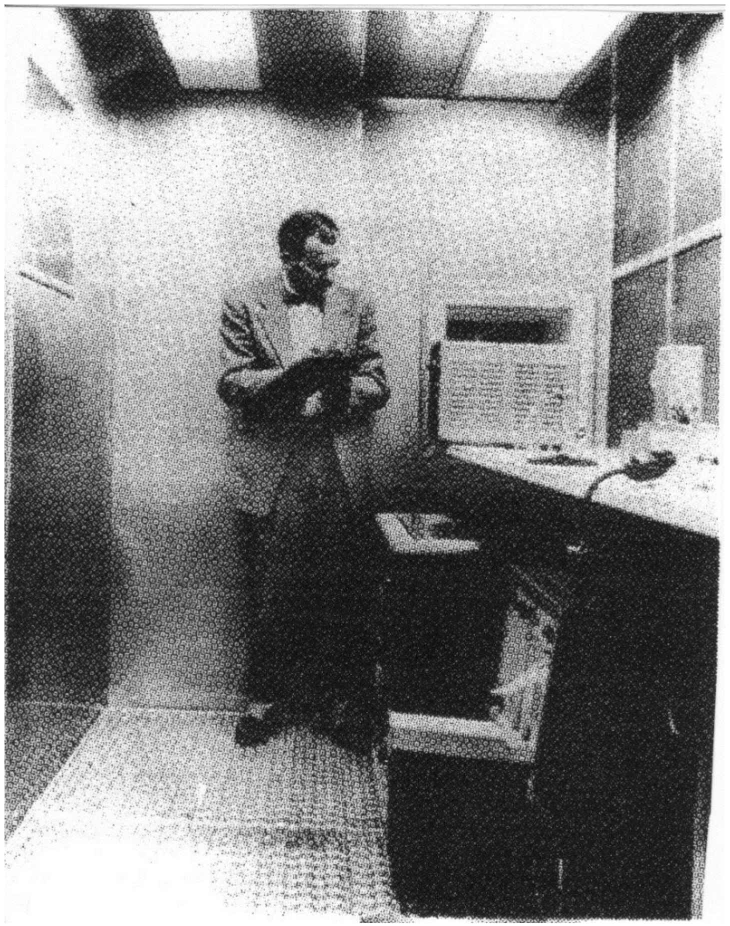
HIGH EFFICIENCY PARTICULATE AIR FILTER UNITS

HUMPHREY GILBERT
U. S. Atomic Energy Commission
Washington, D. C.

JAMES H. PALMER
General Electric Company
Richland, Washington

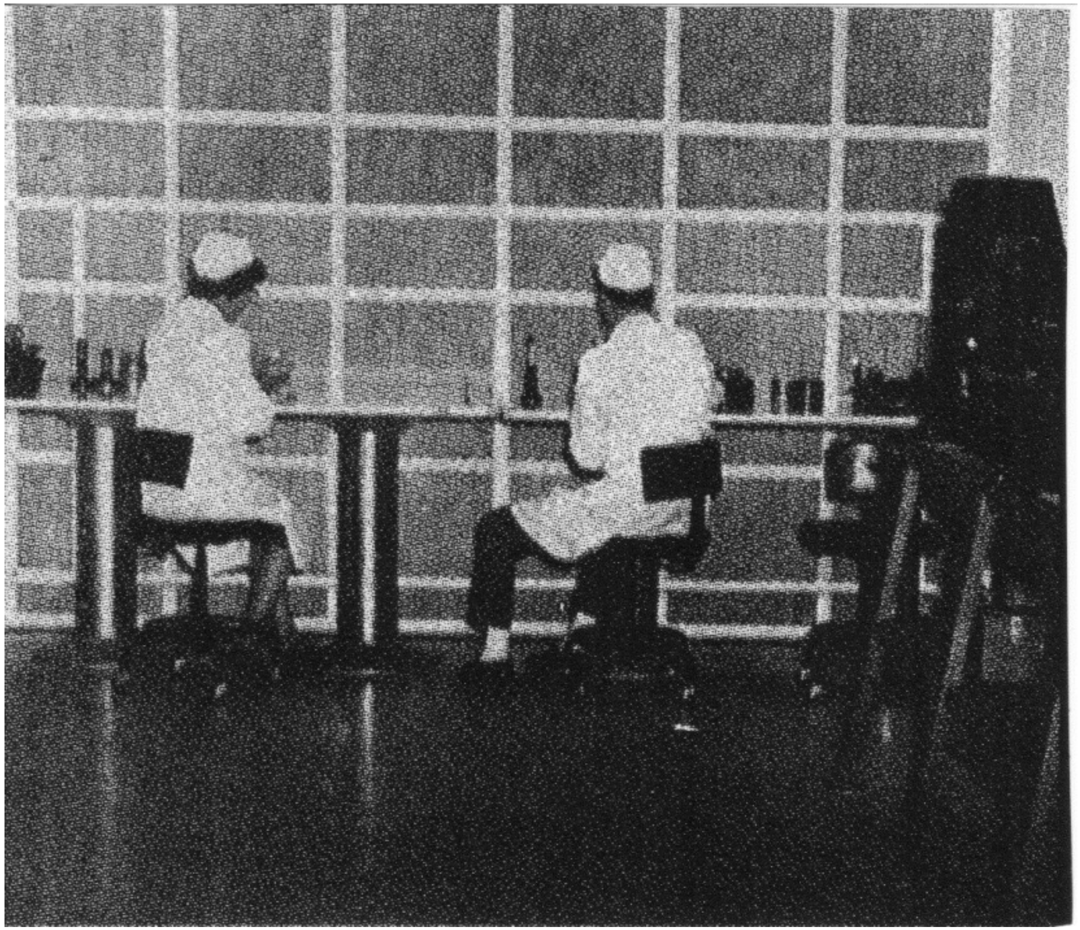
U. S. Atomic Energy Commission
Washington 25, D. C.
August 1961

Willis Whitfield (1961)



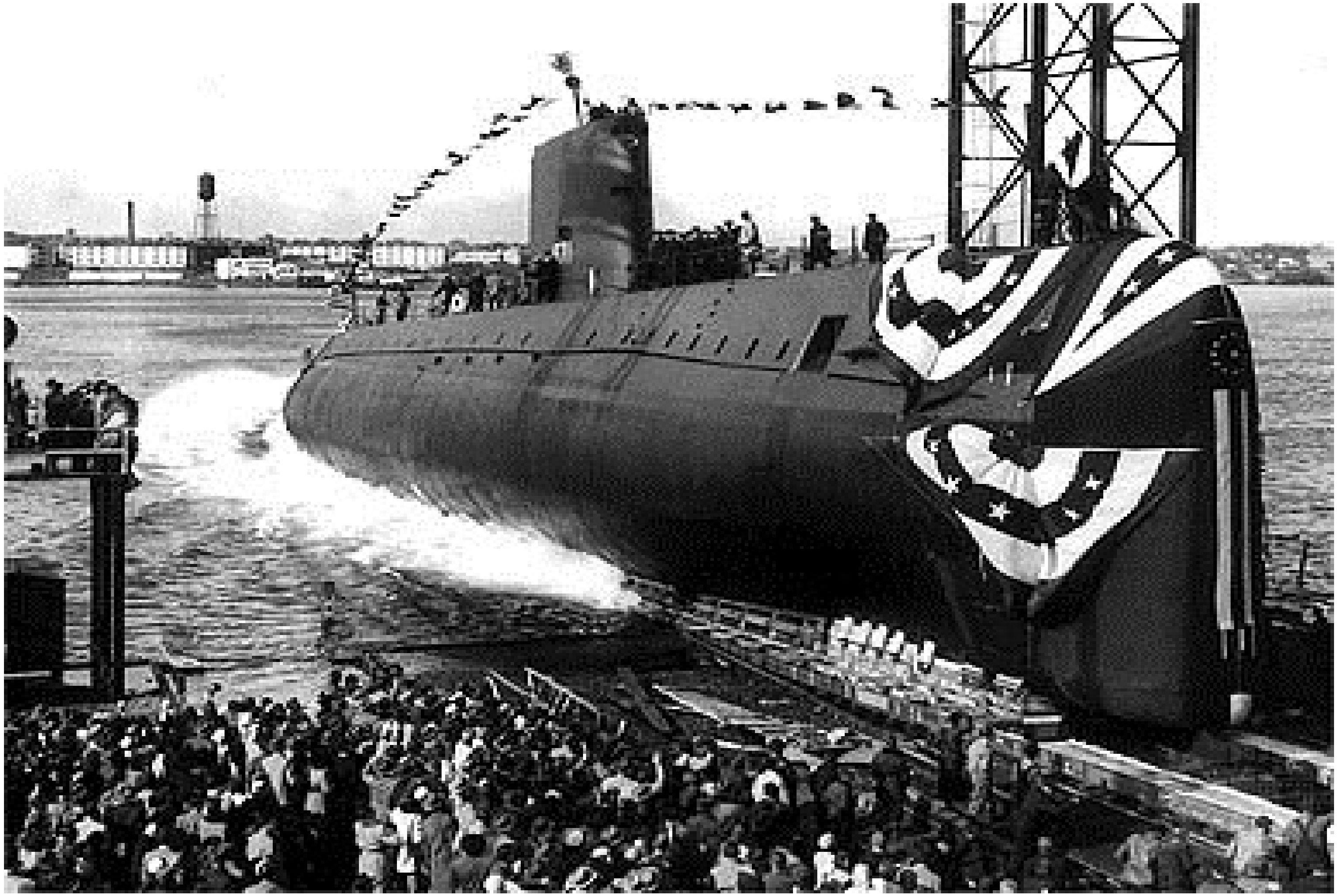
Discovery of Laminar Flow at Sandia National Labs
发明层流在Sandia国家实验室

SNL Demonstrates Clean Room Concept in Chicago for IES(T)
Sandia国家实验室在芝加哥为IEST演示洁净室

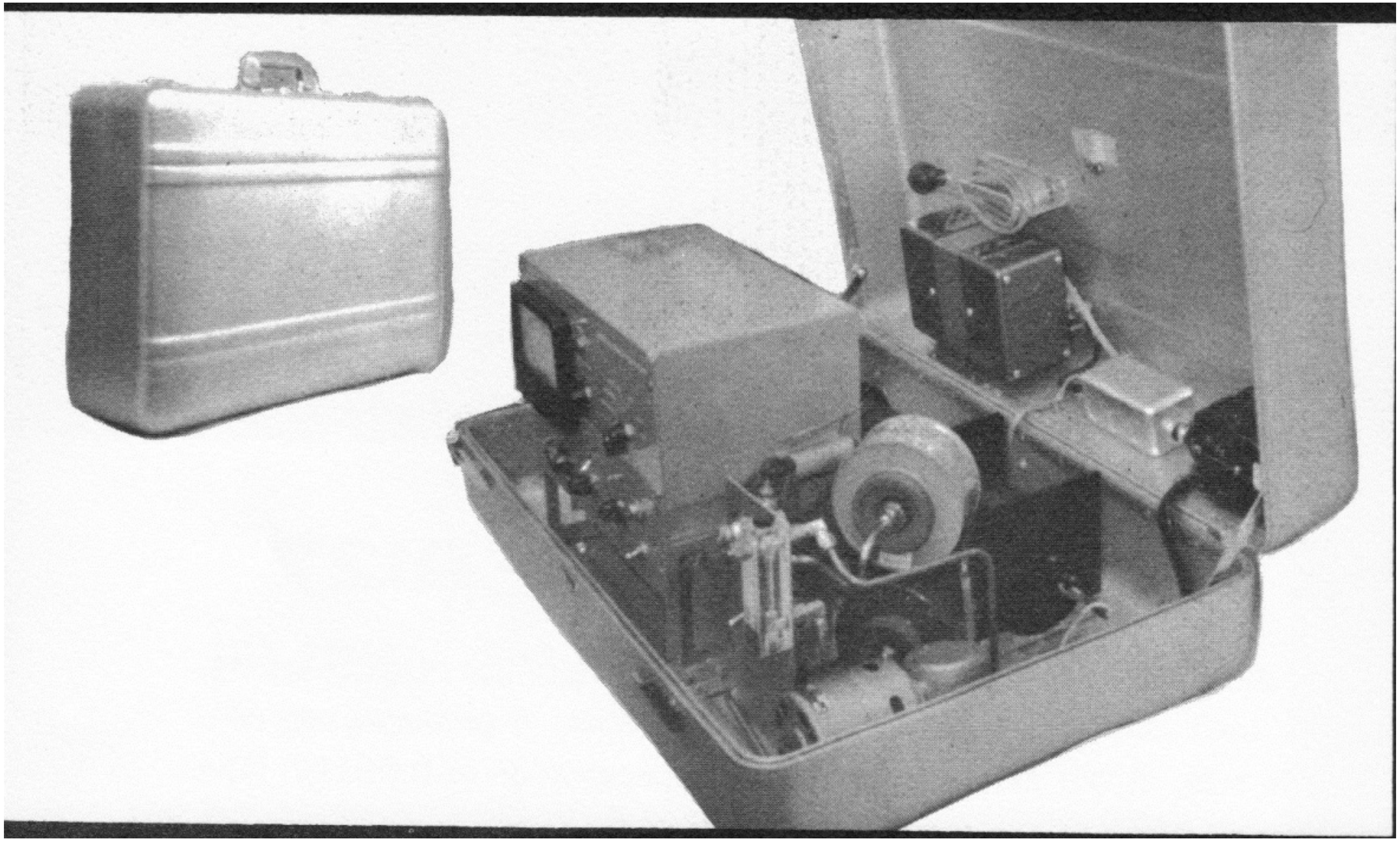


(1962)

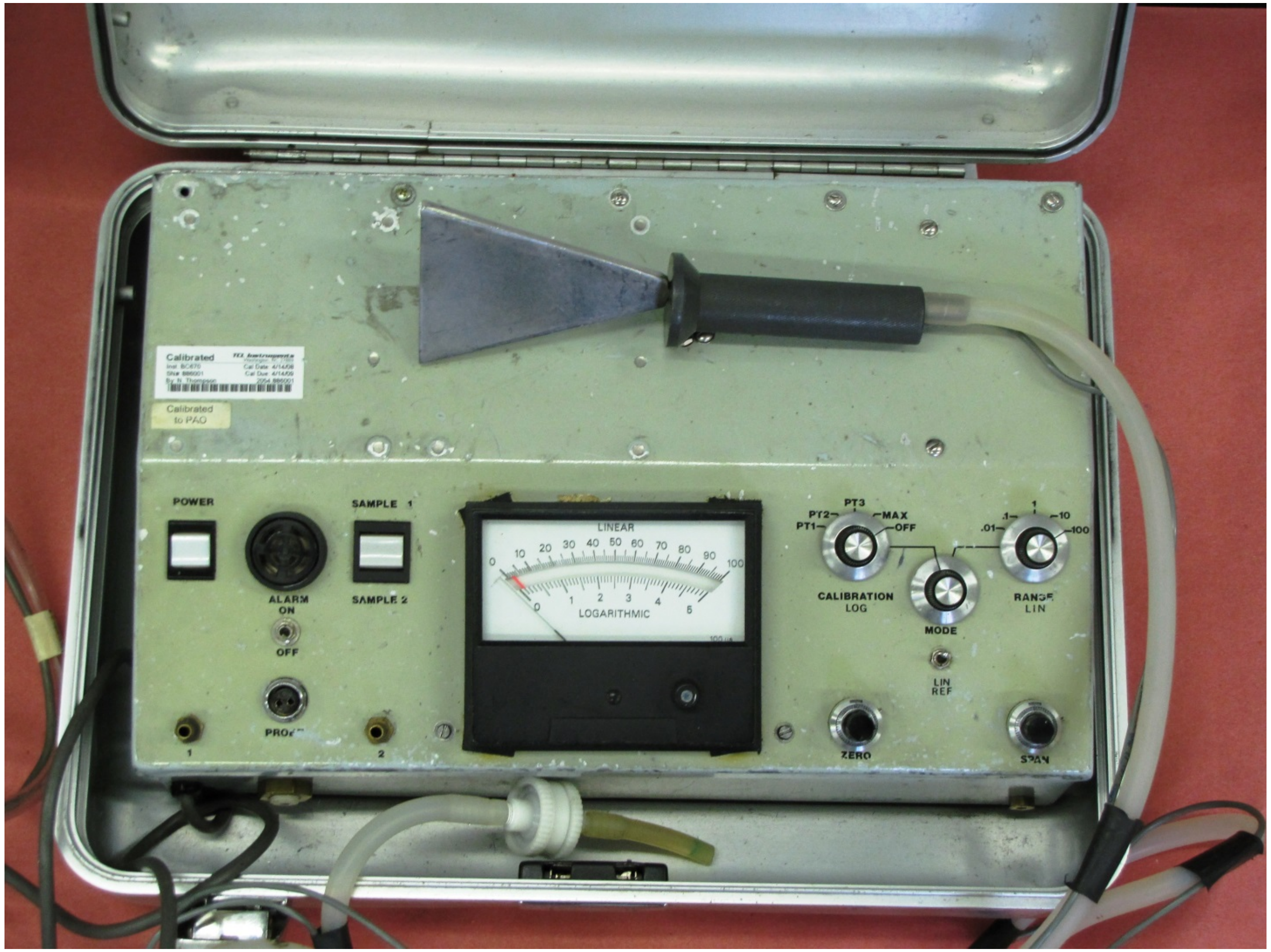
First “In Place Filter Test”



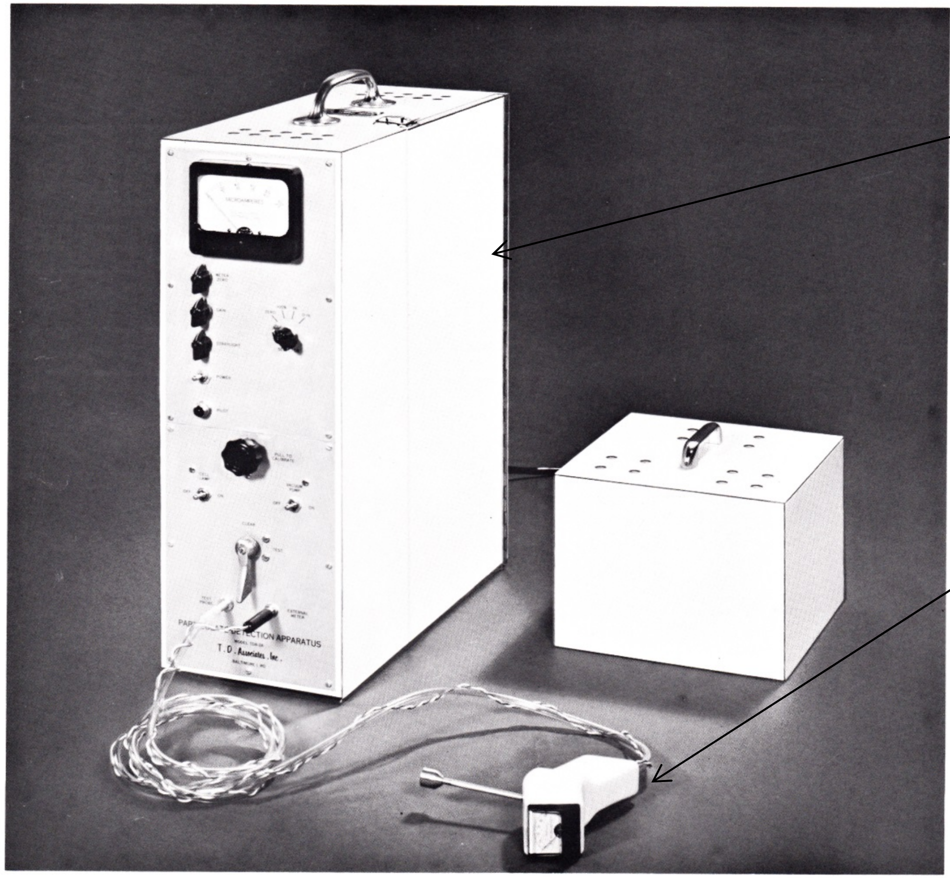
First Portable Linear Photometer TDA-2 (1962) 第一个便携式的线性光度计



JM-1000 Photometer (1964)



Next Portable Photometer TDA-2A (1964)



TDA-2A PARTICULATE DETECTION UNIT

Cabinet covered
in white Formica
(White Rooms)

First Scanning
Probe

Next Portable Photometer
TDA-2B (1965-66)

TDA-2B
PARTICULATE
DETECTION UNIT

Ergonomic front panel design

First Commercial Standards (1967)
第一个商业化标准

Tentative Standard for

HEPA FILTERS

AACC Designation: CS-1T

AACC Tentative Standard CS-1T has been prepared by Sub-Committee CS-1 of the Codes and Standards Committee of the American Association for Contamination Control. Committee members and principal contributors to the Standard are:

John M. Eagleson, The Baker Co. (Chairman)
Clifford A. Burchsted, Oak Ridge National Laboratory (Secretary)
Richard D. Bond, Air Control Inc.
George H. Cadwell, Jr. Flanders Filters, Inc.
Humphrey Gilbert, U. S. Atomic Energy Commission
Roger T. Goulet, Cambridge Filter Corp.
Charles A. Gunn, Mine Safety Appliances Co.
R. Claude Marsh, Envirco, Inc.
Robert D. Peck, Controlled Environment Equipment Corp.
Wilson V. Pink, Western Electric Co.
Samuel B. Steinberg, Air Technology Associates
Charles D. Weston, Dynac Corporation

Tentitive Standard CS-1T was approved for publication by the National Council of the AACC in Chicago, Illinois on May 17, 1968.

Comments on CS-1T are invited and should be addressed to: Codes and Standards Committee, AACC, 6 Beacon Street, Suite 620, Boston, Massachusetts 02108. All comments should be received by May 1, 1969.

First Commercial Standards (1967)

Tentative Standard for

LAMINAR FLOW
CLEAN AIR DEVICES

AACC Designation: CS-2T

AACC Tentative Standard CS-2T has been prepared by Sub-Committee CS-2 of the Codes and Standards Committee of the American Association for Contamination Control. Committee members and principal contributors to the Standard are:

Robert D. Peck, Controlled Environment Equipment Corp. (Chairman)
Clifford A. Burchsted, Oak Ridge National Laboratory (Secretary)
Boyd Agnew, Agnew-Higgins, Inc.
Wendell L. Anderson, Naval Research Laboratory
John Bolt, Morison Products, Inc.
Richard D. Bond, Air Control, Inc.
Burt Brown, The Lau Blower Co.
George H. Cadwell, Jr., Flanders Filters, Inc.
Robert N. Culbert, Farr Co.
Harold F. Farquhar, The Lau Blower Co.
Humphrey Gilbert, U. S. Atomic Energy Commission
Roger T. Goulet, Cambridge Filter Corp.
Charles A. Gunn, Mine Safety Appliance Co.
Alexander E. Irons, Jet Propulsion Laboratory
Paul C. Issberner, Jr., Farr Co.
Keith Linn, Pure Aire Corp. of America
R. Claude Marsh, Envirco, Inc.
Wilson V. Pink, Western Electric Co.
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Discussion

What is a Filter过滤器是什么

Before Photometry在光度计之前…

- What is a Filter?过滤器是什么
  - Filtration Mechanics过滤机理
  - MPPS最易穿透滤径
- How to Test a Filter怎样测试一个过滤器
  - Efficiency效率
  - Leak (Integrity)泄露（完整性）

What is a Filter?过滤器是什么

Separation of one phase from another从另一种物质中分离一种物质

•Solids or liquids in Air (Home Furnace)空气中的固体或液体

•Solids in liquid (Auto Oil/Gas)液体中的固体

•Liquid in Air (Air oil separators)空气中的液体

•Liquid in liquid (RO)液体中的液体（反渗透）

•Gas in Gas (Activated Carbon)气体中的气体（活性碳）

What is a Filter?

A Controlled Leak!一个被控制的泄露

Filtration controls the amount of impurity that is allowed to pass.过滤控制杂质允许通过的量

There is no such thing as a ‘perfect’ filter

(no resistance and 100% efficiency)没有一个完美的过滤器，没有阻力但有100%效率

Filtration Types过滤器类型

- Materials滤材
  - Fibers纤维
  - Fibrous Structures纤维状结构
  - Micropores微孔
- Performance性能
  - High Efficiency 高效率
  - Low Efficiency 低效率

What are we dealing with?处理什么？

Solids or liquids in Air空气中的固体或液体

&

Fibrous Filters纤维过滤器

Other structures are more common in ultra filtration and special applications在超高效过滤器中和特殊的应用的其它的结构也是很普通

Fibrous Filters纤维过滤器

- Typically Depth Filters典型的深度过滤器
  - Filtration throughout media depth通过滤材的深度来过滤
  - Very low to very high particle removal 低到高的颗粒除去范围
- Fibrous Filter Construction
  - Filter Disks/Pads 过滤饼状/平板状
  - Pleated Cartridges邹摺的园筒状
  - Bags/Pockets包/口袋

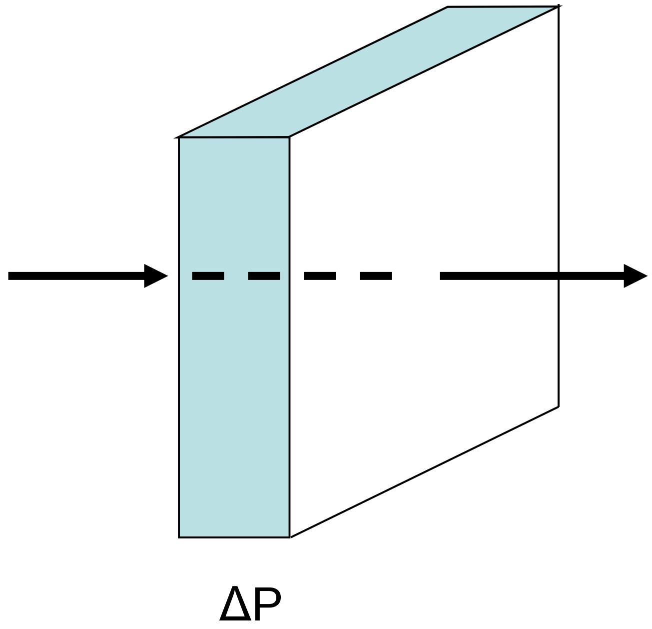
Filtration Mechanics过滤机理

- Pressure Drop压力降
- Single Filter Efficiency单个过滤器效率
- Collection Mechanisms收集的方法

Darcy's Law Darcy定律

- A way to determine pressure drop while designing a filter

$$\Delta P = KU\mu L$$



Where:

ΔP = pressure drop

K = Darcy's Law constant

U = face velocity

μ = viscosity

L = filter thickness

设计一个过滤器时，决定阻力（压力降）的公式，K 常数，U过滤器面速，u风粘度， L过滤器厚度

Darcy's Law

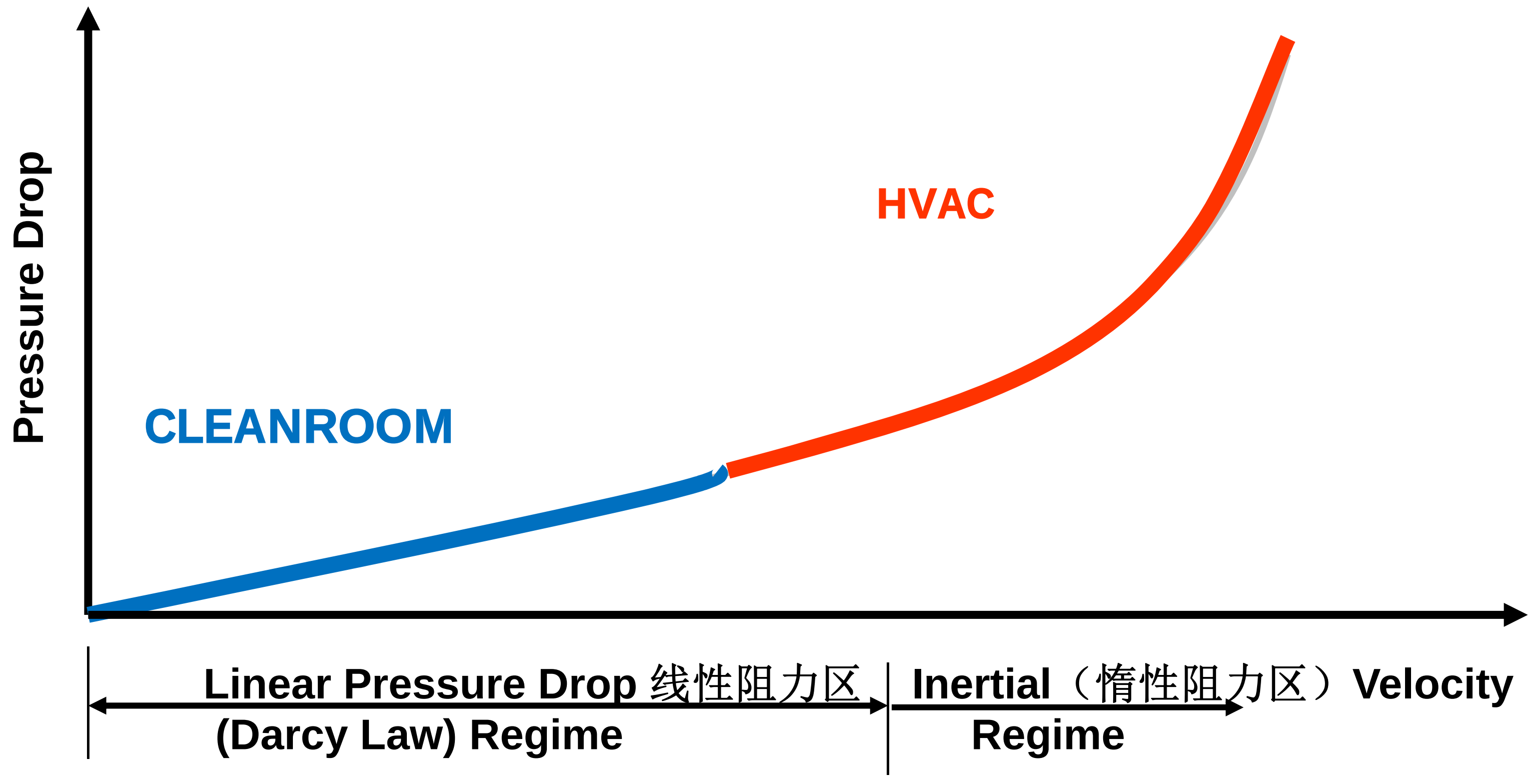
Simplified: $\Delta P = KU$

Key take away:

Pressure Drop is Proportional to Flow

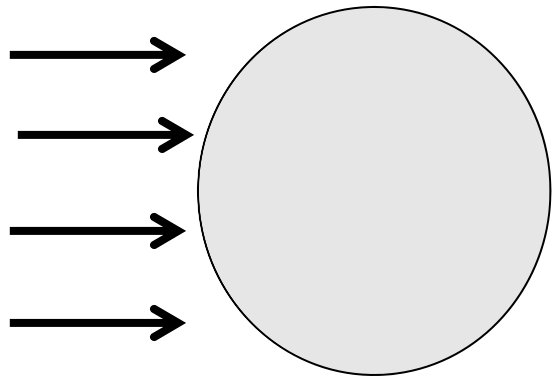
公式可简化为阻力与风量成正比

Filter Pressure Drop

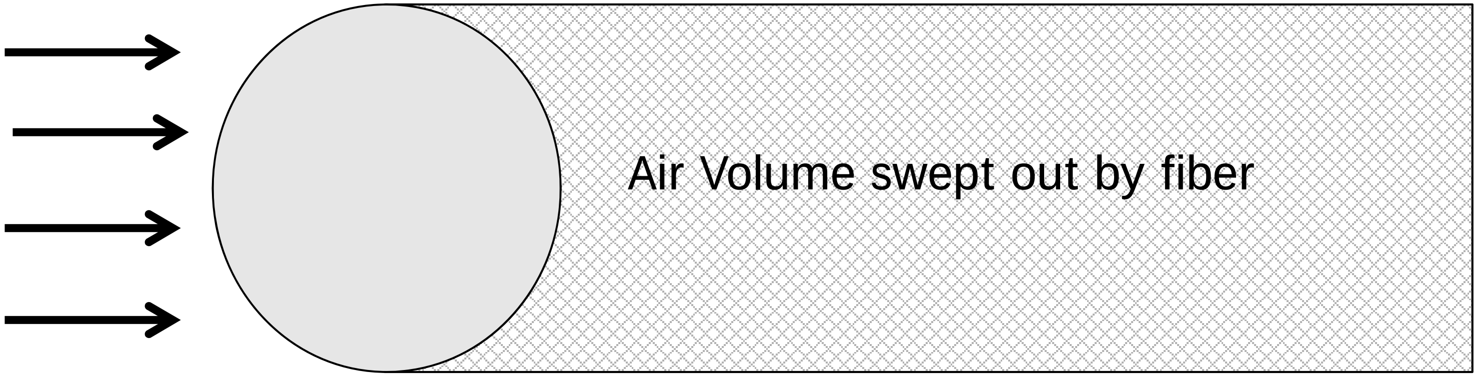


Filtration Assumptions过滤设定

- Fibers are in cross flow
  纤维在交叉流动气流中
- Particles are ‘collected’ upon contact with fiber
- 一接触纤维，颗粒将被收集
- Uniform fiber diameter 均匀一致的纤维直径
- Uniform particle size 均匀的颗粒尺寸



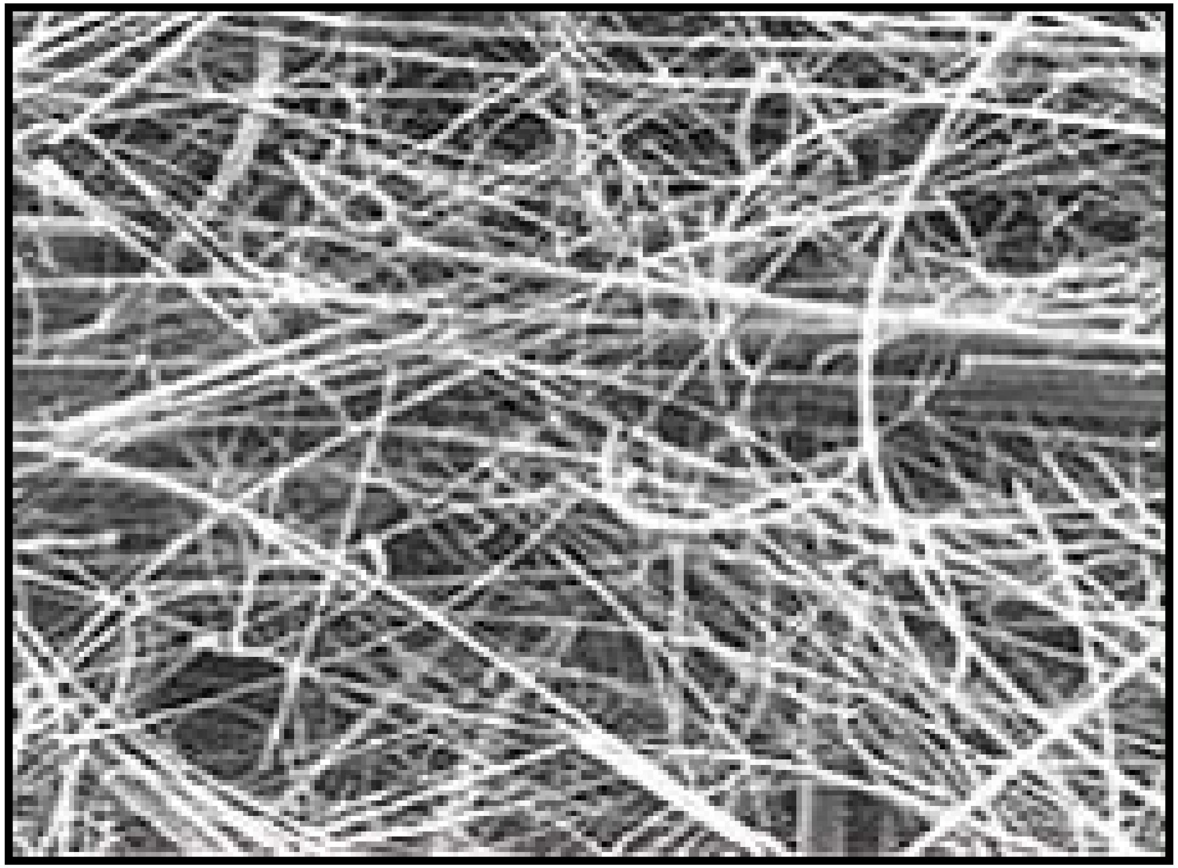
Single Fiber Efficiency单一纤维的效率



Single Fiber Efficiency

$$\eta_s = \frac{\text{Particles collected by fiber 被纤维收集的颗粒}}{\text{Particles in volume of air geometrically swept out by fiber纤维结构中的总颗粒}}$$

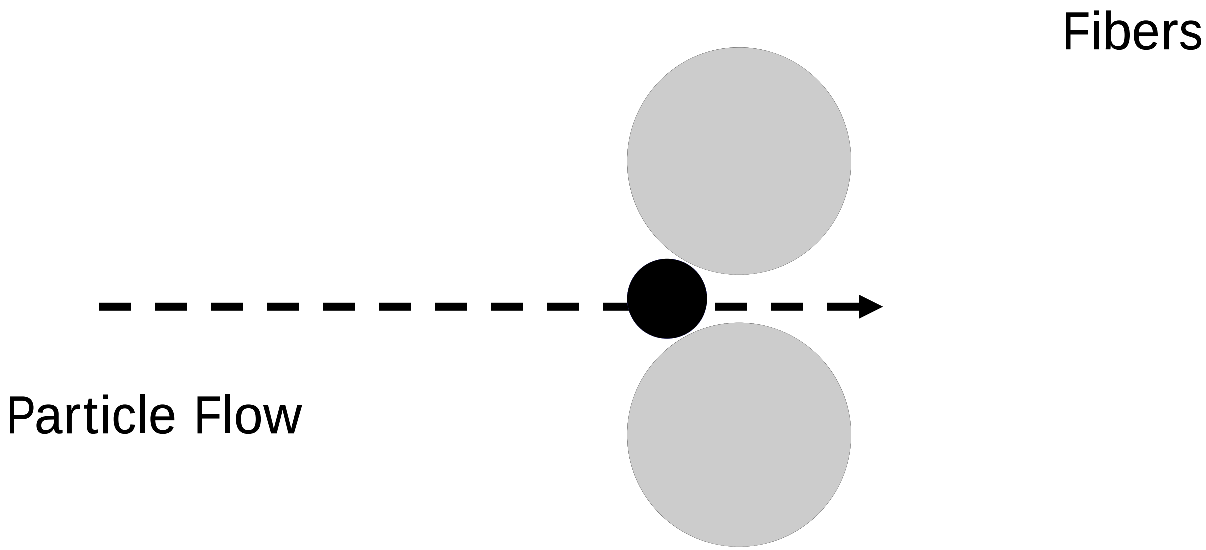
Fiber Structure – HEPA
HEPA 中纤维的结构



Particle Collection Mechanics 颗粒被收集的机理

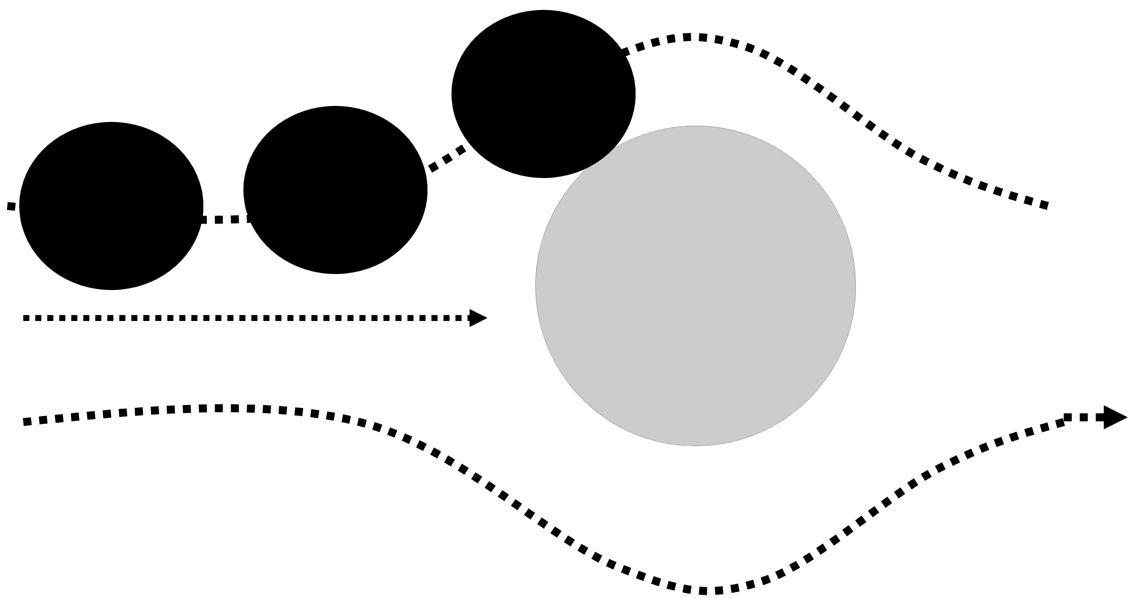
- Sieving 筛
- Inertial Impaction惯性撞击
- Diffusion扩散
- Interception拦截

Particle Collection: Sieving



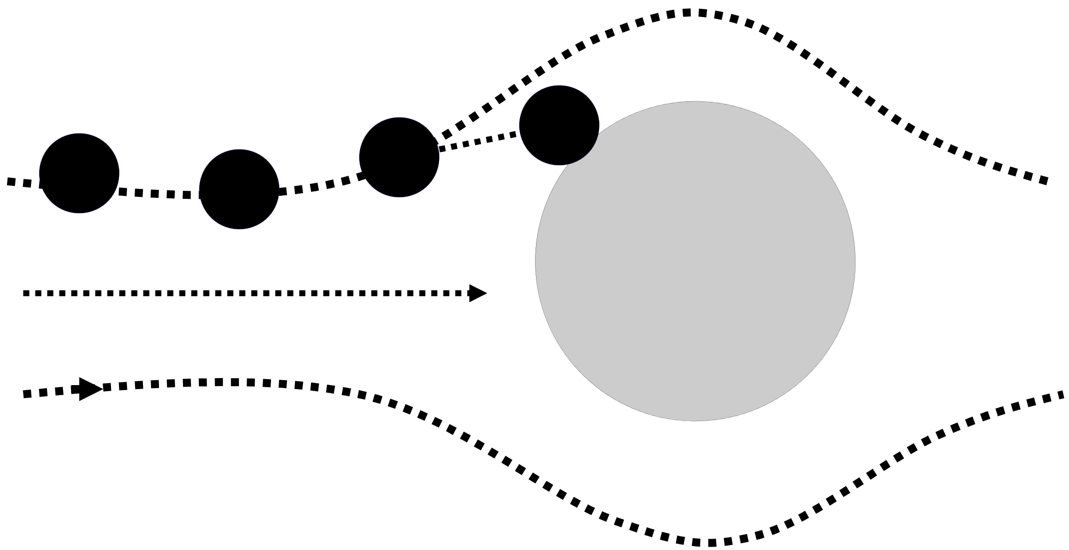
筛是一种最直观的收集方法，然而这个机理通常是发生在预过滤而不是 HEPA过滤器

Particle Collection: Interception拦截



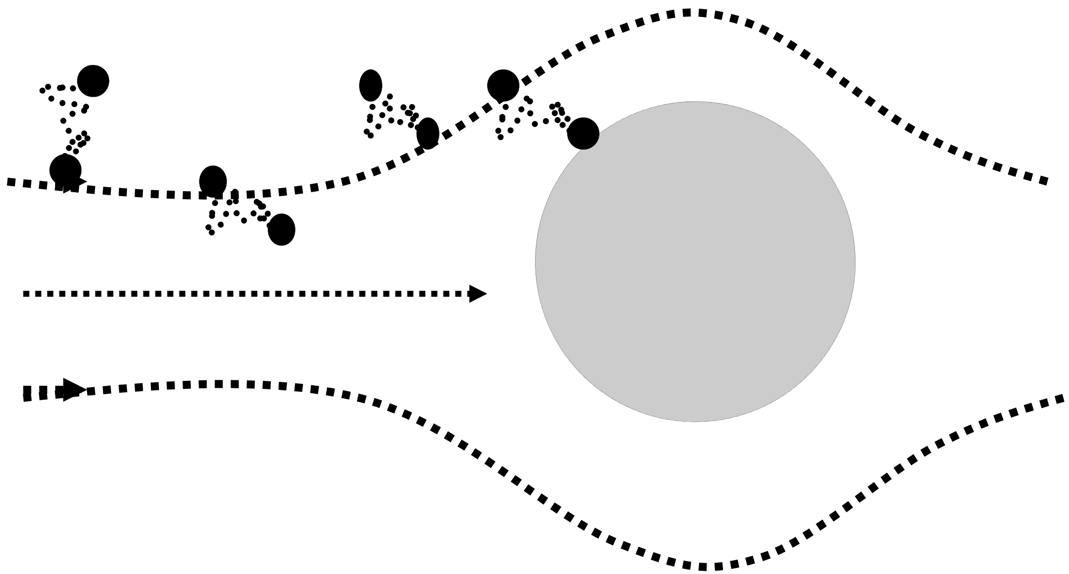
拦截机量是一个撞击， 颗粒撞击到纤维上于是被收集，大于颗粒常发生，因为其几何体积减少了其扩散的可能性

Particle Collection: Inertial Impaction惯性撞击



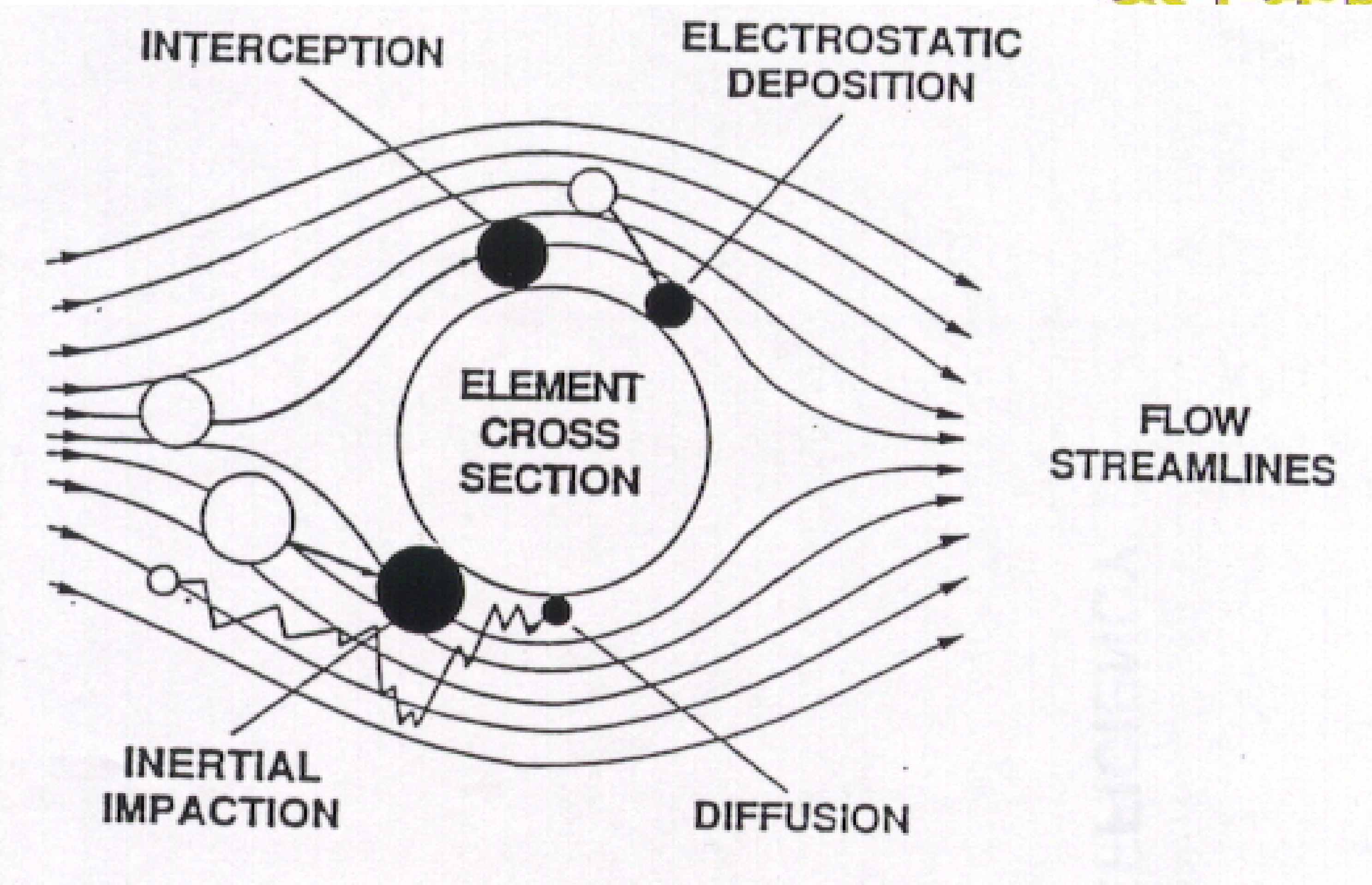
大颗粒，由于其巨大的质量，因而有大的惯性，从空气中分离，当气体混合一个纤维，并撞击到纤维上，在一个高的气流中惯性撞击的效果是很大的。

Particle Collection: Diffusion
颗粒收集：扩散



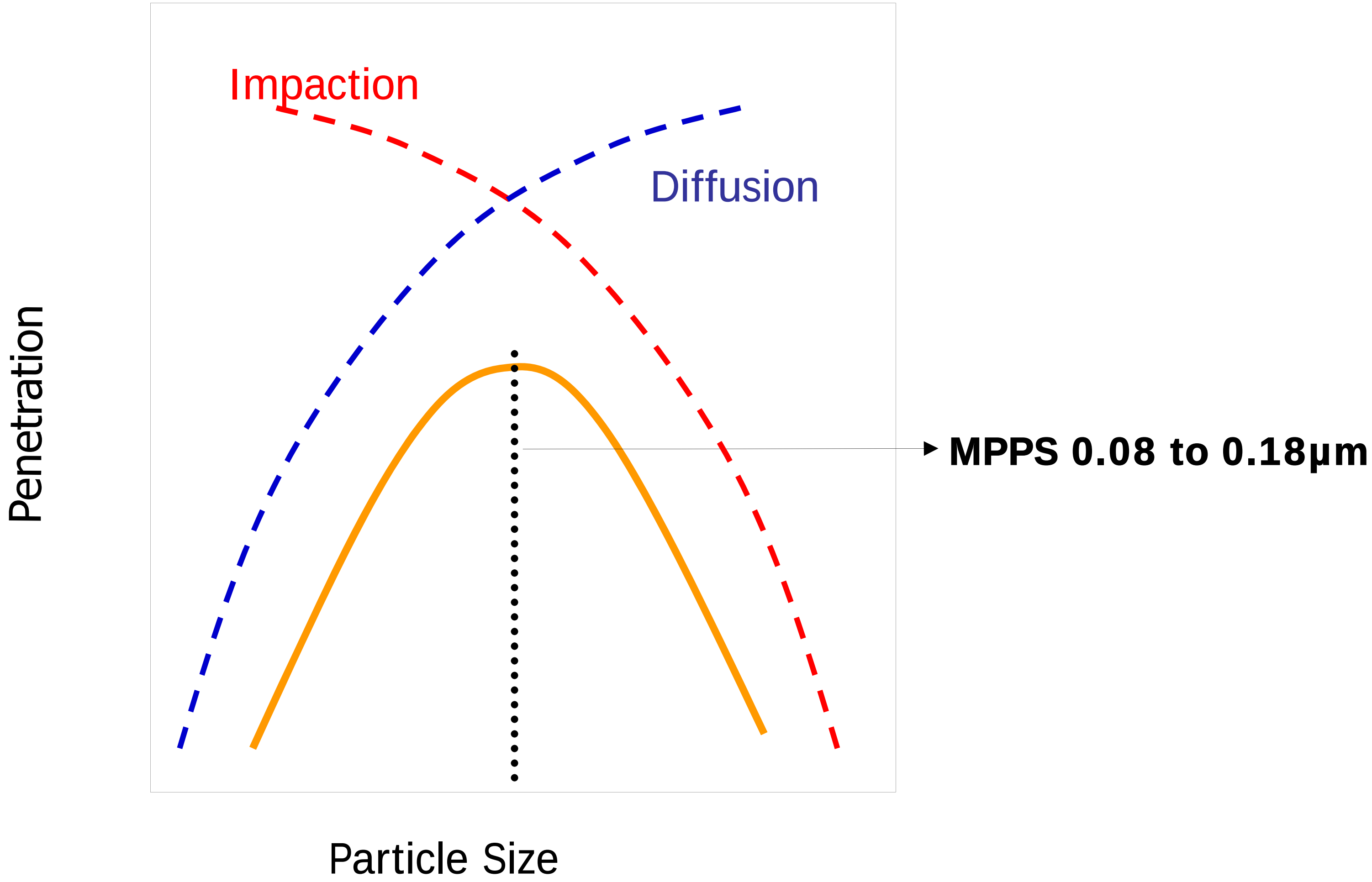
由于小颗粒的无序运动，扩散会产生，对于小颗粒来说扩散是很明显的，他们的无序的运动当碰到纤维时就会被收集到，但对于大颗粒来说扩散效果会减少。

Particle Collection Mechanisms

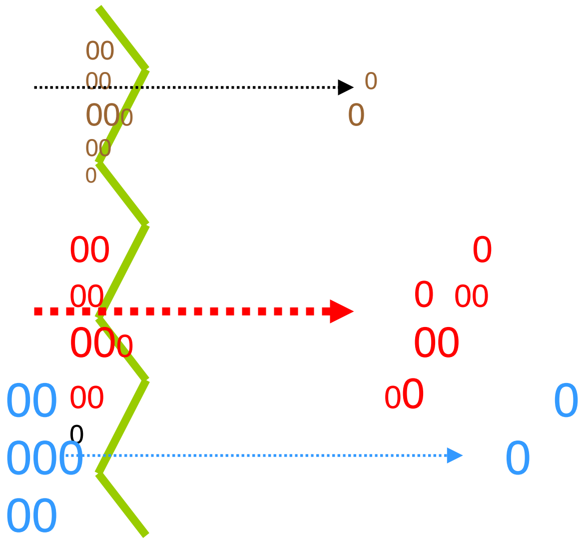


范德华力是一旦接触，颗粒就被捕捉到。这是小的在分子间的电子束缚力，这是为何壁虎能爬垂直的墙，并没有吸或粘的东西。当纤维被带上电荷，颗粒被速上相反的电荷 ，也有发生这样的，但仅仅是对于一些材质。为了得到静电的永久效果，滤材必须保持干的并被速上电荷的。如果湿气存在，电荷将被泄露掉。实际上高效被带上静电被快速的消散掉。

High Efficiency Filter MPPS
(Most Penetrating Particle Size)

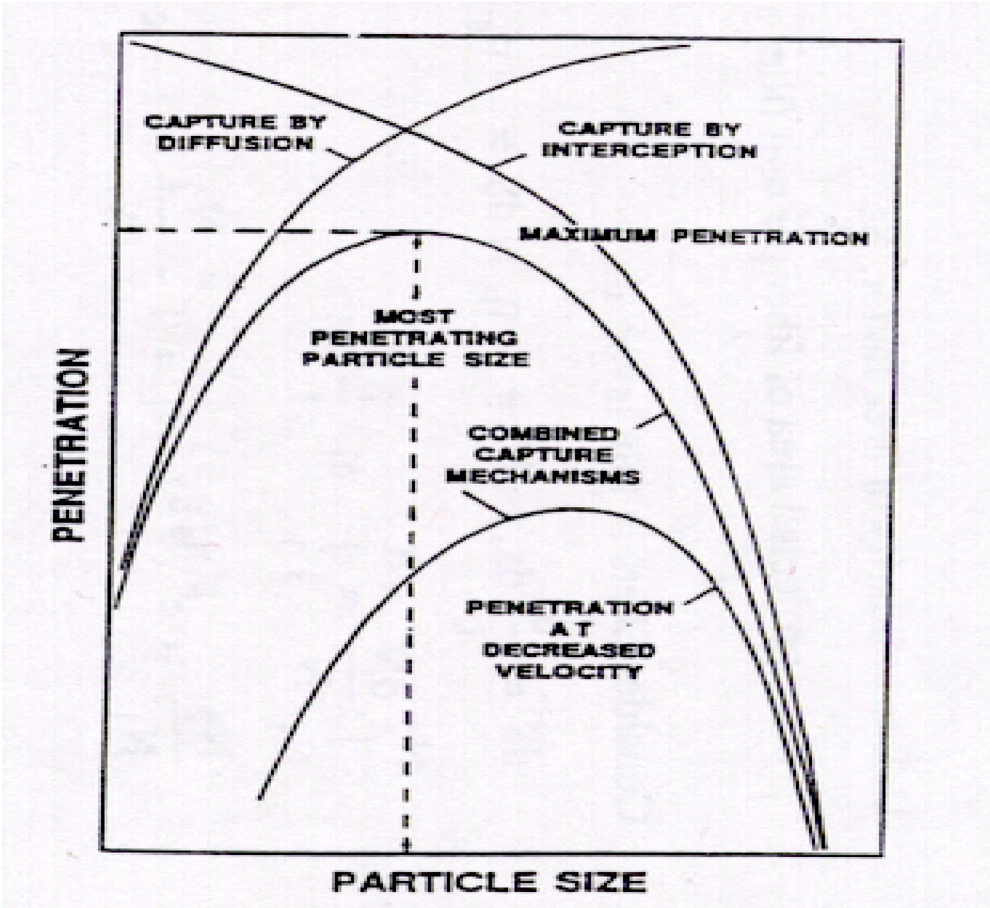


Filtration is
Selective Particle Collection

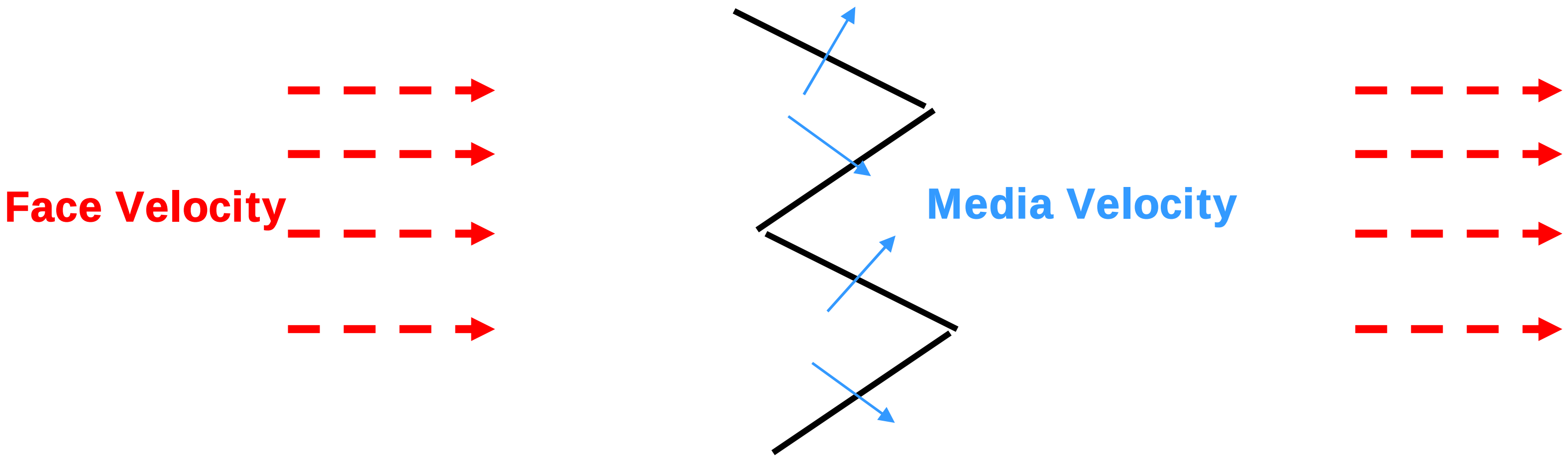


Small and big particles are more effectively collected

Impact of Flow Rate on Efficiency



Media Velocity is Lower Than Face Velocity滤材的速度是低于面速



A Filter’s Performance is Determined
at Media Velocity 过滤器的性能决定于滤材的速度

Consideration in Filter Design 过滤器设计中的考虑

- Penetration or efficiency穿过率或效率
- Critical Particle Size关键颗粒尺寸
- Pressure Drop or resistance压力降或阻力
- (Cost)成本

Filter Tests过滤器测试

- Efficiency效率
  - Media Manufacturer滤材制作
  - Filter Manufacturer过滤器制作
  - 3rd Party Certification第三方论证
- Leak/Integrity泄露/完整性
  - Filter Manufacturer过滤器制作
  - Field/In-Situ现场

Efficiency Testing效率测试

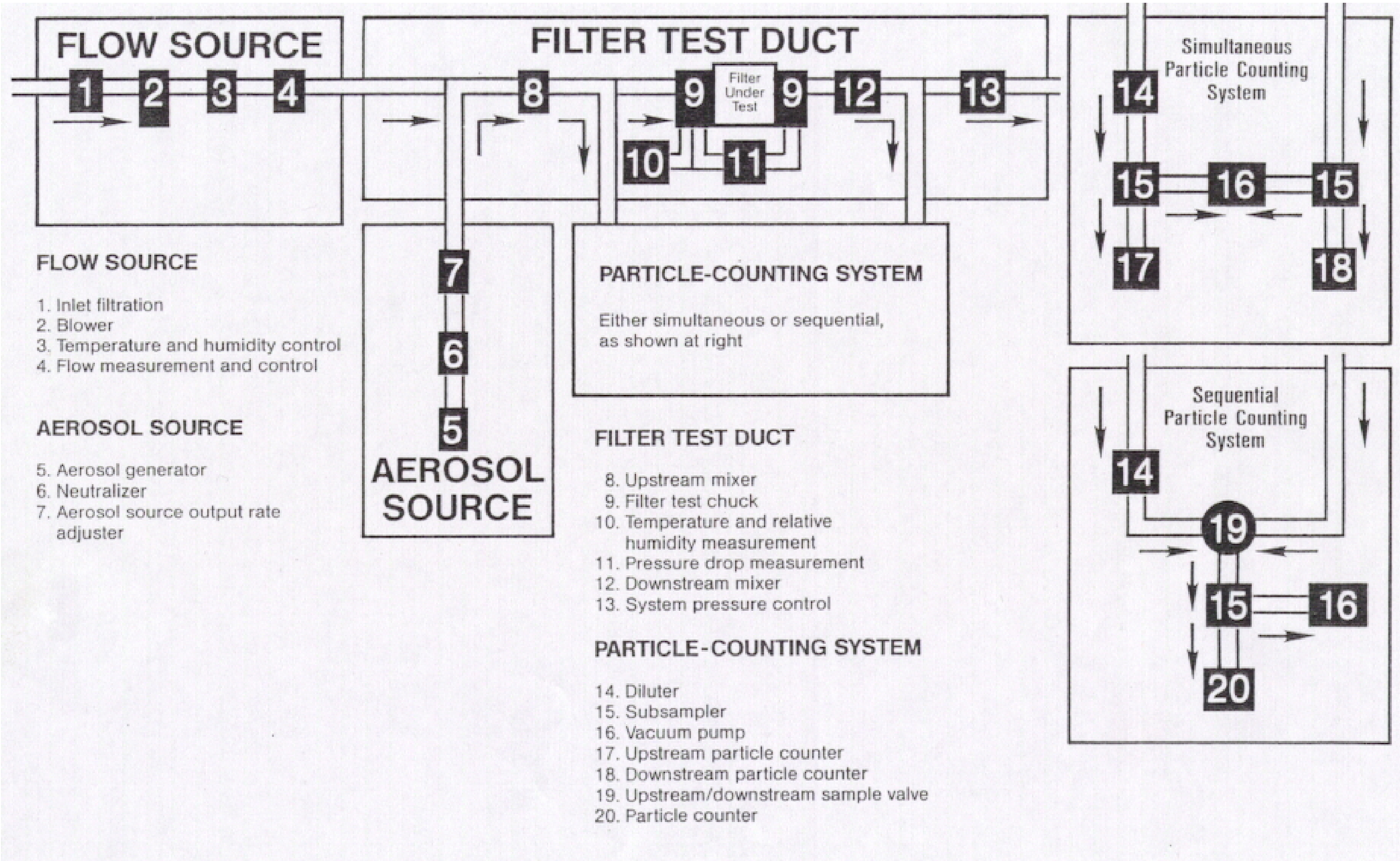
- Challenge filter with aerosol at or near the MPPS
  - This requires a mono-dispersed aerosol (tight distribution)

    用等于或接近于 MPPS尺寸的颗粒来挑战过滤-需要单一分布的气溶胶
- Measure upstream and downstream concentration测量上下游浓度
- Sequential or parallel (simultaneous) measurements

  按次序的或平行的测量
- Efficiency = 1 – $\frac{\text{Downstream}}{\text{Upstream}}$

Note: This is a ‘global’ measurement (i.e. entire filter)

Typical Filter Efficiency Test System典型的过滤器效率测试

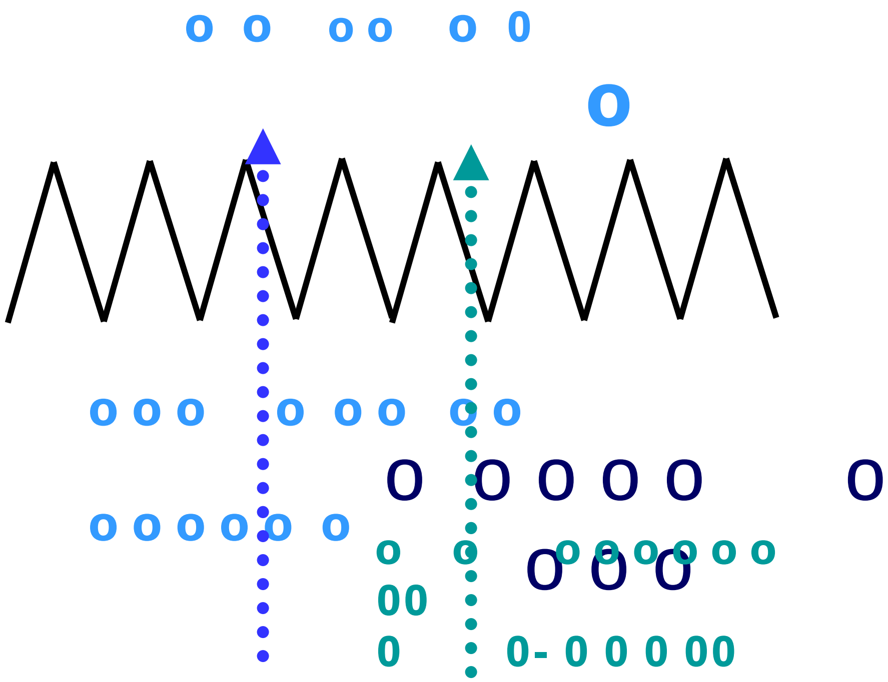


Recommended filter performance test system from IEST RP-CC-0021

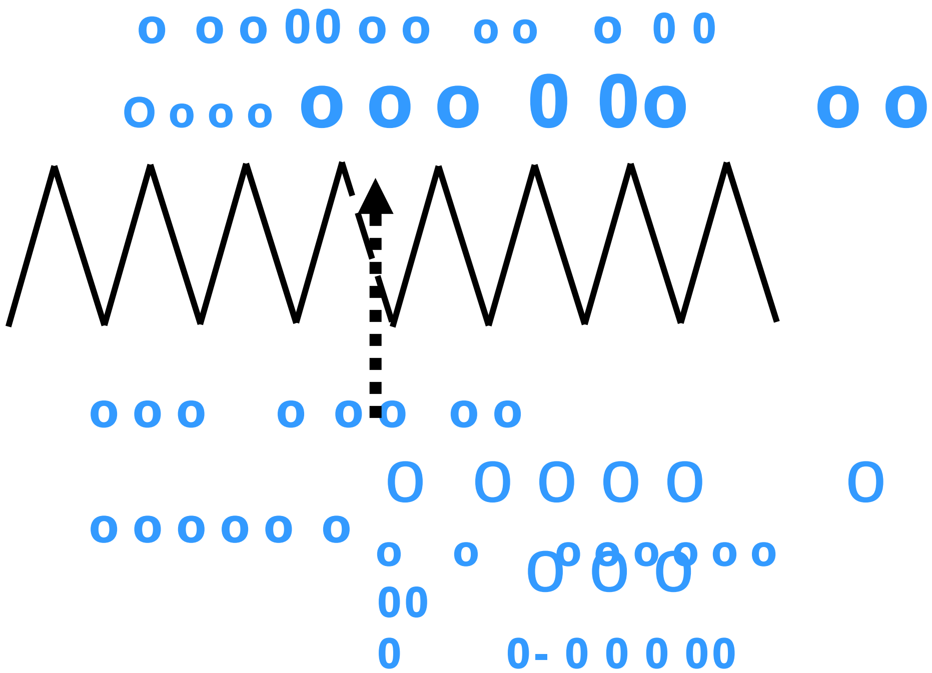
What is a Leak?什么是泄露

- Leak is a local measurement泄露是一个局部的测量.
- Leak is generally 5 –10 times the average penetration at a local spot.
- 泄露是在一个局部点上测试约为5-10倍的平均穿透率。
- Therefore we do not require a mono-dispersed challenge aerosol at the MPPS因而我们不需要一个单一尺寸的挑战性粒子
  - Easier and less costly to generate larger particles with a broader distribution.
  - 容易且低成本的产生颗粒且一个广泛的分布

A Good Filter Will Allow Few Particles to Penetrate好的过滤器允许少一些粒子透过



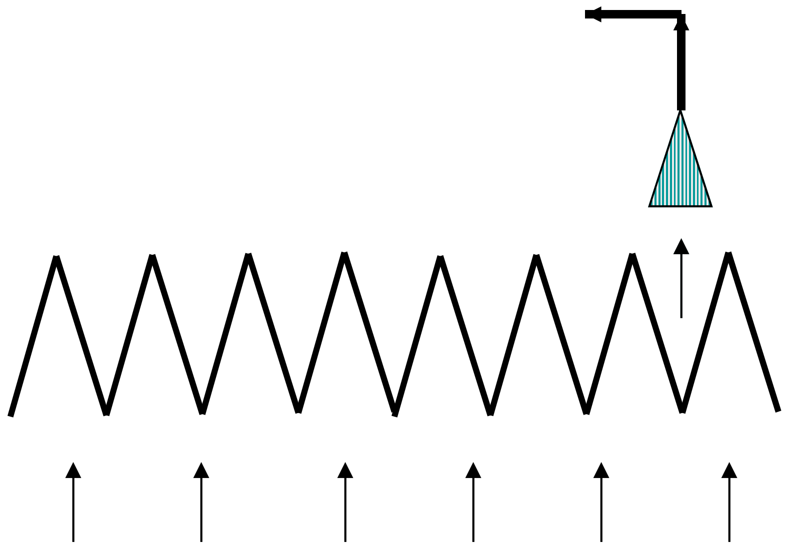
Add a Leak and…



Test for a Leak/Integrity

- Measure local penetration at each sample location to determine在每一个取样位置取样决定本地的穿透率:
  - Filters are not faulty / not been damaged
  - 过滤器没有问题且没有被破坏
  - Filters have been installed properly
  - 过滤器被正确的安装
  - There are no leaks in the mounting frame / between mounting frame and housing在过滤器安装的边框也没有泄露
  - System contains no by-pass of the filter

Leak/Integrity Scanning泄露扫描



Ensure that all parts of filter are within specification
确认过滤器所有部分都在合适的范围内

Efficiency vs. Leak/Integrity in General Terms

		Efficiency Testing 效率测试		Leak Testing 汇露测试
		Global整体		*Local局部*
Determine % Penetration 决定穿透率		Yes		Yes[1]
Pinpoint Leaks 针眼泄露		No		Yes
Manufacturer Test厂家测试		Yes		Yes[2]
Field Test 现场测试		No		Yes

1 – Local % penetration, not overall efficiency
2 – Due to variations in the media manufacturing process

Discussion

When Testing a Filter What are We Looking For?

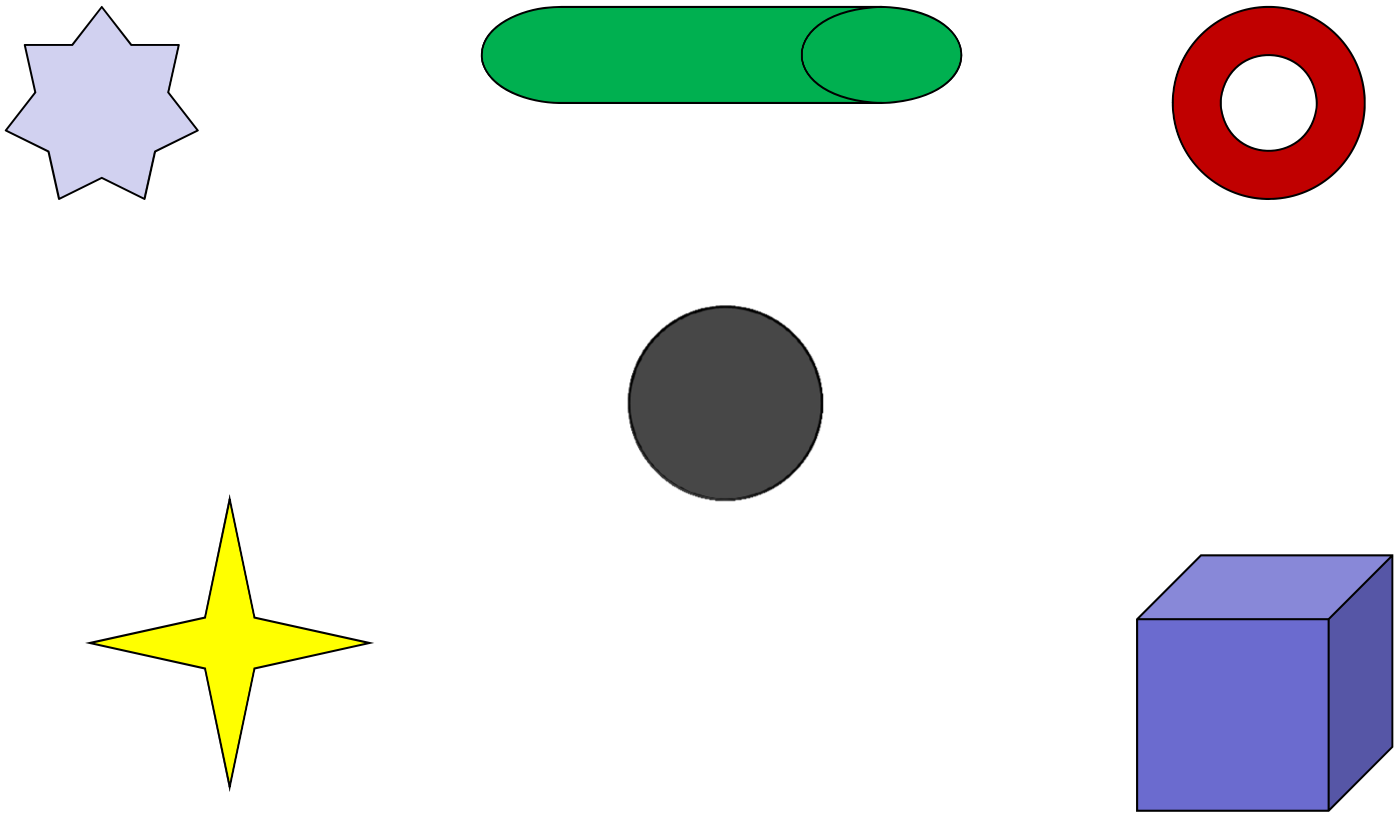
当测试一个过滤器时我们在寻找什么？

Let’s Review…

- Particulate penetration as颗粒穿透作为
  - Efficiency效率
  - Leak泄露
- Size of interest?感兴趣尺寸
  - MPPS from 0.08 to 0.18 micron MPPS 0.08-0.18微米
  - Even when looking for a leak?甚至当我们寻找一个泄露

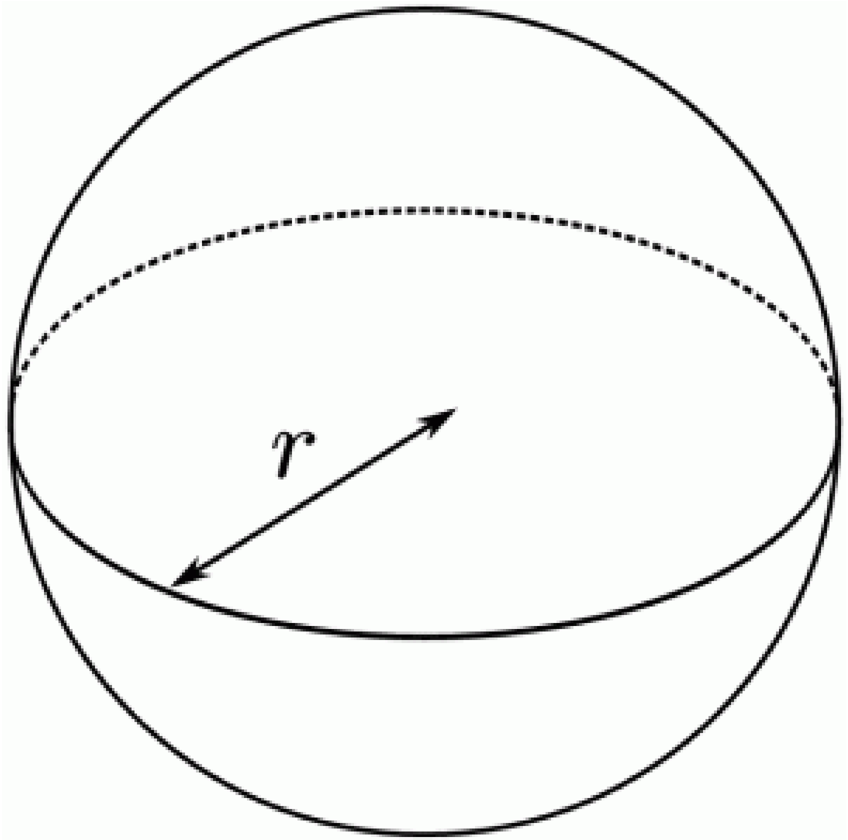
However然而…..

What is a particle什么是颗粒?



颗粒有不同的形状和尺寸，可见的有机物还能改变形状，所以我们怎么能指定一个颗粒粒径呢？

The Simplest Particle最简单的颗粒?



真实的世界是复杂的，所以我们必须是简化我们所看到的，最简单的3维形状处理是一个球，球的尺寸是它的半径或直径

Equivalent Particle Sizes相等的颗粒尺寸

- Diameter of a *<u>Sphere</u>* that has the same magnitude of a chosen Property as the particle In question 直径有不同的属性
  - Optical Diameter (Eye/microscope)光学直径（眼/显微镜）
  - Scattering Diameter (Light Scattering)散射直径（光散射）
  - Electric Mobility (Charge On Particle)电子迁移（给颗粒充电）
  - Mobility (Diffusion)移动（扩散）
  - Stokes Diameter (Drag Forces)
  - Aerodynamic Diameter (Settling Speed)空气动力学直径

In Filtration, Collections of Particles Interest Us在过滤器，收集过滤吸引我们

- Aerosol气溶胶 Solid/Liquid and Gas (dust, fog)固体/液体和气体

- Hydrosol水溶胶 Solid固体/Liquid液体 and Liqu (milk牛奶, paint油漆, lotion洗液

- Foam泡沫 Gas in Solid or Liquid
- 在固体或液体间的气体 (sponge海绵, 香波shampoo)

Key Concepts主要的概念

- Drag Force牵引力 – proportional $d_p > 10\mu m$
- Slip Correction for $d_p < 10\mu m$
- Stopping Distance and Relaxation Time
- Settling velocity
- Mobility and Electric Mobility
- Diffusion and Brownian Motion
- Coagulation
- Dimensionless Numbers

Units of Measurement in Filtration测量中的单位

- µm		Micrometer, 10^{-6} meter
- Nm		Nanometer, 10^{-9} meter
- A		Angstrom Unit, 10^{-10} meter

1 µm = 1,000 nm = 10,000 A

Some perspective:

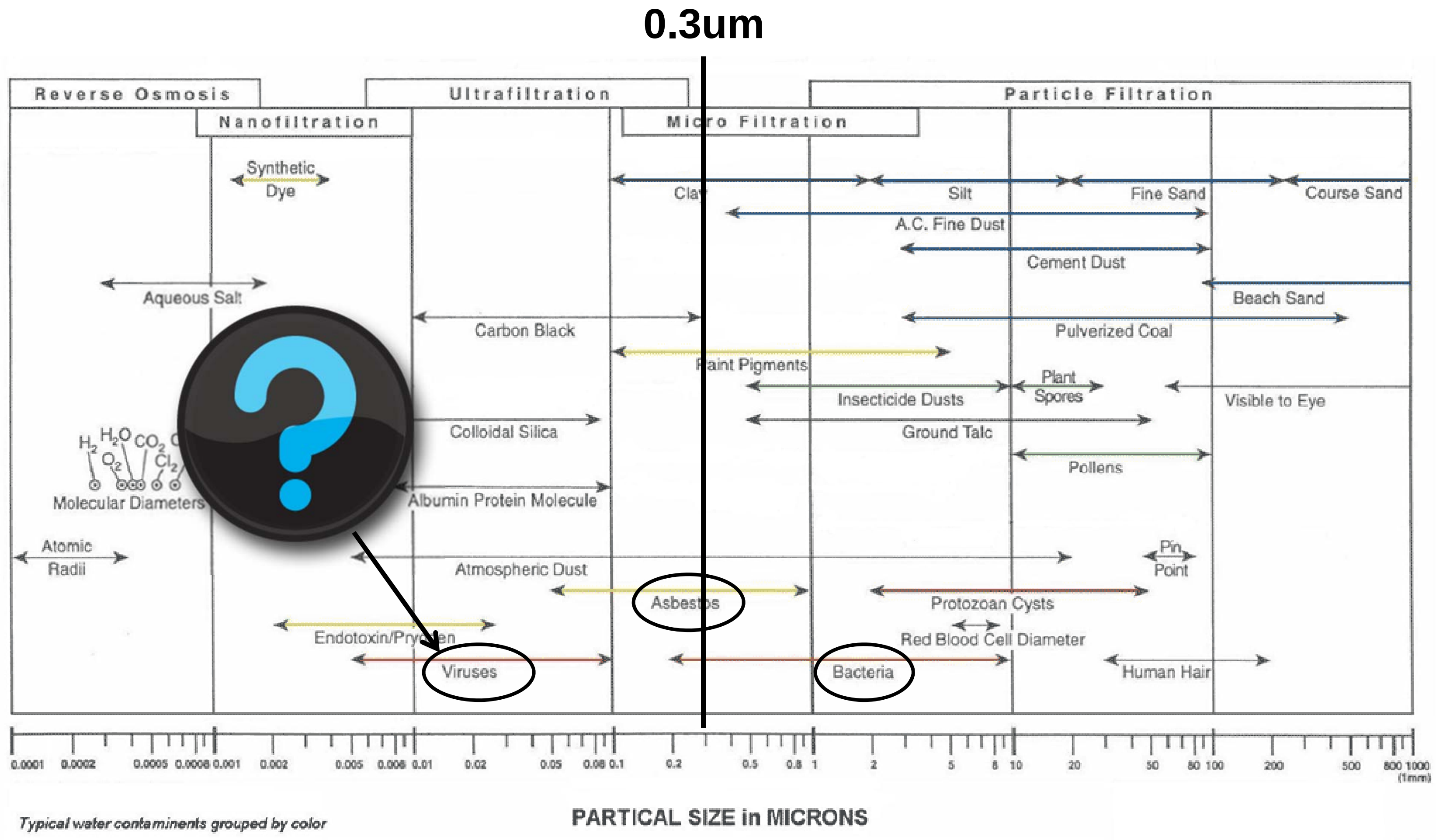
1cm is 1000 µm

1in = 2.54 cm = 25,400 µm

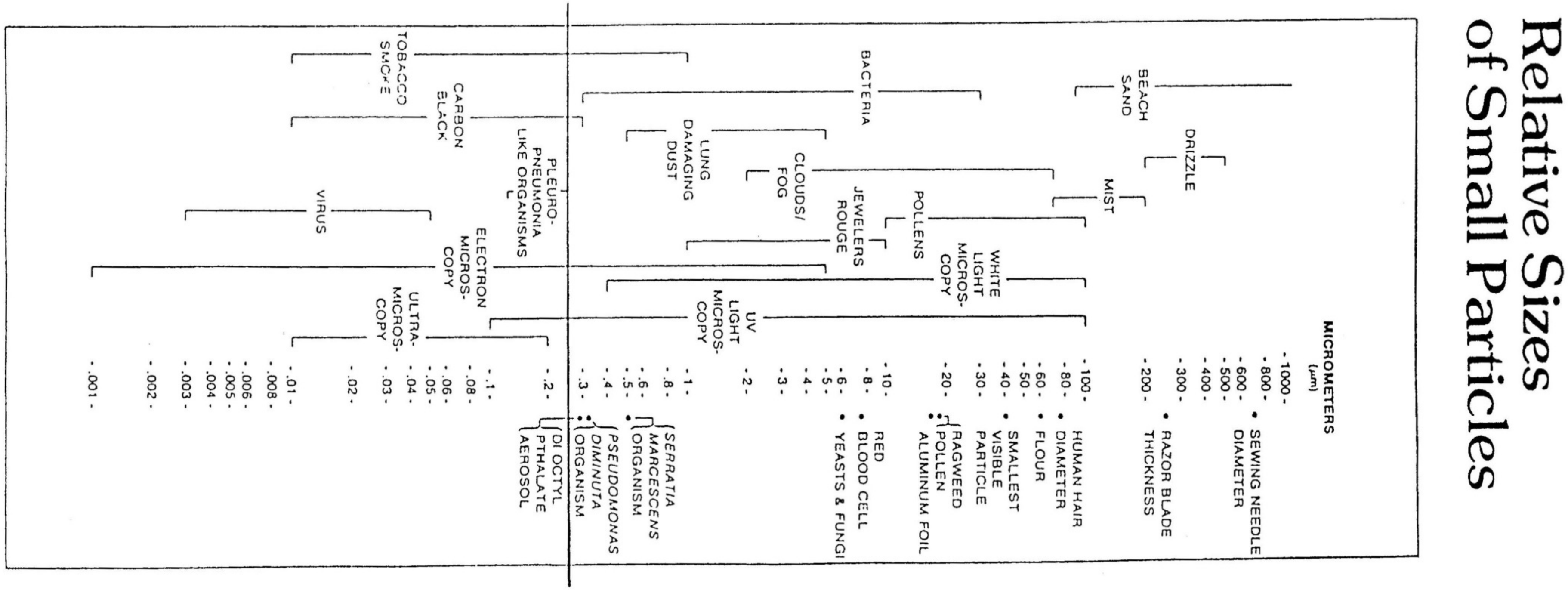
Particle Sizes of Interest感兴趣的颗粒尺寸

Item	Approximate Particle Diameter 对应颗粒尺寸
Eye of a Needle针眼	1,230 microns
Beach Sand沙滩	100 – 2000 microns
Table salt餐桌上的盐	~100 microns
Human hair人头发	40 - 300 microns
Talcum powder	~10 microns
Tobacco Smoke烟	0.01 – 1.0 microns
Bacteria细菌	0.2 - 0.3 microns
Virus病毒	<0.005 – 0.05 microns

Typical Particle Sizes



Another Particle Size Chart



Typical Settling Velocity典型沉降速度

Diameter (um)	**Feet/min英尺/分钟**
0.1	0.00016
1.0	0.002
10.0	0.59
100	59.2

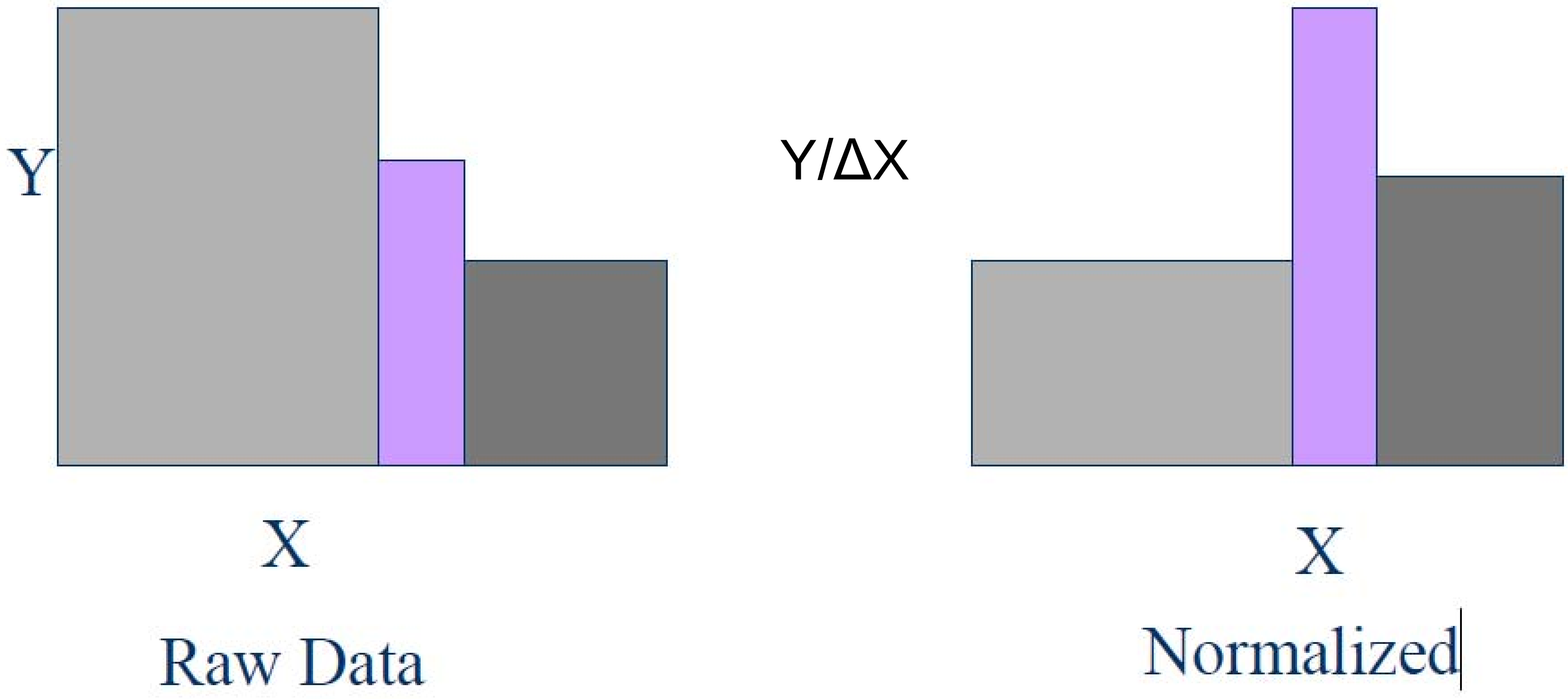
我们感兴趣的颗粒可在空气中停一些时间，大的颗粒将沉降得非常快。

How is an Aerosol Characterized?气溶胶的特性

Consider this data set

		Frequency	
X (range)		Raw Data	Normalized
0 to 5		100	20
5 to 6		70	70
6 to 8		60	30

Normalized Frequency Distribution标准化的分布

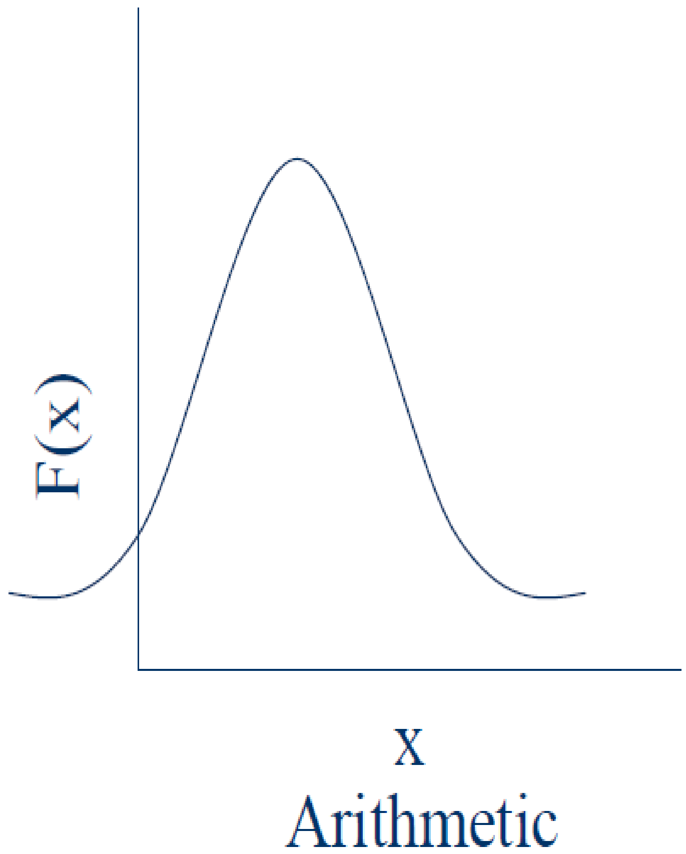


Size Distribution Terms尺寸分布定义

- Independent variable独立变量, X
- Mean 平均X_m
- Standard Deviation标准偏差, σ
- Mode (peak)顶值
- Median (50^{th} percentile)中值（50%）

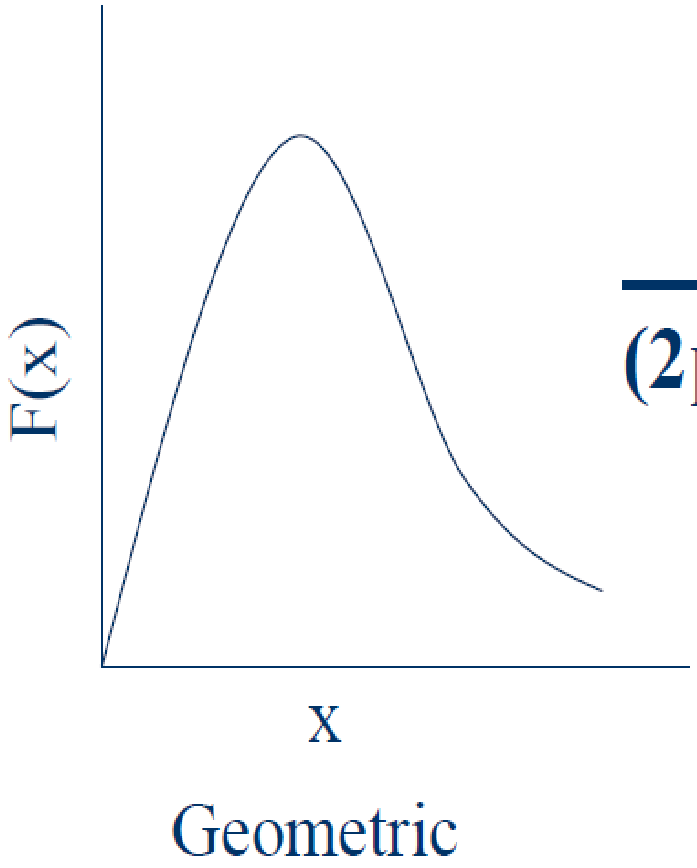
Arithmetic Standard Deviation
算术标准偏差

$$F(x) = \frac{1}{(2p)^{1/2}\, s} \int e^{-(x-x_m)^2/2\, s^2}\, dx$$



Geometric Standard Deviation几何标准偏差

$$F(x) = \frac{1}{(2p)^{1/2} \ln s} \int e^{-(\ln x - \ln x_m)^2 / 2(\ln s)^2} dx$$



这个世界是几何的，ln表示自然对数，

Particle Size Distribution

- Most Natural Processes are Geometrically Distributed and often multi modal自然界的存在大多的几何标准分布并且是多种模式存在

- Number (count), Surface, or Volume (mass) Distribution are common weightings计数，表面积或体积（质量）是通常被称量

Why is this important?为什么是重要的

Due to data weighting相于数据称量…

…the 0.3um DOP particle measured in the 50’s is a volume (mass) mean…0.3um DOP颗粒测时在50%时是体积平均

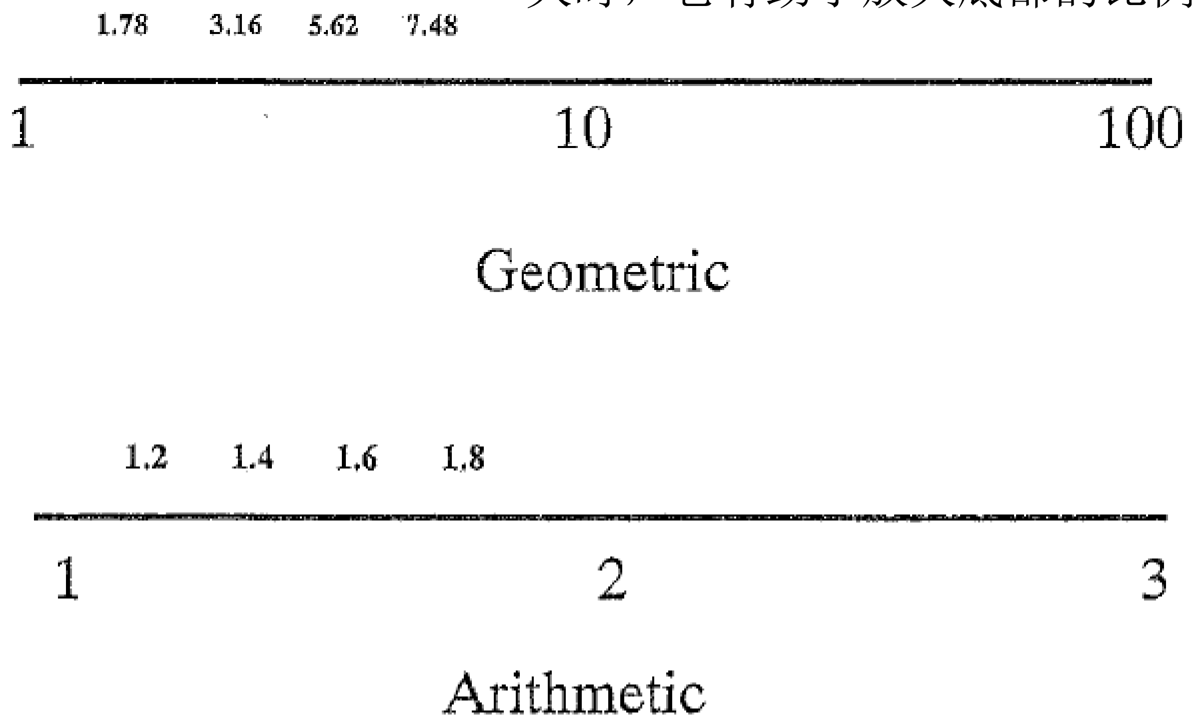
…whose number (count) median is actually closer to 0.18um…the MPPS 它的计数中值接近0.18um.

Geometric vs. Arithmetic几何&算术

- Consider Geometric as Arithmetic or Linear on a log scale考虑几何作为算术或者线性的作为一个对数比例
- Geometric spreads out the lower end
- 几何分布在低一点的端
- In Arithmetic, equal differences result in equal spacing在算术，相等的差别造成相同的空间
- In Geometric, equal ratios result in equal spacing在几何，相同的比例造成相同的空间

Geometric vs. Arithmetic几何&算术

几何的比例是非常有用的当数据分布是非常大时，它有助于放大底部的比例



Equal intervals

Arithmetic: 2-1.8 = 1.8-1.6 = … (equal differences相同的差别)

Geometric: 10/7.48 = 7.48/5.62 = … (equal ratios相同的比例)

Why Use Log Normal Distributions为什么用对数分布?

- No Negative Values非负数值

- For known distributions, the Means of different weightings can be calculated from the others 对于知道的分布，不同的称量的平均能被用下式计算
  - For example, Mass (volume) Mean calculated from Count (number) mean
  - 如，质量（体积）平均，计算从计数平均

Number and Volume Weighting数量和体积称量

d_p	**Number Counts**	**Volume ($\pi d^3/6$)**
1	1,000,000	523,000
10	100	523,000
100	1	523,000

Key Points to Remember

- Particles come in many shapes and sizes
- 颗粒有许多形状和尺寸
- ALL measurements determine some physical property and provide an Equivalent Size
- 所有的测试由物理特性决定需提供一个相等的尺寸
- In filtration, larger particles settle out and are not important, particularly cleanrooms
- 在过滤中，但一点的颗粒下降不重要，特别是洁净室
- Geometric Distributions (aka Log Normal) are used to define particle size distributions
- 几何分布（或对数分布）被用于定义颗粒尺寸分布
- Mass and Number weightings are common in particle measurements质量和数量称量是通常在颗粒计量中

Discussion

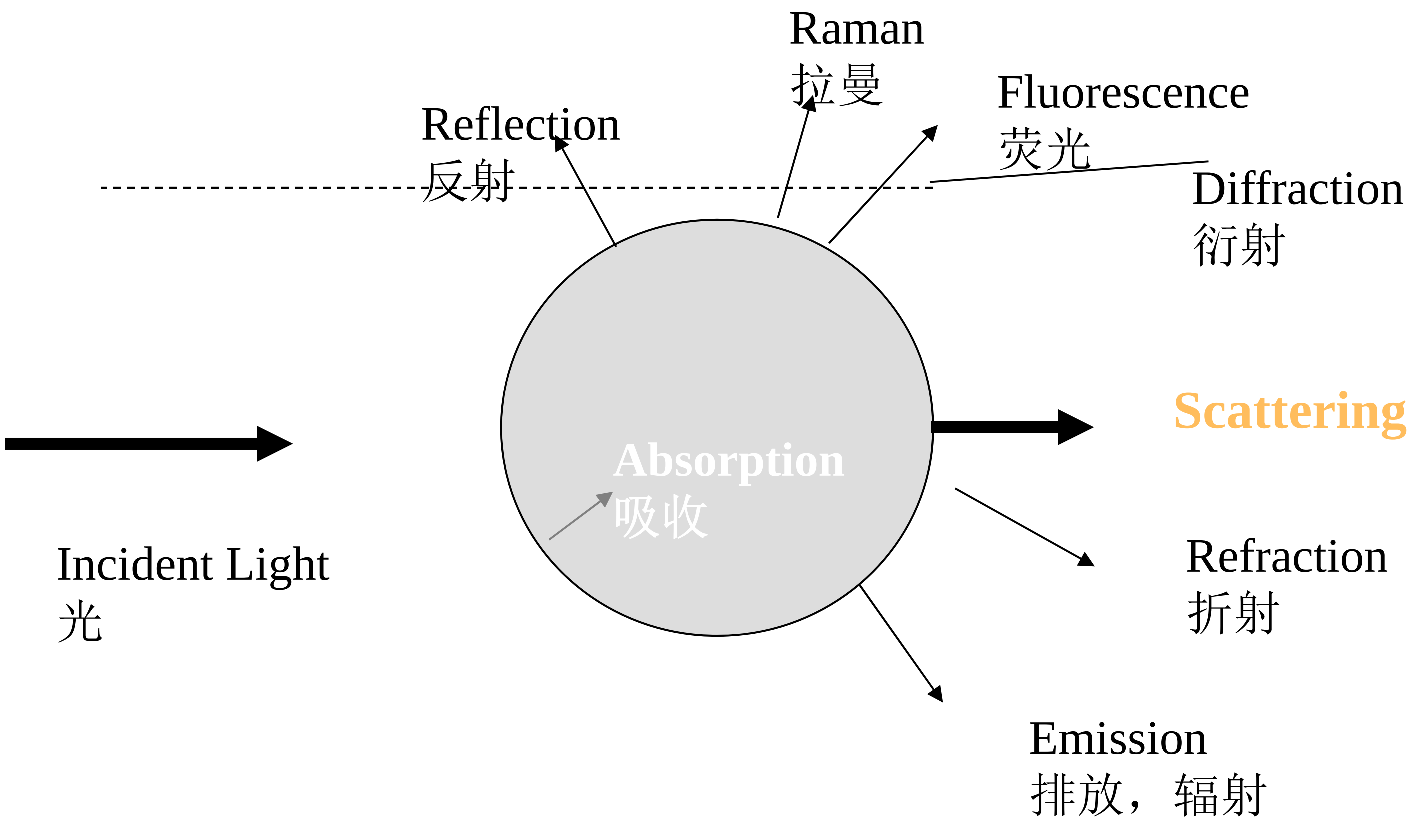
Now we know we are looking for particles…

The Light-Particle Interaction光颗粒的相互作用

Primary Light-Particle Interactions基本的光颗粒作用

- Elastic Scattering弹性散射
  - Rayleigh Scattering 瑞利散射
  - MIE Scattering 米级散射
  - Phase Shift 相位变化
  - Polarization偏振
- Absorbtion 吸收

LIGHT PARTICLE INTERACTION光颗粒相互作用



Common Properties共同的特性

- Refraction – the apparent change in direction of light due to change in *refractive index* within one medium or between dissimilar medium在一个材质中或不同的材质中光改变方向
- Reflection – redirection of light at the surface of a material反射 –材质的表面改变方向
- Diffraction – bending or deflection of light around a particle衍射-光在颗粒周围弯曲或偏移
- Polarization – oscillations of the light occurring in a defined plane偏振-在一个定义的平面光振动

Complex Numbers数

- $(4)^{1/2} = 2$
- What is $(-1)^{1/2}$?
- It is defined by the symbol $\boldsymbol{i}$
- A complex number is written as (a - b $\boldsymbol{i}$)
  where the imaginary part is represented by the symbol $\boldsymbol{i}$

Refractive Index折射系数

- Refractive Index of a material is a complex number
  一个材料的折射系数是一个复杂的数，如下

  Usually given as 2 - 4i

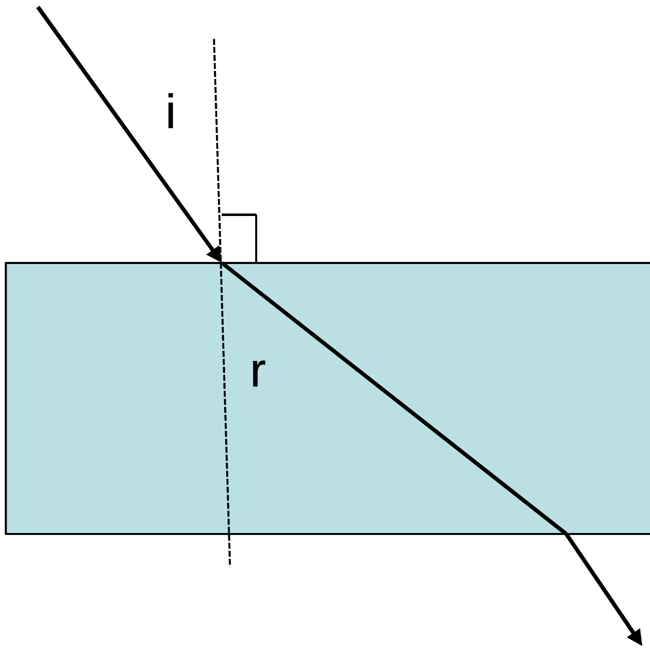
- The imaginary part is due to absorption

Refractive Index of Common Materials通常材制质的折射系数

折射系数是一个复杂的数，虚拟部分以i表示，是指折射系数中被吸收的部分，许多透明的材质如玻璃，油滴，没有吸收部分，许多金属和有颜色的部分有吸收的部分

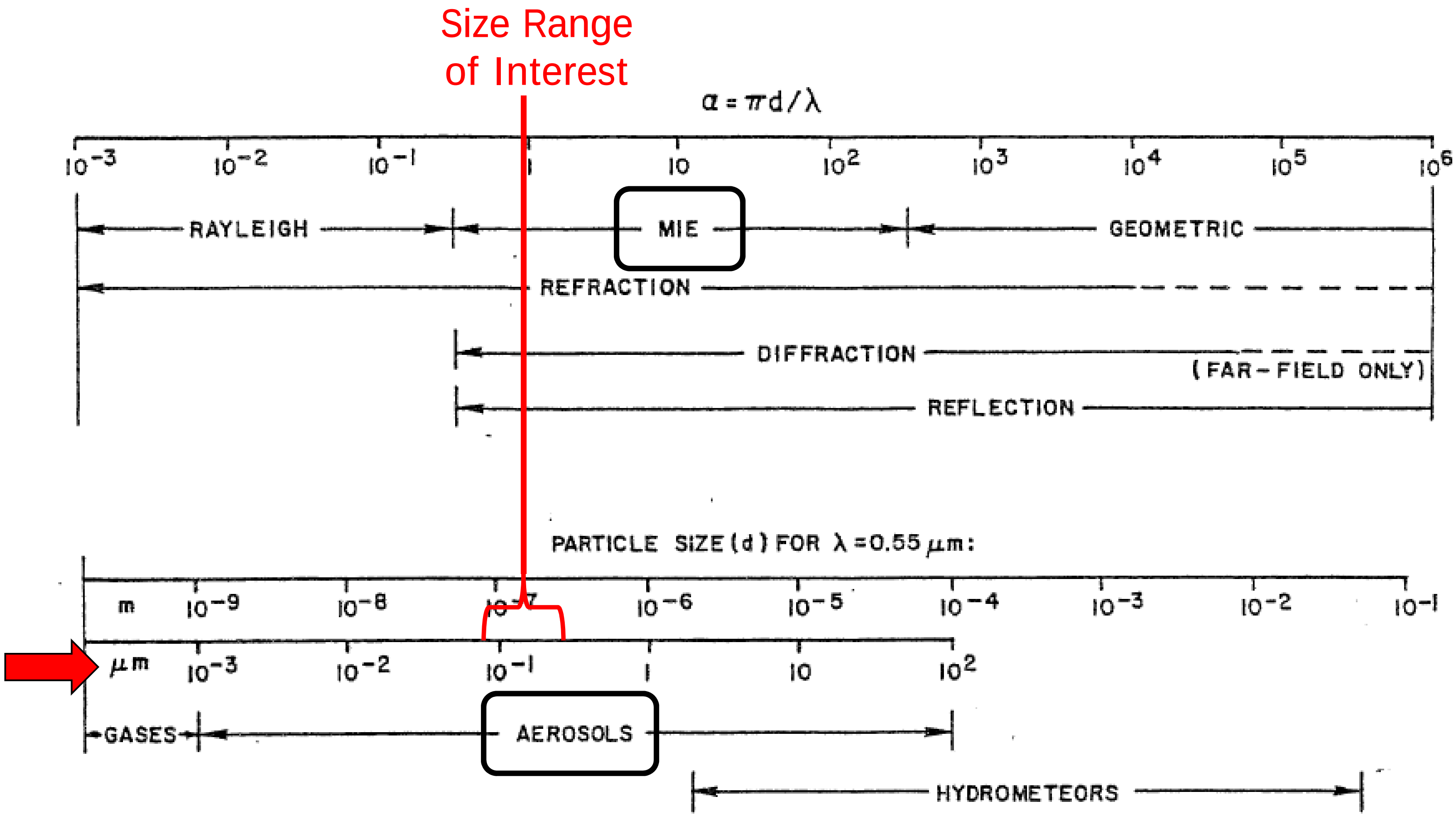
• Quartz	1.54 - 0*i*
• Glass	1.5 to 1.9 - 0*i*
• PSL	1.59 - 0*i*
• Ca Sulfate	1.57 - 0*i*
• Carbon	2.0 – 0.33*i*
• Iron	1.5 – 1.63*i*

Refraction折射



Refractive Index = sine r / sine i

Size and Scattering Regimes



From Univ of Minn, Aerosol Measurements Short Course

Elastic Scattering弹性散射

Redirection of Incident Light without change in wavelength光被转向后波长没有改变

- Refraction – internal to particle, wavelength and composition dependent
- Reflection – at surface of particle, dependent on wavelength and composition
- Diffraction – external to particle, independent of wavelength and composition

Particle Size Affects Elastic Scattering

- Optical Particle Size (α) 光学颗粒尺寸

$$\alpha = \pi d / \lambda$$

where:

d = particle diameter颗粒直径

λ = wavelength波长

- Scattering Intensity (I_s)散射度

$$I_s = \lambda^2 \mathbf{f}(\alpha)$$

where:

f(α) is a size dependent function

Light Scattering光散射

- Particles much smaller (< 0.025um) than the wavelength of light results in Rayleigh Scattering颗粒小于0.025um造成瑞利散射
- Particles comparable to the wavelength of light (0.025> x < 2.5um) results in MIE Scattering 颗粒在0.025到2.5um间与光波长差不多，这个段是米级散射
- Much larger particles result in geometric scattering.大一点的颗粒造成几何散射

Light Scattering光散射

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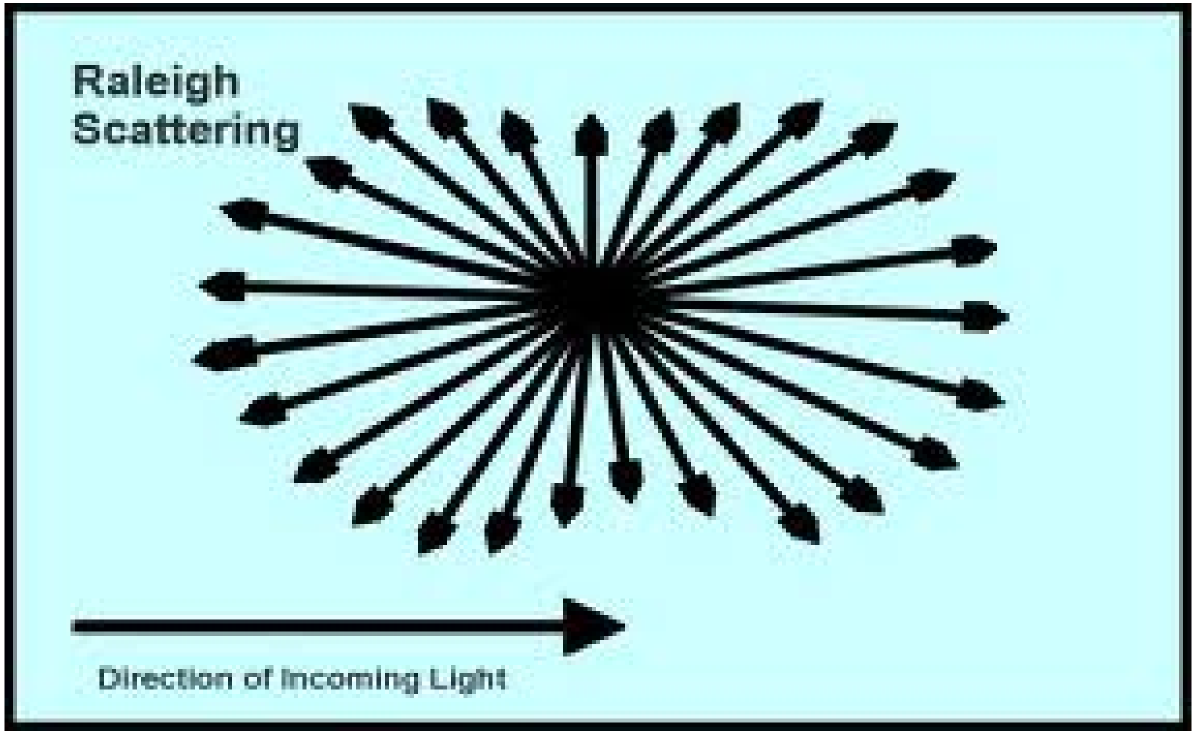
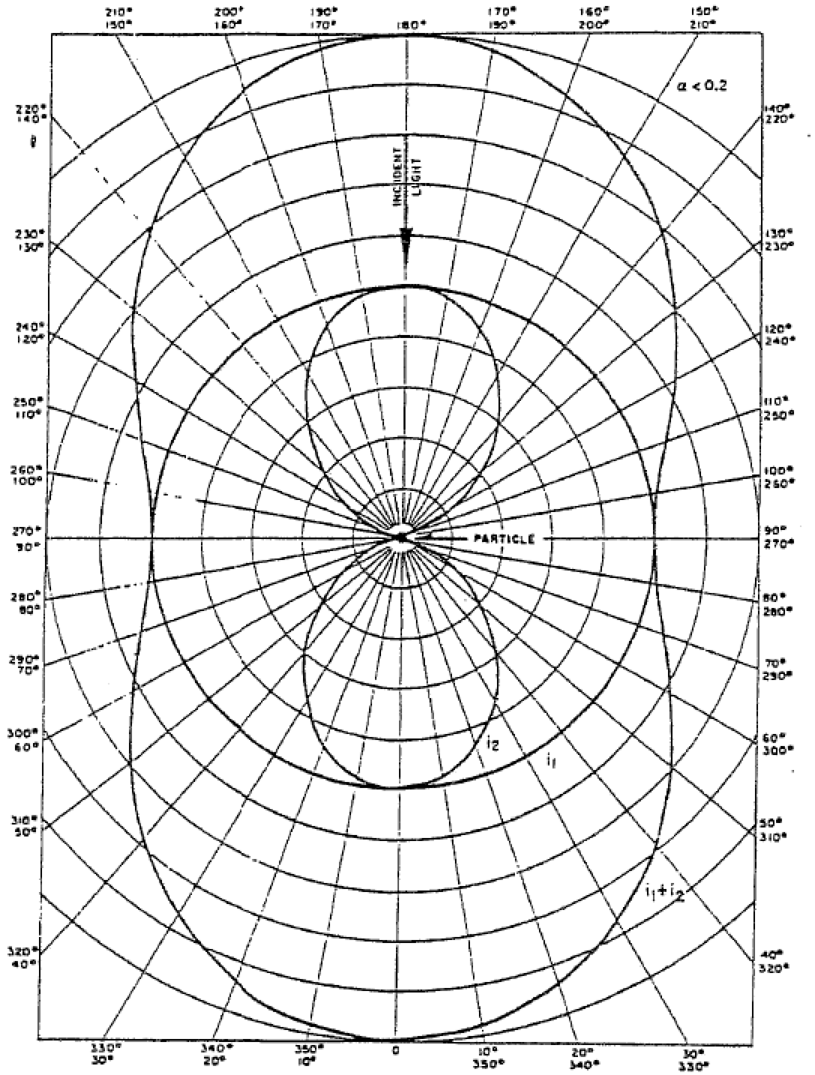
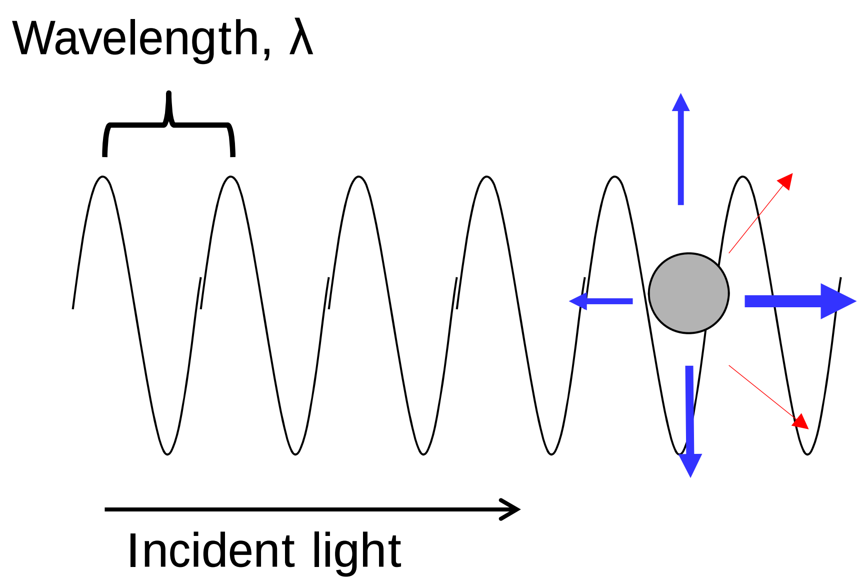
Rayleigh Scattering瑞利散射



Rayleigh Scattering瑞利散射

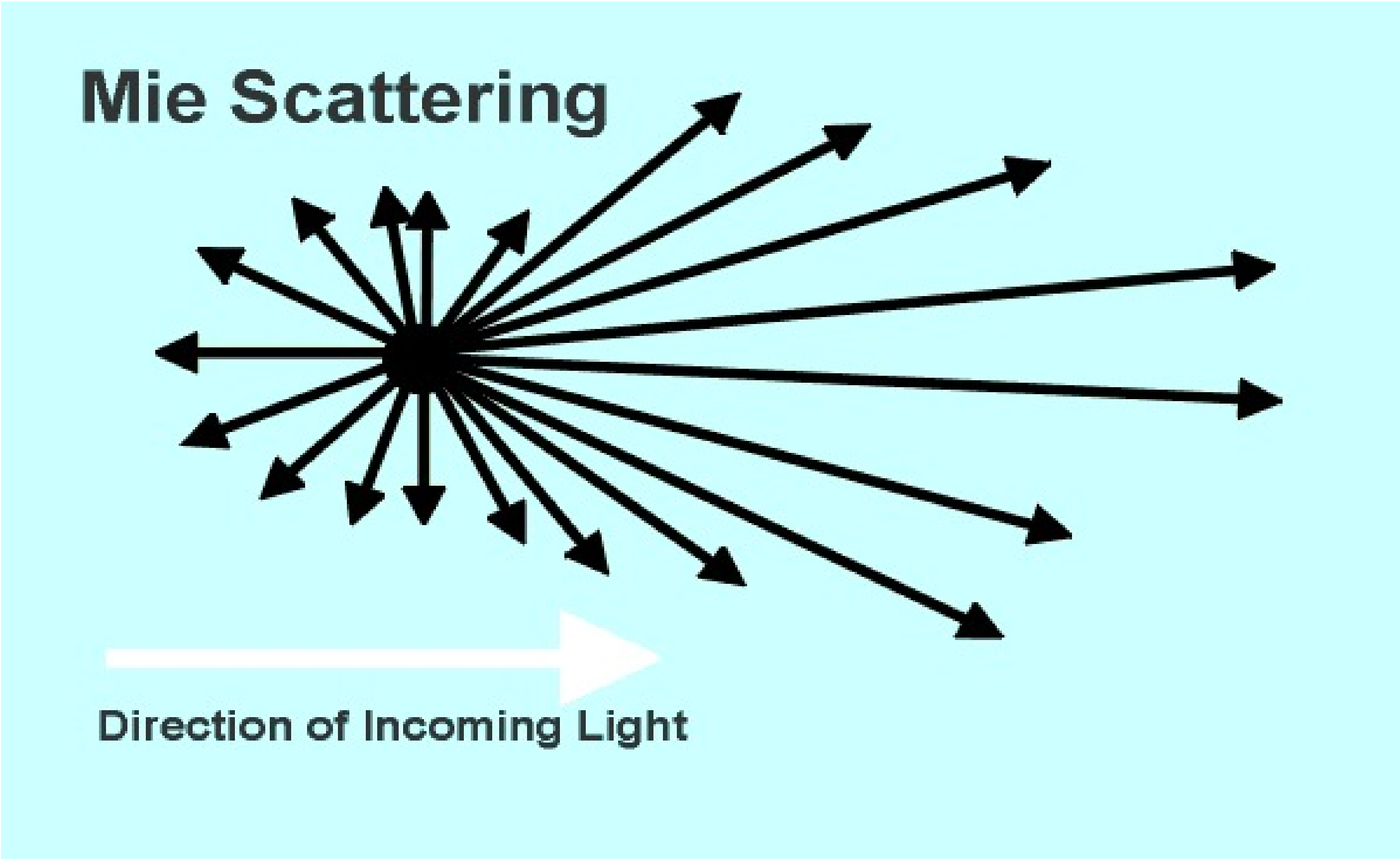


Mie Scattering米散射

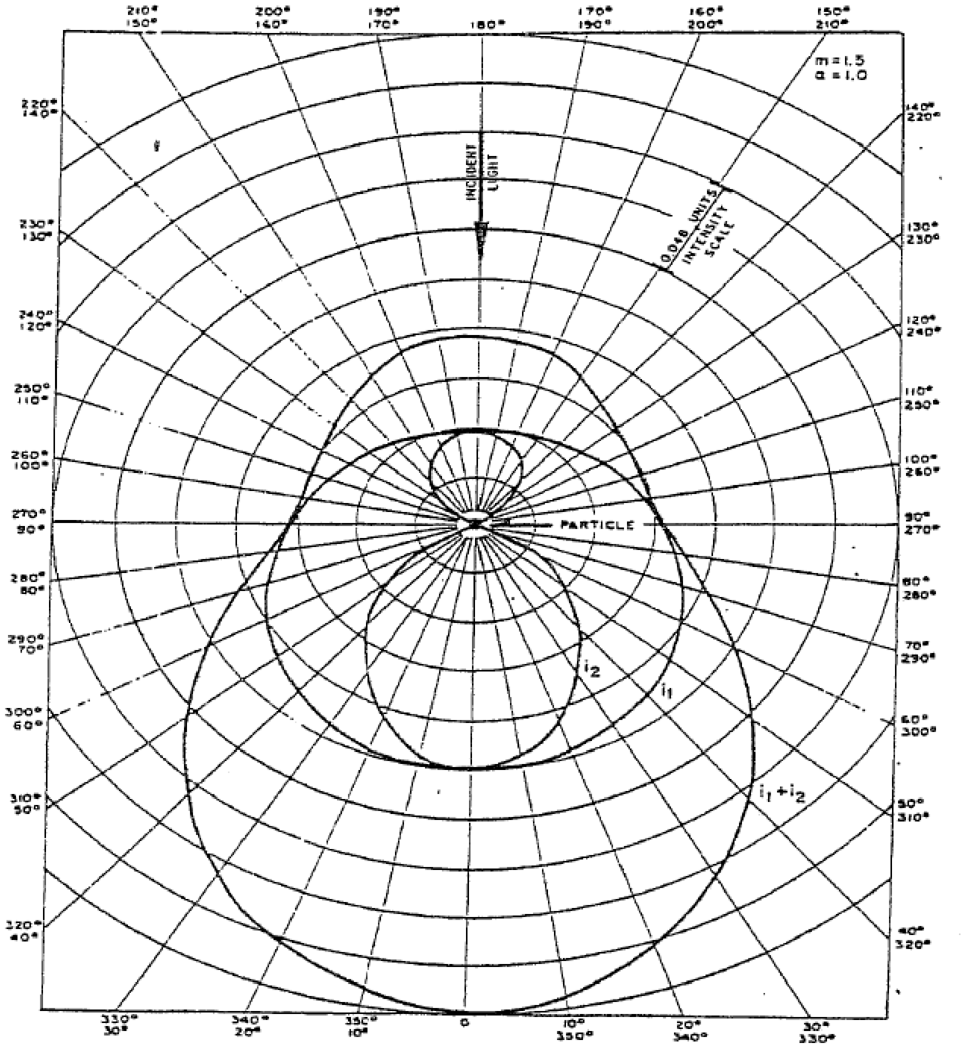


颗粒尺寸接近于光波长，前向散射度更强，散射度少于波长导数的4次幂，这是颗粒计数的操作原理

MIE Scattering米散射



MIE Scattering



Discussion

Multiple and Single Particle Sensing and Sensors 多个和单个颗粒感应及传感器

Multiple Particle Sensing多个颗粒感应

- Sampling Volume ≥ 1/number concentration 取样体积大于颗粒数量浓度的导数
- Independent of sample volume (measuring a ‘cloud’)独立的取样体积（测试一个颗粒云）
- Precision depends on averaging time (due to variations in the ‘cloud’)
- 精密取决于平均的时机（由于云的变动）

Multiple Particle Sensors多颗粒传感器

- Extinction (umbrella)光阻法
  - Smoke Meter (soot content in exhaust stack)
  - 烟尘测量仪（排出口的物质是烟）
  - Transmissometer (visual ranging)
  - 透光仪（可看到可见光范围）

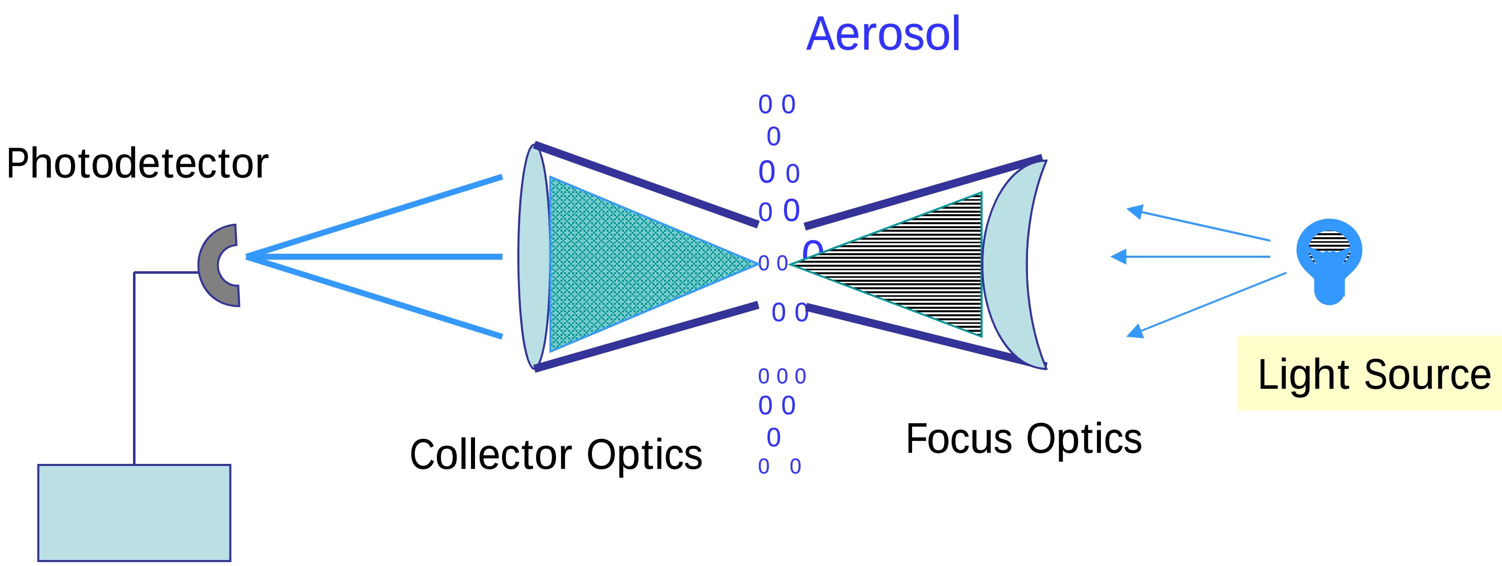
- Scattering散射
  - Intensity (nephelometry) 照度（浊度计）
  - Backscatter (LIDAR) 背光散射
  - Photometry 光学计量

Photometer光度计

- Aerosol is illuminated by a light source
- 气溶胶被光源照射
- Total scattered light is detected by PMT
- 所有的散射光被PMT光电倍增管测到

- Total concentration is measured
- 整个浓度都被计量

Photometer光度计

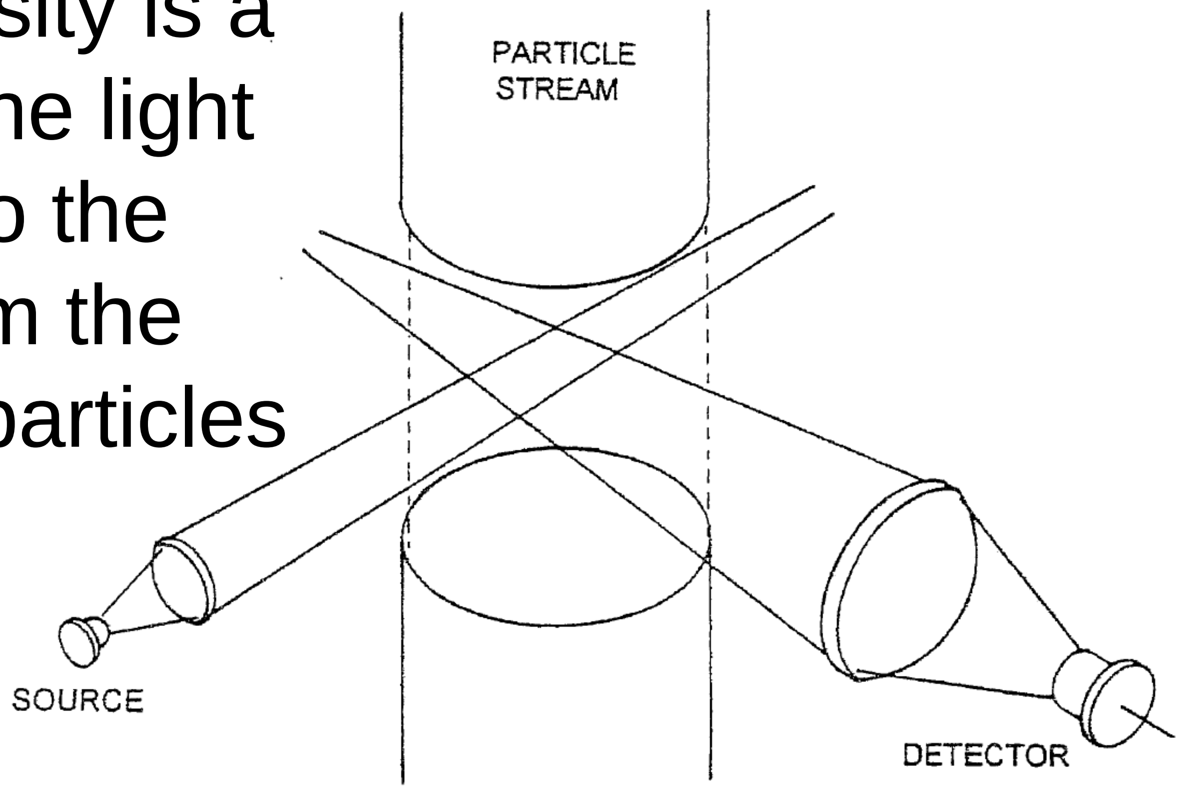


光度计用一个已知的气溶胶尺寸，分布和浓度，DOP或PAO.
它内部的参考设定也可以提供其它物质作气溶胶。仪器的反应是瞬时的和常态的
输出是基于质量多少，校准时通过重量来校准。

Photometer Focal Point
光度计焦点

Nephelometer浊度计

- Particle density is a function of the light reflected into the detector from the illuminated particles



通过测量感应腔的整个散射光来测量浓度，比气溶胶光度计测量的体积大一些，用于外界的污染，气象测量以及可见部分测量

Multiple Particle Sensors Summary多个颗粒传感器总结

- Light-Particle interaction results in scattering 光颗粒的相互作用造成散射
- Optical instruments in particle measurement is dependent upon the particle size and scattering properties
- 在颗粒测量的光仪器基于颗粒尺寸和散射特性
- Multiple particle scattering is independent of volume; depends on averaging time.多个颗粒散射 基于体积，平均时机等

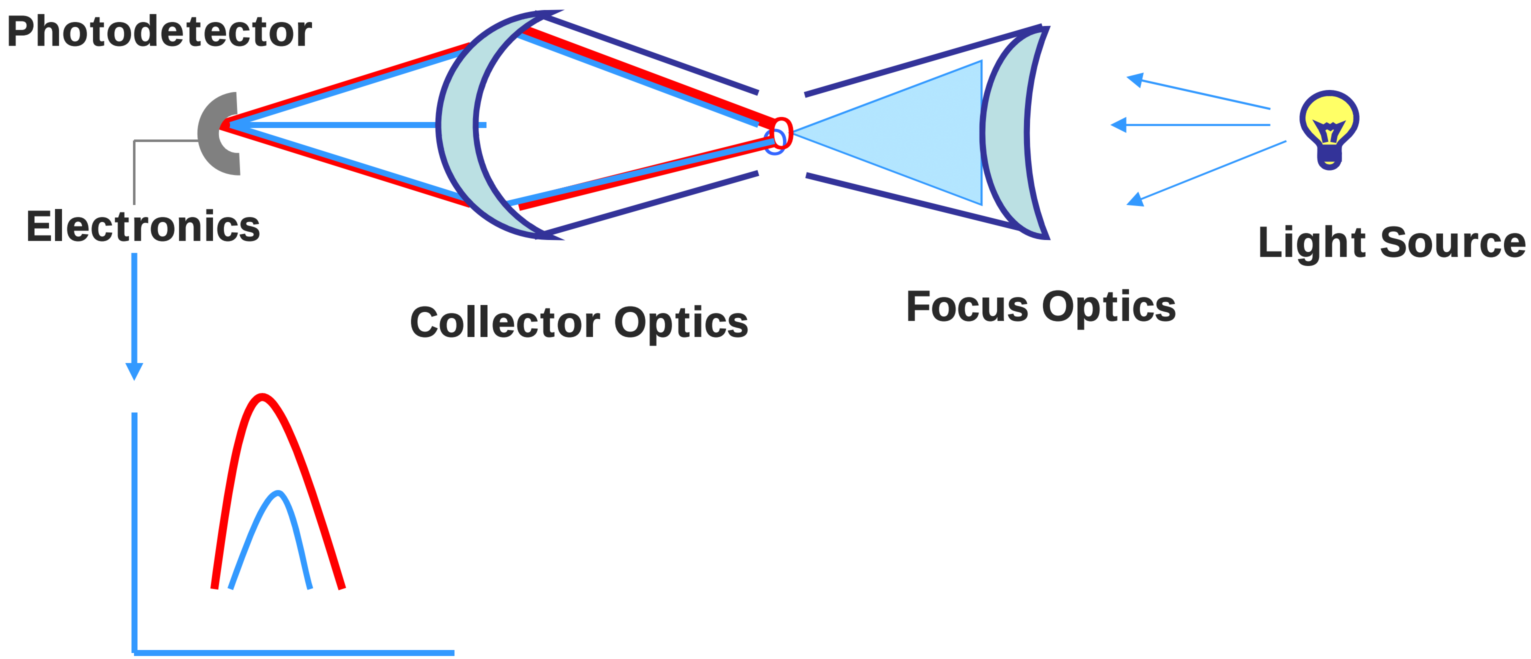
Single Particle Sensing单一颗粒感应

- Sample Volume << 1/number concentration
- Requires a precise, known volume of sampled air 需要一个精密的，已知体积的取样体积
- Same as counting events; precision depends on total counts精密依靠整个计数

Single Particle Sensors单一颗粒传感器

- Light attenuation (extinction)光阻
- Scattering (Particle Counters)光散射
  - Laser激光
  - White Light白光
- Angular Scattering角度散射
- Doppler anemometer多普勒风速计

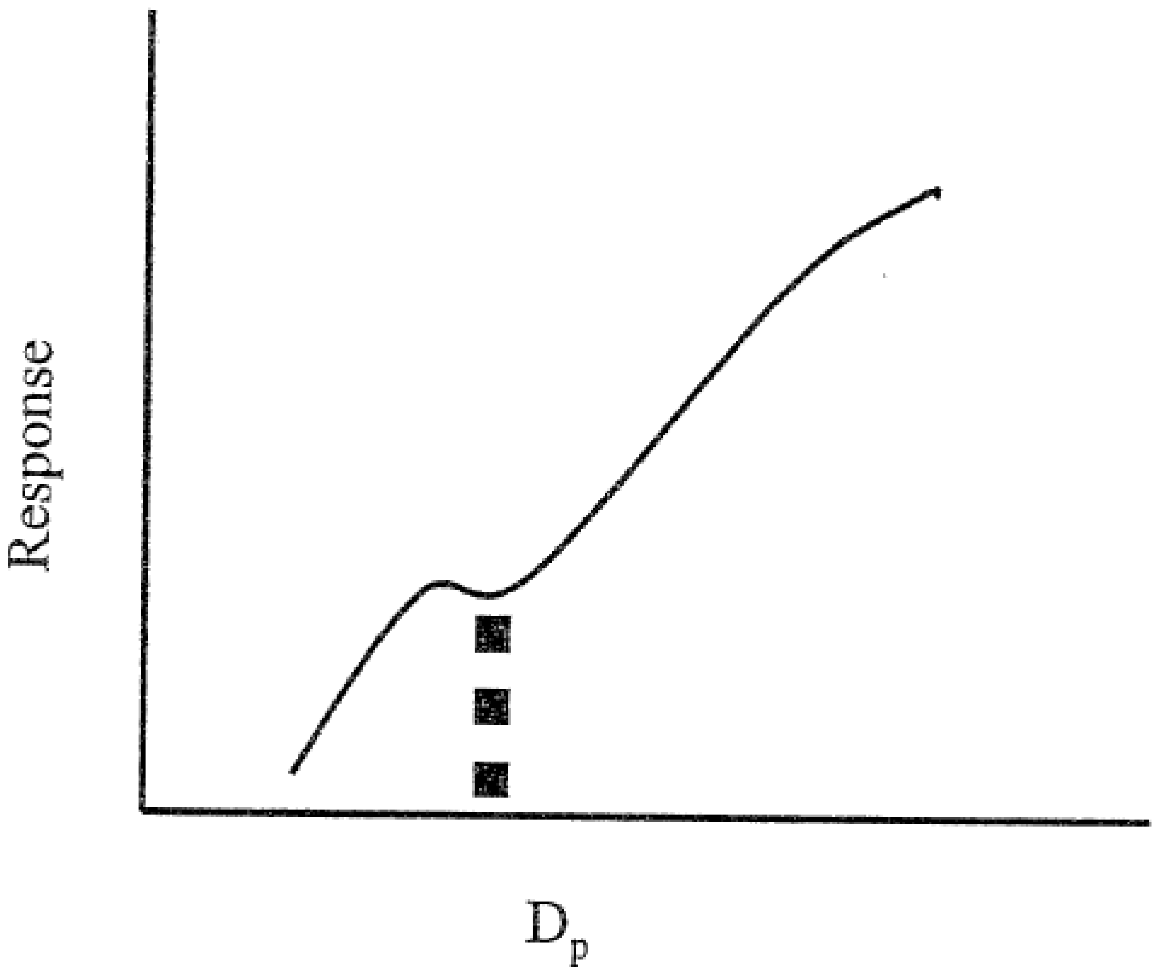
Particle Counter颗粒计数仪



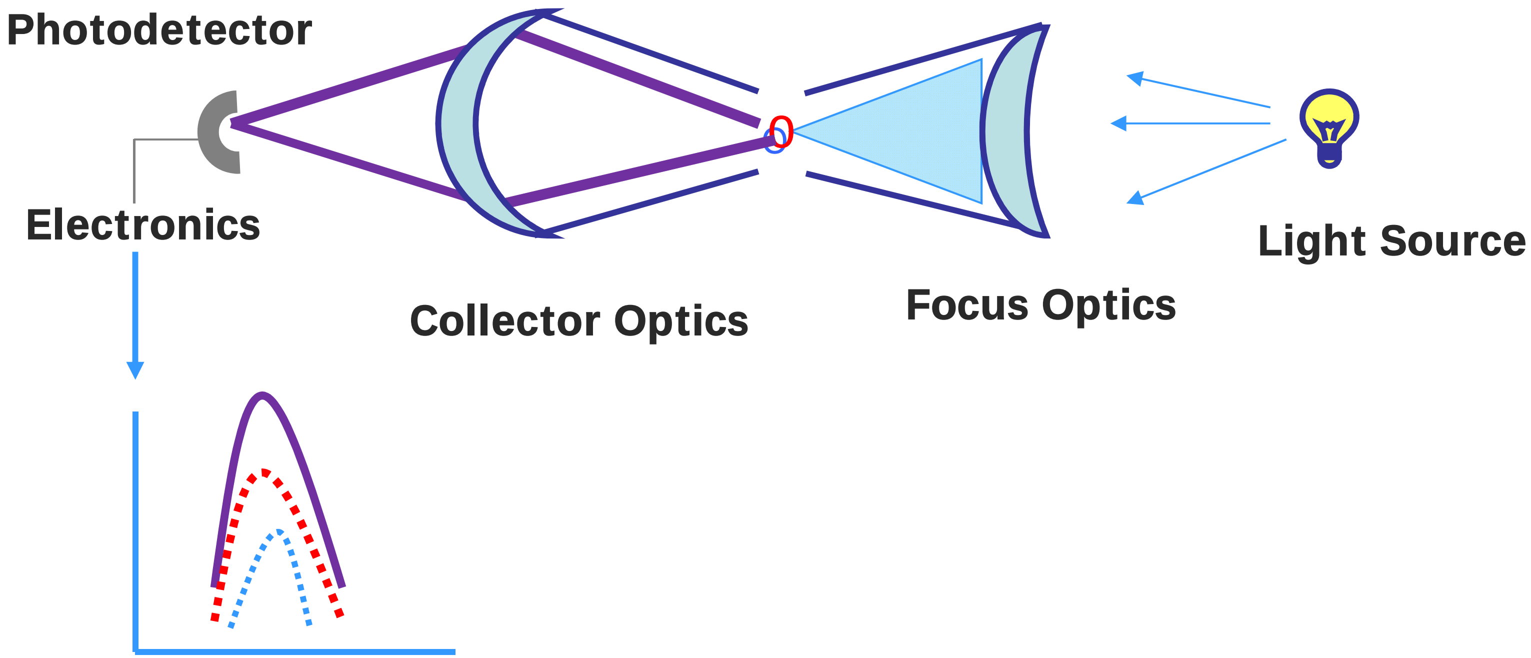
Common Particle Counter Challenges颗粒计数仪共同挑战

- Multi Valued Response 多值的反应
- Coincidence颗粒重合
- Problems at small particle sizes
- 小颗粒尺寸问题

Multi Valued Signal多值的信号



Coincidence



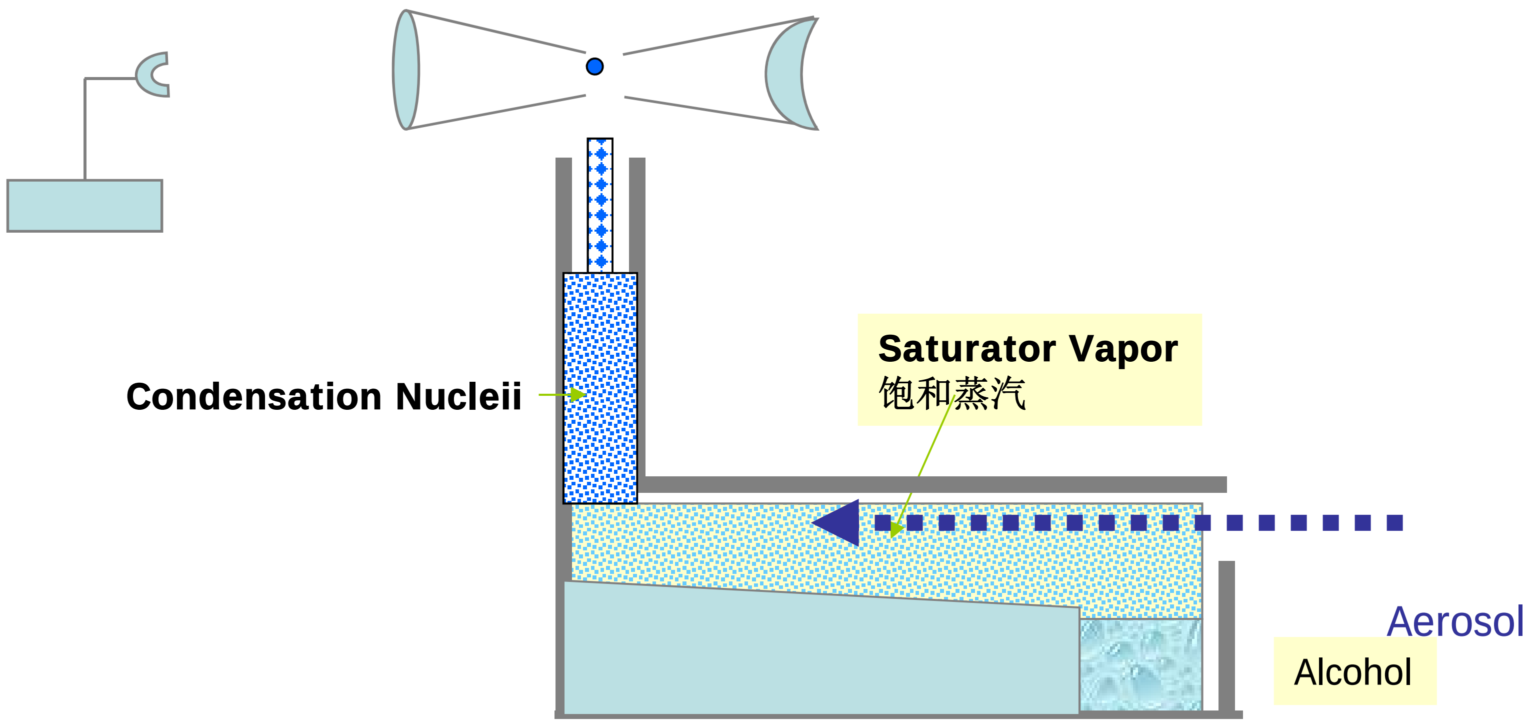
Small Particle Detection小颗粒侦测

- Scattering intensity is very small散射能量非常小
- Common Solutions 共同的解决方案
  - Increase intensity of light 增加光能量
  - Change light source wavelength改变光波长
  - New techniques?新技术？

Small Particle Detection小颗粒侦测

- Increase Intensity 增加能量
  - Improves signal from particles增加颗粒的信号
  - Increases noise from air molecules但也增中了从空气分子中杂音
- Reduce the wavelength减少波长
  - Shifts the curves to smaller sizes 转变曲线到小的尺寸
  - Increases noise from molecules增加了杂音
- Reduce the viewing volume减小可视体积

Condensation Nucleus Counter凝结核计数器



颗粒被导入到一个有饱和蒸汽的环境，典型的是乙醇，也有其它的如水。蒸汽在气溶胶中冷凝就象是人工下雨中的播种。这些颗粒在蒸汽的冷凝中长大成一个大的颗粒从而被传统的光散射测到。由于人工的云和液滴建立在颗粒上，颗粒象0.03um都能测到，然后液滴包在颗粒上使它不能测到实际的颗粒尺寸。

Single Particle Sensors Summary单一颗粒传感器总结

- Most optical measurements are in the MIE regime
- 许多的光计量在米级
- Single particle counting requires known volume of sampled air单一颗粒计数需要已知取样体积
- Same as counting events; precision depends on total counts – long sample times at low counts 如果取样时间长颗粒少会准确一些
- Problems of coincidence at high concentrations在高浓度时会有重叠的问题
- Non unique response and low signal to noise ratio at small sizes 在小尺寸范围时，低信噪比
- Small sizes handled by using smaller wavelengths or proprietary methods

Photometer vs.
Particle Counter vs. CNC
光度计&计数仪&凝聚核计数器

- Photometer光度计
  - Measures Total Aerosol测量整个气溶胶
  - Response Linear With Total Aerosol Volume与整个气溶胶量反应线性
  - Requires Known Aerosol And Relatively High Concentration需要知道气溶胶和相对高浓度
  - Problems:
    - No Particle Size Information 没有颗粒尺寸信息
    - Requires High Concentrations 需要高浓度

Photometer vs.
Particle Counter vs. CNC

- Particle Counter (Laser)颗粒计数器（激光）
  - Detects and sizes particles测试和尺寸颗粒
  - Counts by size通过尺寸计数
  - Measures down to 0.1 μm最小测量到0.1um
  - Can use any aerosol可用气溶胶
  - Problems问题:
    - Assumes everything measured is a PSL 假设每个颗粒都是聚莱乙烯
    - Multi Valued Response多值反应
    - Coincidence重叠
    - Problems at small particle sizes小颗粒问题
    - Long sample times to obtain a statistically valid results

Photometer vs.
Particle Counter vs. CNC

- CNC 凝聚核计数仪
  - Particle detector only仅仅测颗粒
  - Can measure less than 0.05 µm
  - Problems问题:
    - Requires mono-dispersed aerosol需单一分布的气溶胶
    - Counts all particles, noise at bottom end
    - Long sample times to obtain a statistically valid results

Discussion

Aerosols and Aerosol Generators
气溶胶和气溶胶发生器

What is a Standard?标准是什么

- A KNOWN and Universally Accepted value of a physical property or quantity
- 已知的并且被广泛接受的物理特性或数量值
  - Meter for measure of length米
  - ◦C for Temperature摄氏度

Why are Standards Necessary?为什么需要这些

- They establish accuracy of measuring instruments这些建立了测量仪器的准确度
- Calibrate the accuracy of instruments in use
- 让仪器准确的校准
  - Temperature温度
  - Scales比例
  - Flow Meters流量
  - Photometers光度计
  - Particle Counters颗粒计数仪

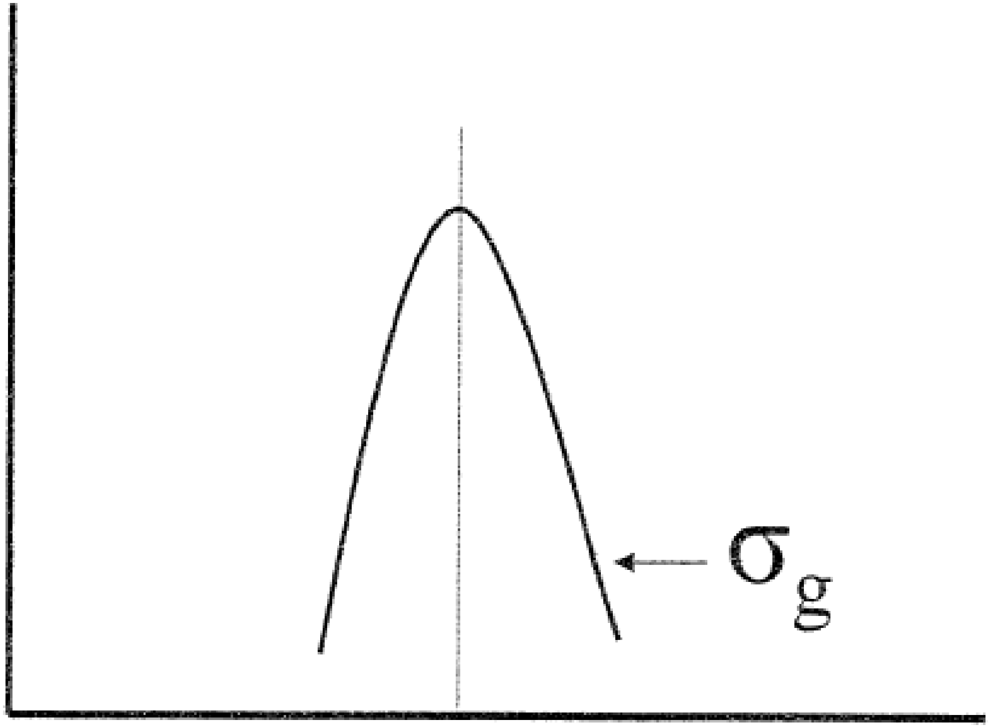
How Does this Affect Aerosols这些因素怎样影响气溶胶?

- A Standard Aerosol has KNOWN properties 已知特性
  - Particle Size and Distribution颗粒尺寸和分布
  - Concentration浓度
  - Shape (usually spherical)形状
  - Chemistry (inert)化学（惰性）
  - And Refractive Index in our business反射系数

Aerosol Standards气溶胶标准

- Mono-disperse Aerosol 单一分布的气溶胶
  - ‘Single’ size particles $\sigma_g \leq 1.4$
    - Instrument Calibration for PCs
    - Research & Development
- Near Mono-disperse Aerosol 接近于单一分布的气溶胶
  - Narrow distribution $1.4 < \sigma_g \leq 1.6$
    - Some Production QC Level of accuracy
- Poly-disperse Aerosol 多分散气溶胶
  - Broad distribution $1.6 < \sigma_g$
  - Industrial measurements
  - Instrument verification
  - Some instrument calibrations

Mono vs Poly Disperse

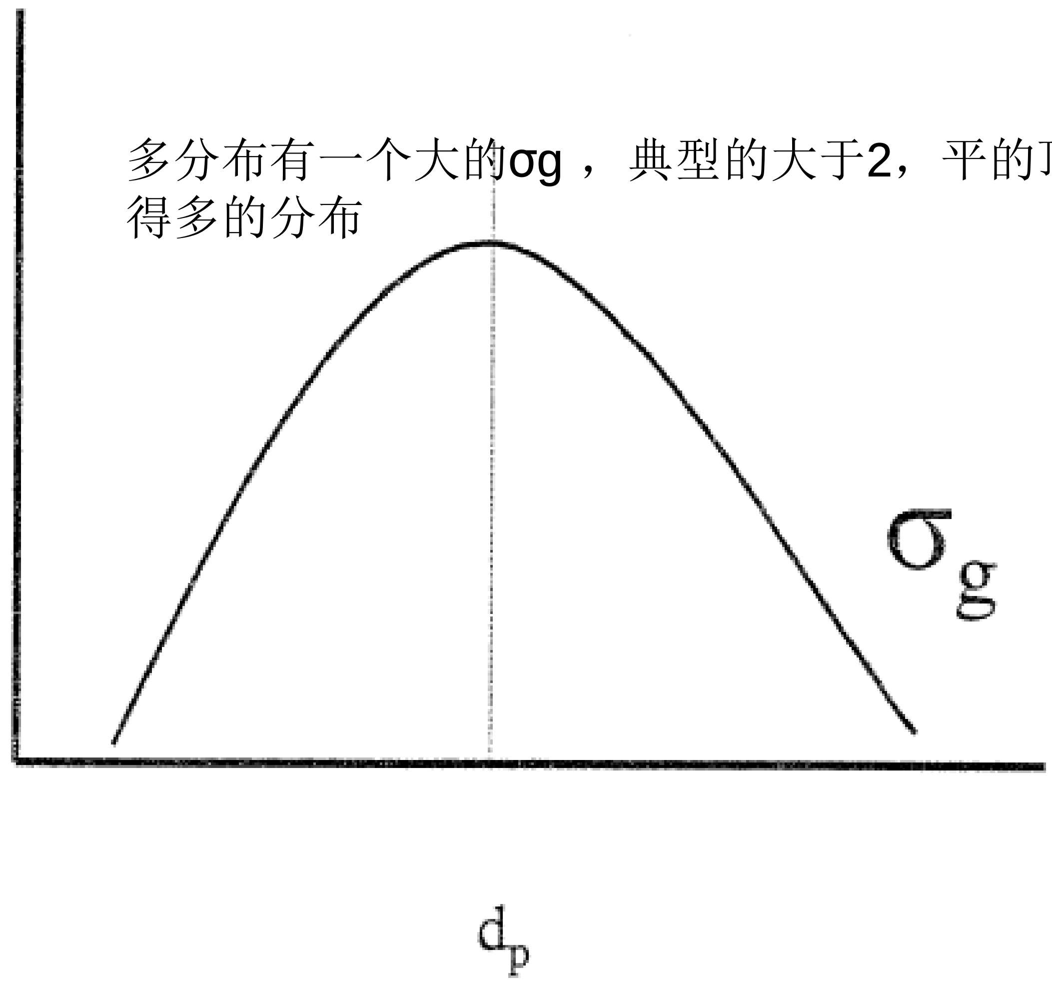


单一的分布有一个尖的顶和一个窄的分布

d_p

Mono vs Poly Disperse

多分布有一个大的σg，典型的大于2，平的顶和宽得多的分布



Implication on Size Dispersion

- For a log normal distribution
  - 95% of the particles are between
  - 对于一个对数的分布，

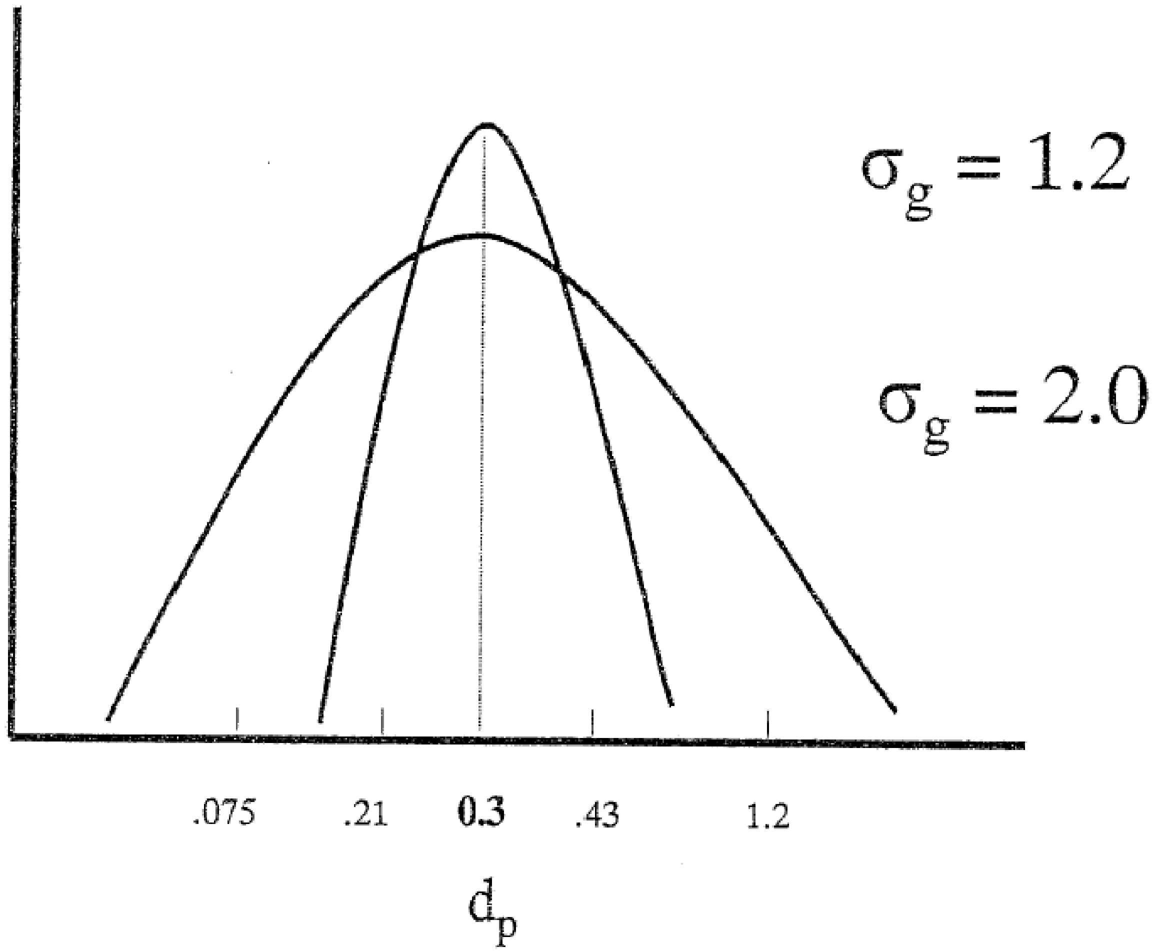
Mean ______ σ_g^2 ______

σ_g^2 &   Mean

Implication on Size Dispersion

- An aerosol with mean of 0.3um
  - $\sigma_g = 1.2$
    - 95% of particles are between 0.21 & 0.43um
  - $\sigma_g = 2.0$
    - 95% of particles are between 0.075 and 1.2um

Mono vs Poly Disperse



Three Types of Aerosol三种气溶胶

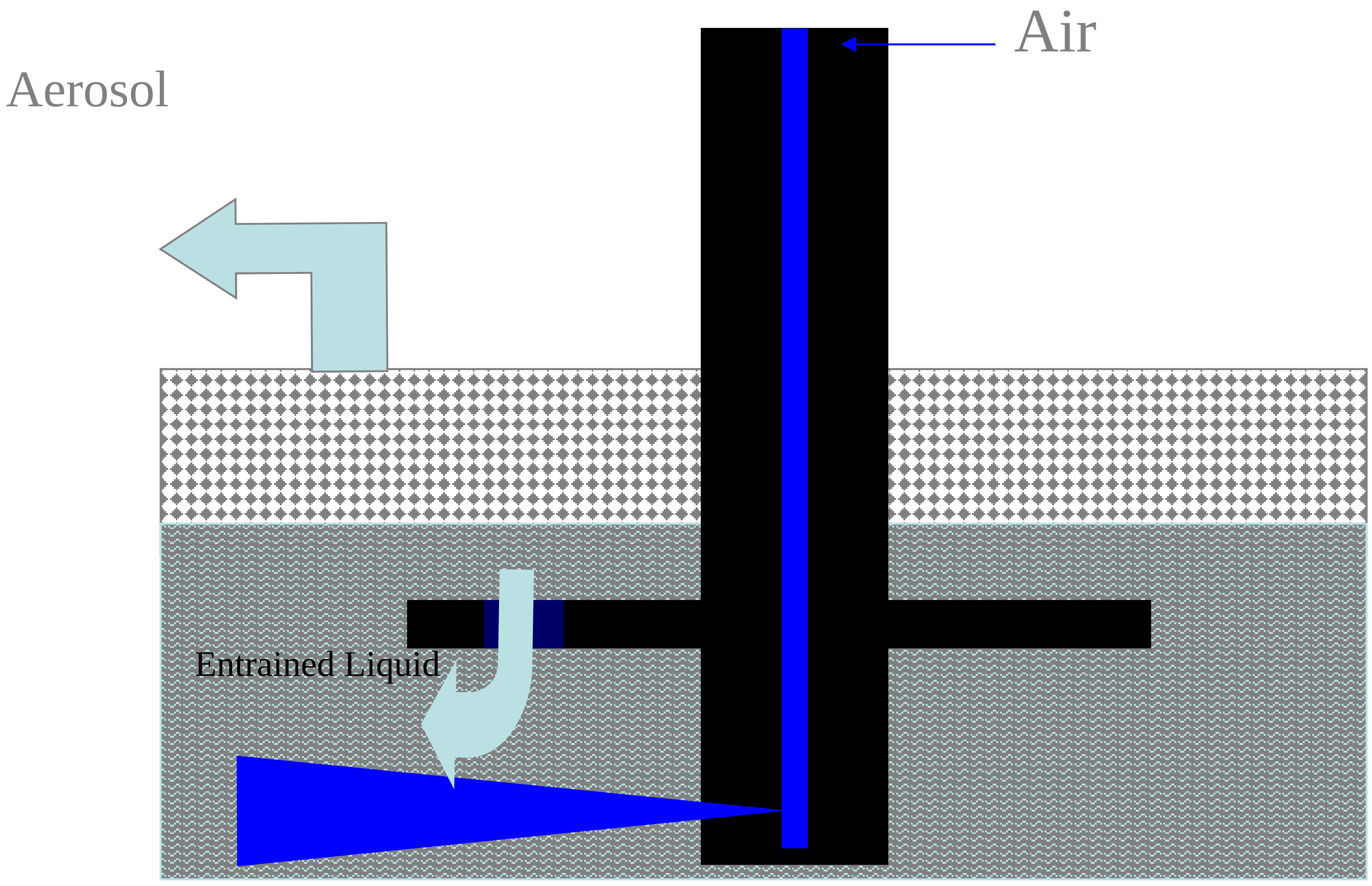
- Mono-disperse: $\sigma_g \leq 1.4$

- Near Mono-disperse: $1.4 < \sigma_g \leq 1.6$
- 接近于单一分布　　分布系数小于1.6大于1.4
- Poly-disperse: $1.6 < \sigma_g$

Typical Poly-Disperse Aerosol Standard典型的多分散溶胶标准

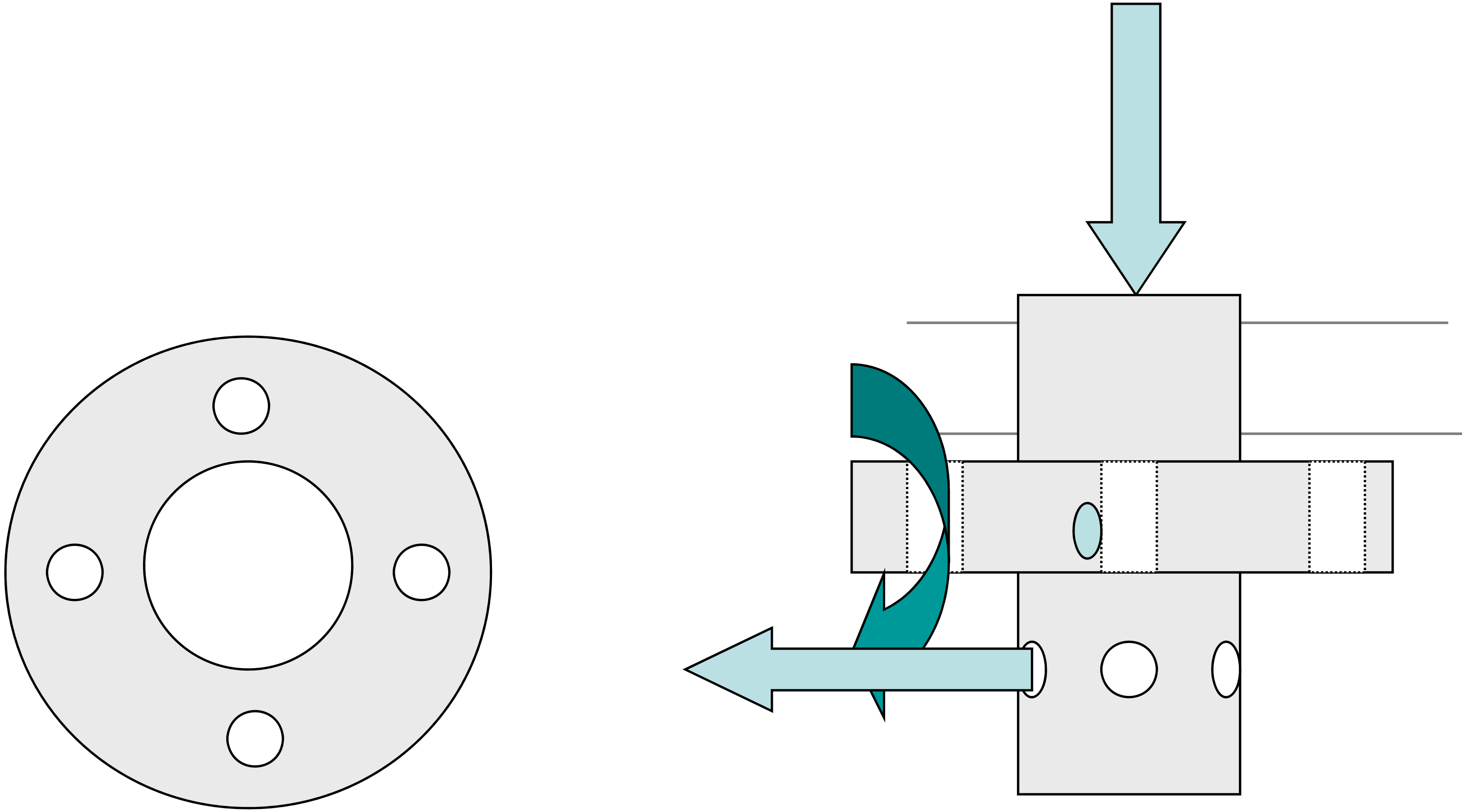
- Laskin Nozzle Laskin喷嘴
- Wright Nebulizer 赖特雾化器
- Pneumatic Nebulizer气动雾化器
- Condensation Generators冷凝发生器
- Spinning Disk 旋流片
- Exploding Wire 爆丝线
- Standard Dusts

Laskin Nozzle



气体喷射流产生气泡，通过液体并且雾沫化液体，增加了气溶胶质量输出以及影响到气溶胶的平均尺寸

Laskin Nozzle



Laskin Nozzle

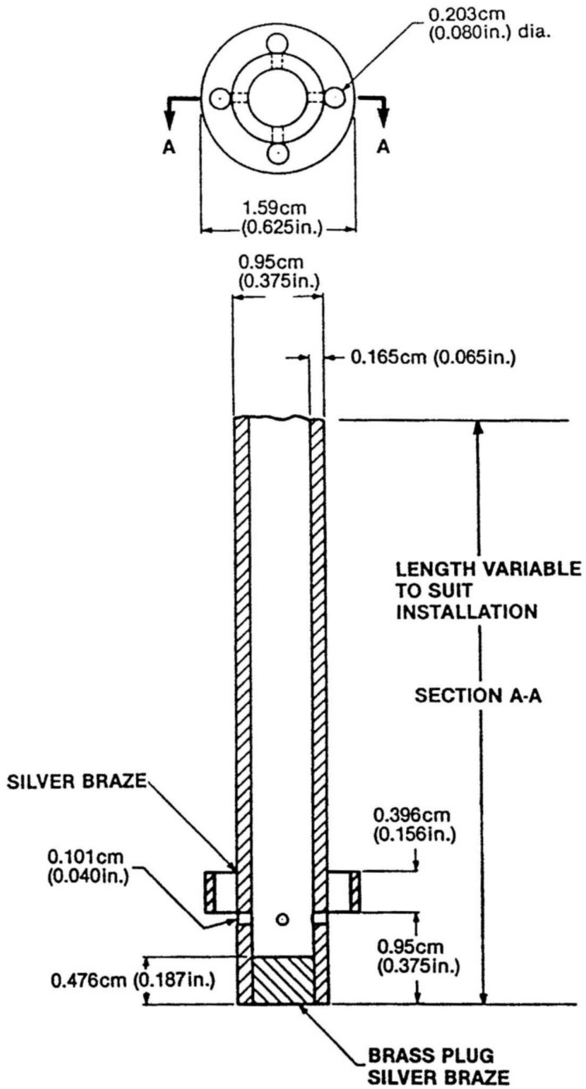


Figure 1. Details of Laskin Nozzle IEST-RP-CC-013-86-T

Laskin Nozzle
Concentration Calculations

Output of Laskin Nozzle is defined:

- By **<u># Nozzles</u>** @ 20 PSIG

$$\text{Concentration} = \frac{\#\ \text{Nozzles} \times 13{,}500}{\text{Total Flow (cfm)}}$$

- By **<u># Jets</u>** at 20 PSIG

$$\text{Concentration} = \frac{\#\ \text{Nozzles} \times 3{,}375}{\text{Total Flow (cfm)}}$$

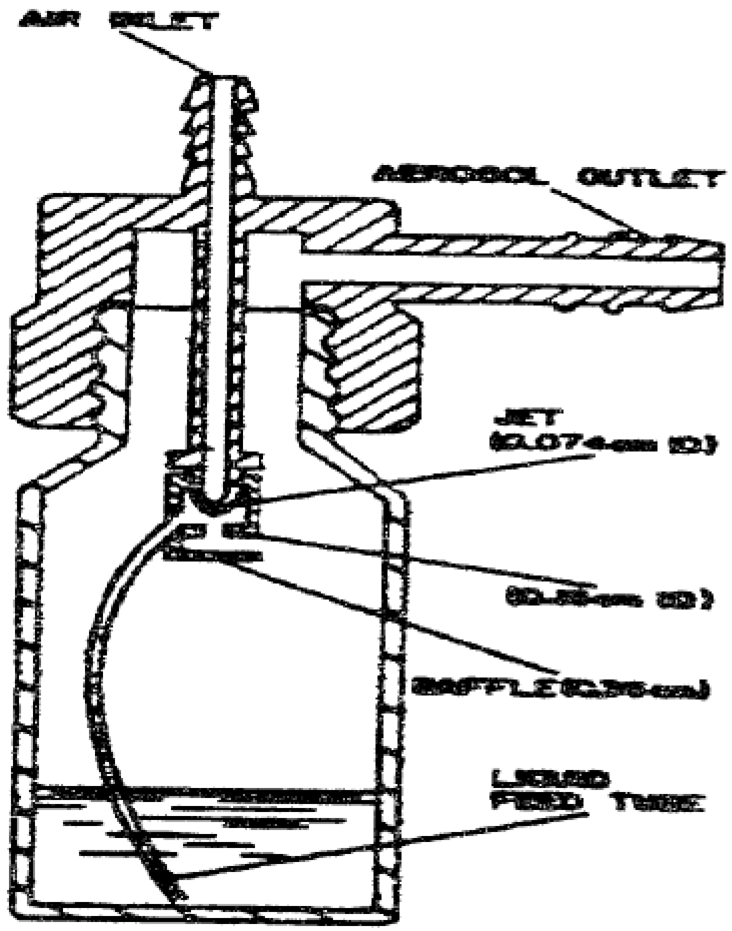
*Note: there are 4 jets in a standard Laskin Nozzle

Laskin喷嘴是由美国海军研究室选择，它的输出大部分是次微米的，气溶胶的尺寸和分布，浓度是可重复的，可重生的。

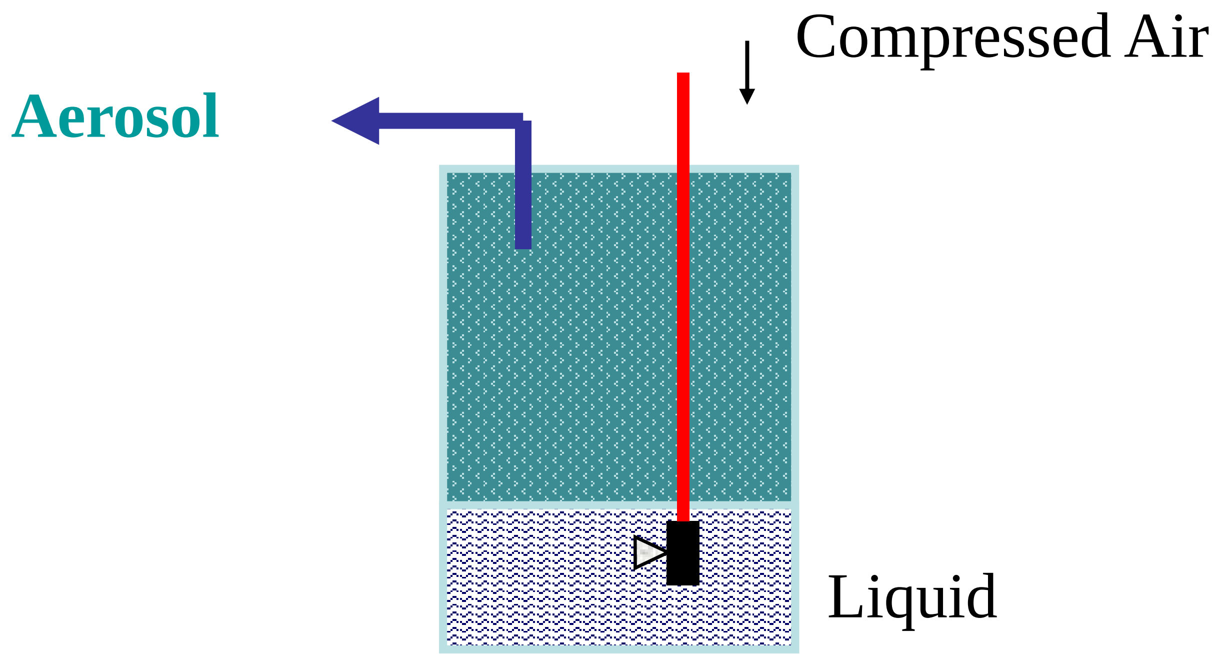
Laskin Nozzle Concentration Calculations Laskin喷嘴浓度计算

- You can calculate the system concentration, if you know:
  - System Air Volume (CFM)
  - Number of Laskin Nozzles/Jets at 20 PSIG
- You can calculate the number of nozzles/Jets, if you know:
  - System Air Volume (CFM)
  - Desired system concentration

Wright Nebulizer赖特喷雾器

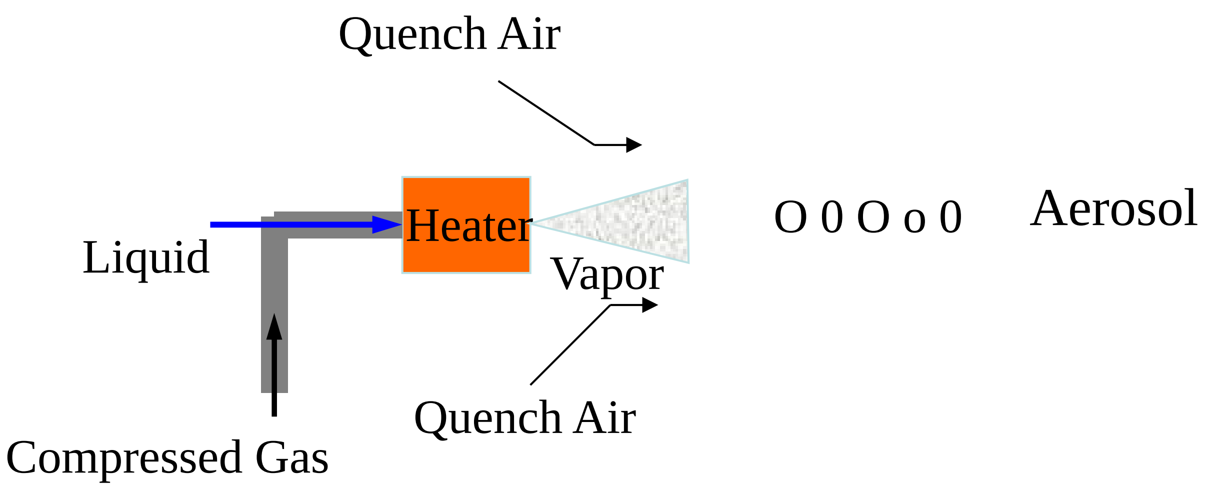


Pneumatic Nebulizer充气雾化器



高速的喷射气泡通过液体，在液体中产生了泡沫，在表面产生了颗粒。类似于开水中水的溅起。小的颗粒或液滴在空气中以雾沫存在并且被带出，大的颗粒掉回液体中。

Thermal Condensation Aerosol Generators热冷凝气溶胶发生

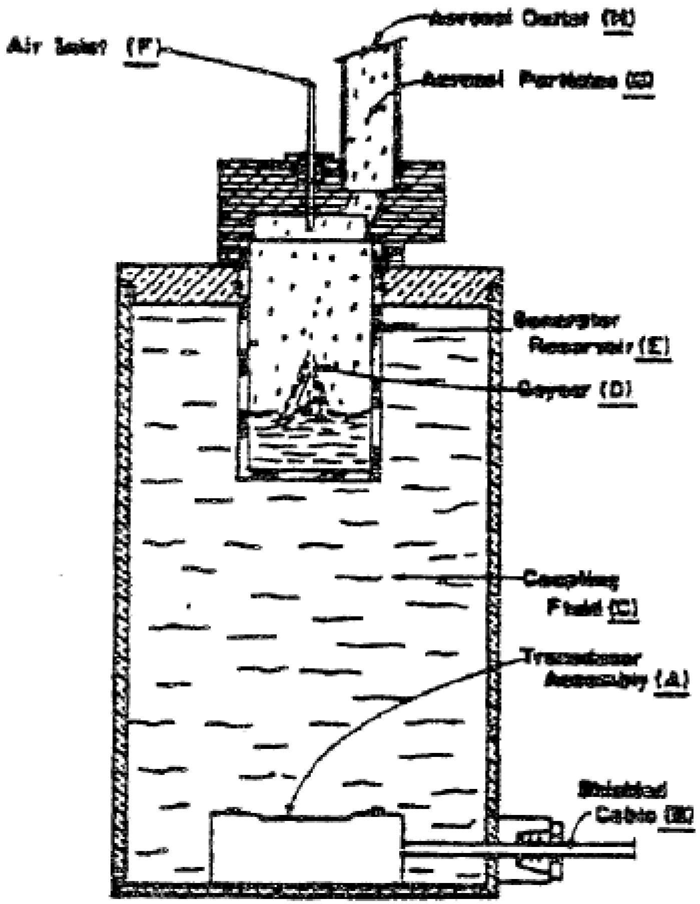


淬冷型雾器形成液滴，淬冷速度和温度对颗粒的尺寸和分布有影响

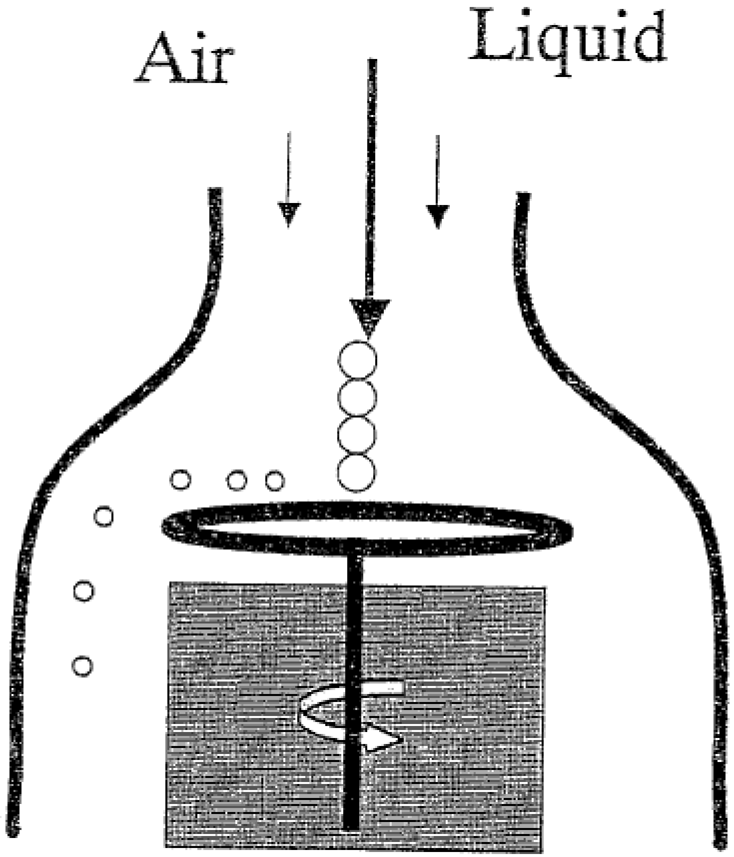
Thermal Aerosol Generator热气溶胶发生器

- Polydispersed 多分散
- Produces a greater level of aerosol concentration than pneumatic type nozzle产生比充气型多得多的气溶胶浓度
- Applications include higher flow systems
- Median particle size is smaller than pneumatic generation平均粒径小于充气型
- Output concentration cannot be calculated as output is variable
- Size and distribution shift with concentration尺寸和分布随浓度的转变而变

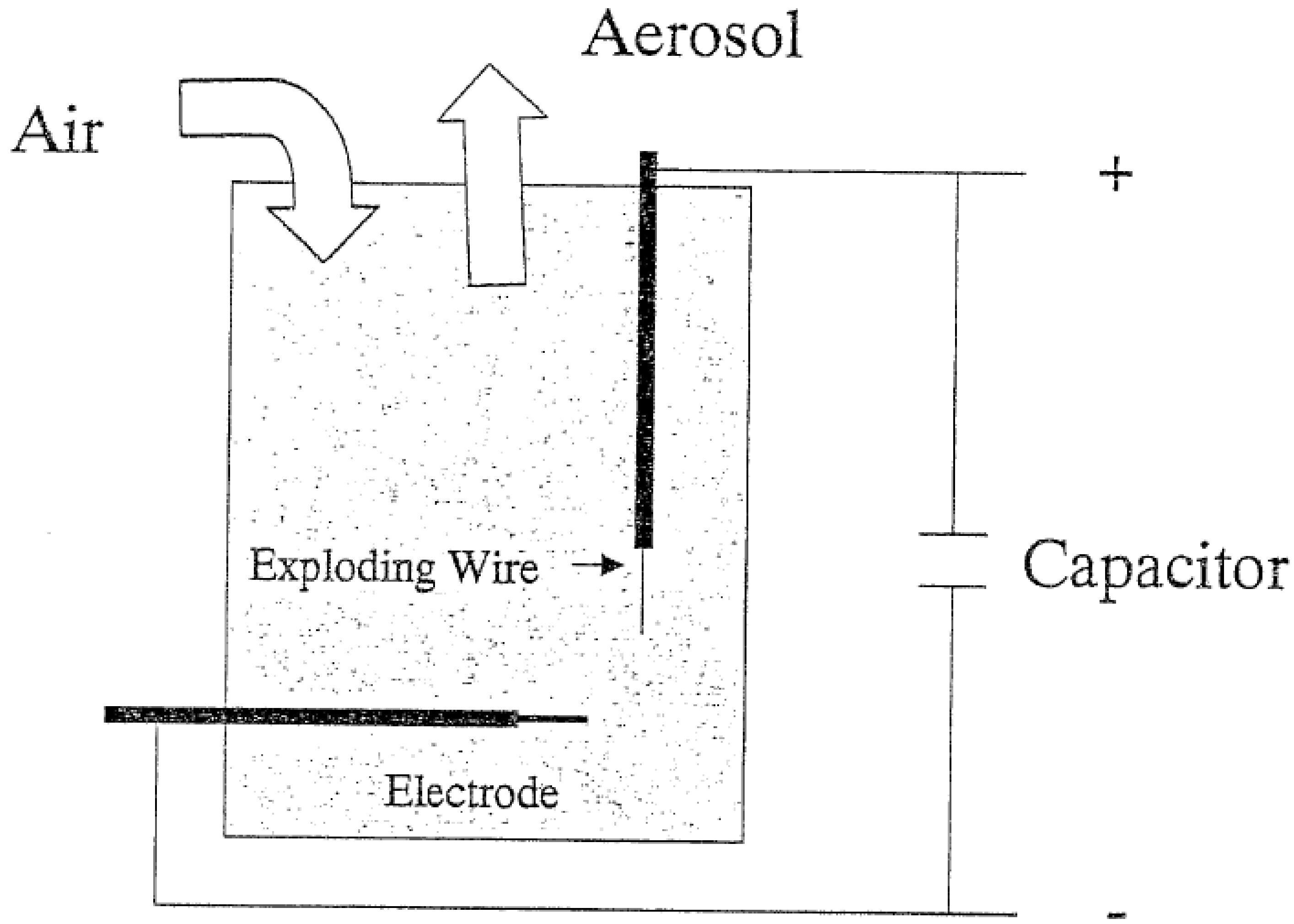
Ultrasonic Nebulizer超声喷雾器



Spinning Disk Particle Generator旋转气溶胶发生器



Exploding Wire



Test Dusts测试粉尘

- Standard Dust (Arizona Road Dust)标准粉尘（亚利桑那州粉尘）
  - Mainly Silica with主要的硅
    - Mass Mean Diameter of 7 μm质量直径平均是7微米
    - σ_g of 3.6分布为3.7
    - Specific Gravity of 2.7重量是2.7
  - Originally collected from Arizona Desert
  - 原始的收集于亚利桑那州沙漠

Test Dusts

- ASHRAE 空调舒适性标准
  - Custom blend of包括:
    - 72% ISO 12103-1, A2 Fine Test Dust,
    - 72%ISO粉尘
    - 23% powdered carbon 23%的碳粉
    - 5% milled cotton linters 5%磨的棉线
  - Attempt to simulate natural dust for HVAC
  - 趋向于HVAC的自然粉尘。

Test Dusts测试粉尘

- SAE Dusts – automotive filter testing
- SAE粉尘-自动过滤器测试
  - Fine 细粉尘
    - Mass Median Diameter ~ 25µm 质量平均直径
    - No particles > 100µm 没有颗粒大于100um
  - Coarse粗粉尘
    - Mass Median Diameter ~ 60µm 60um平均质量粒径
    - 10%+ may be larger than 100µm， 10%以上大于100um.

Common Mono-disperse Aerosol Standards 单一分布气溶胶标准

- Poly Styrene Latex (PSL)聚苯乙烯标准粒子
- Vibrating Orifice 振动孔
- Electrostatic Classification静电分级
- Condensation Techniques冷凝技术

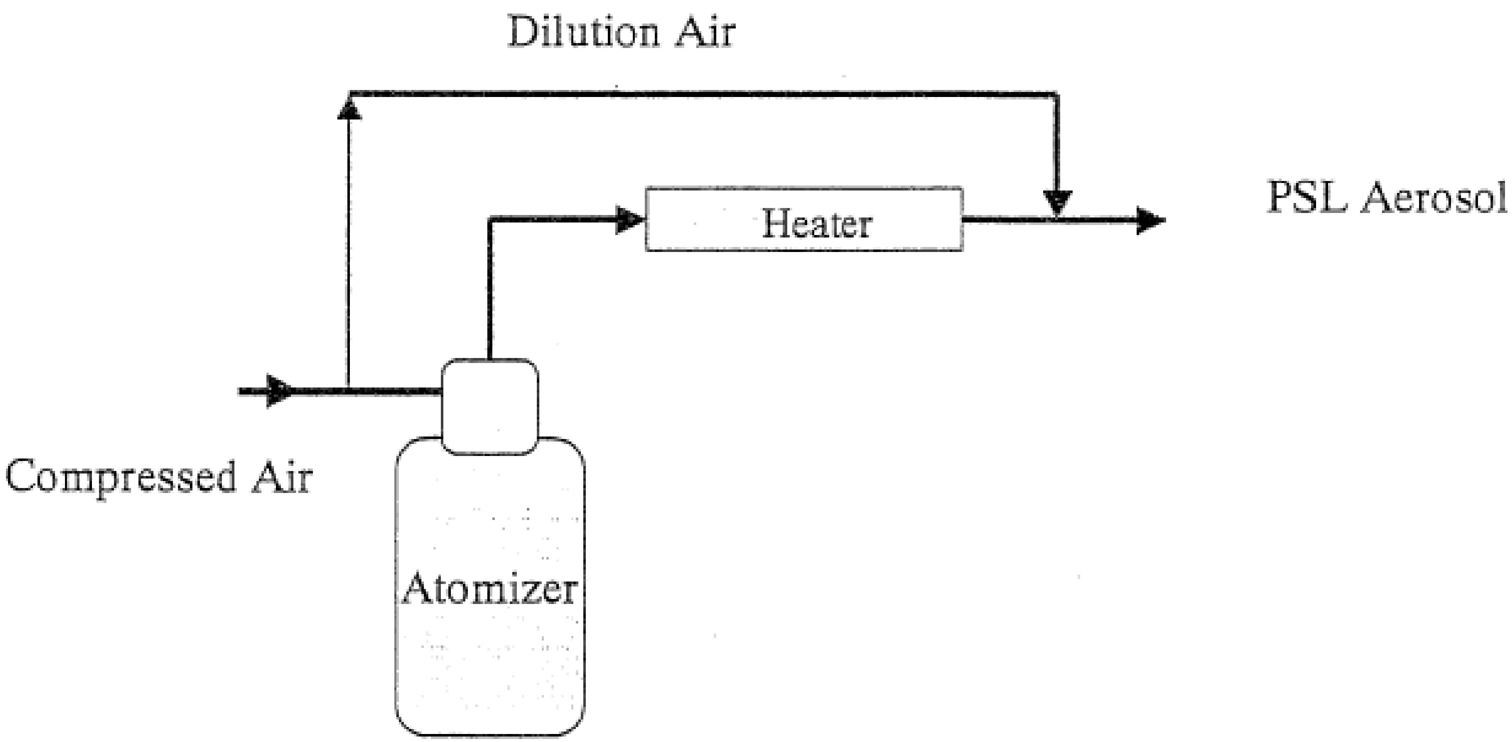
PSL Aerosols PSL 气溶胶

- NIST Traceable PSL Particles 可溯源到NISTPSL粒子
  - Examples

PSL Spheres, NIST SRM, 60.4nm, 101.8nm, 269nm, 895nm				
Product Part #	**Nominal Diameter**	**Certified Mean Peak**	**Std. Dev & CV**	**Solids Content**
AP1690	895 nm	895nm ± 5 nm	0.7 nm	0.50%
AP1691	269 nm	269nm ± 4 nm	5.3 nm	0.50%
AP1963A	101.8 nm	101.8nm ± 1.1 nm	0.55 nm	0.50%
AP1964	60.4 nm	60.39nm ± 0.63 nm	0.31 nm	0.50%

  - Methodology 方法
    - Atomize PSL in Liquid (water)在液体里雾化PSL
    - Evaporate the liquid 蒸发掉液体
    - NIST Traceable PSL Aerosol 可溯源到NIST PSL粒子

PSL Aerosols PSL产尘仪



Residue & PSL Aerosols 残留&PSL气溶胶

- Impurities in water become small particles水中的杂质变成小颗粒
- These particles can be counted as particles in standard aerosol, especially by a CNC 这些可能被计数，特别是凝聚核计数仪

Residue & PSL Aerosols

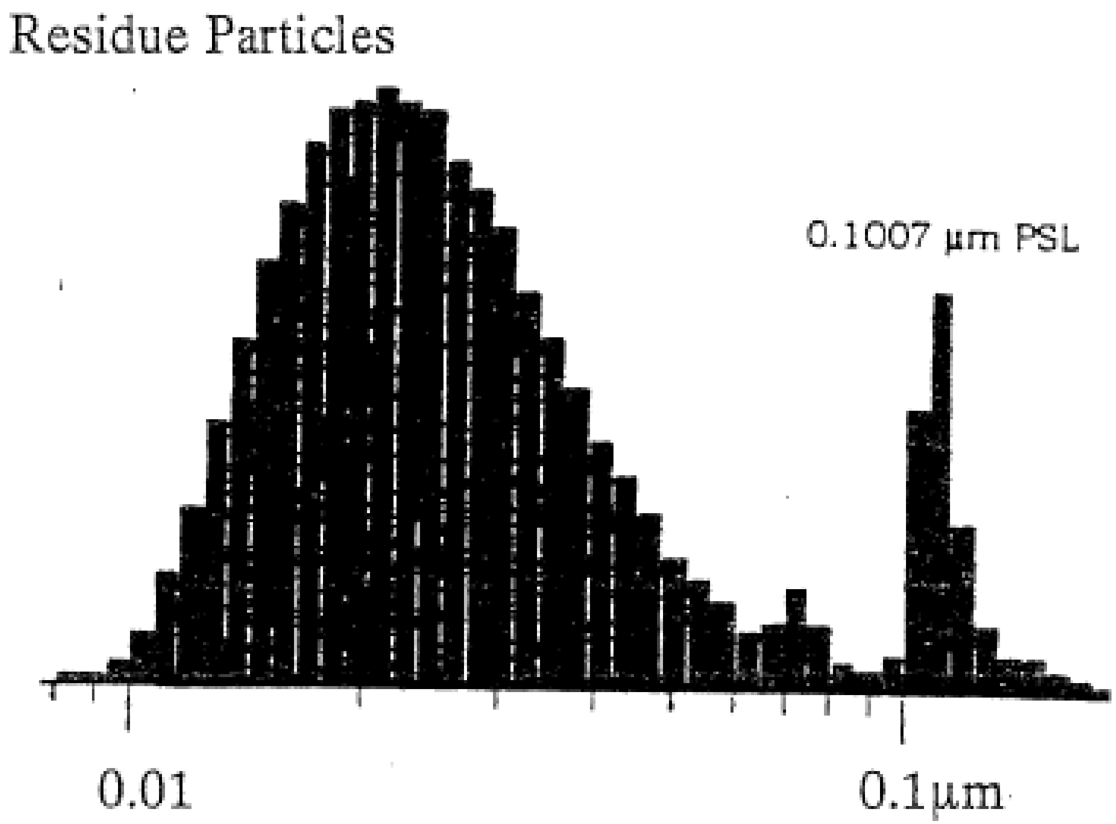
Assuming a typical 2um atomizer droplet and 10 ppm purity water, 比方说我们把2um雾化液滴和10ppm的纯水

Residue particle size can be computed

$10 \times 10^{-6} = (\text{residue dia/drop dia})^3$

Residue Diameter = 0.04um

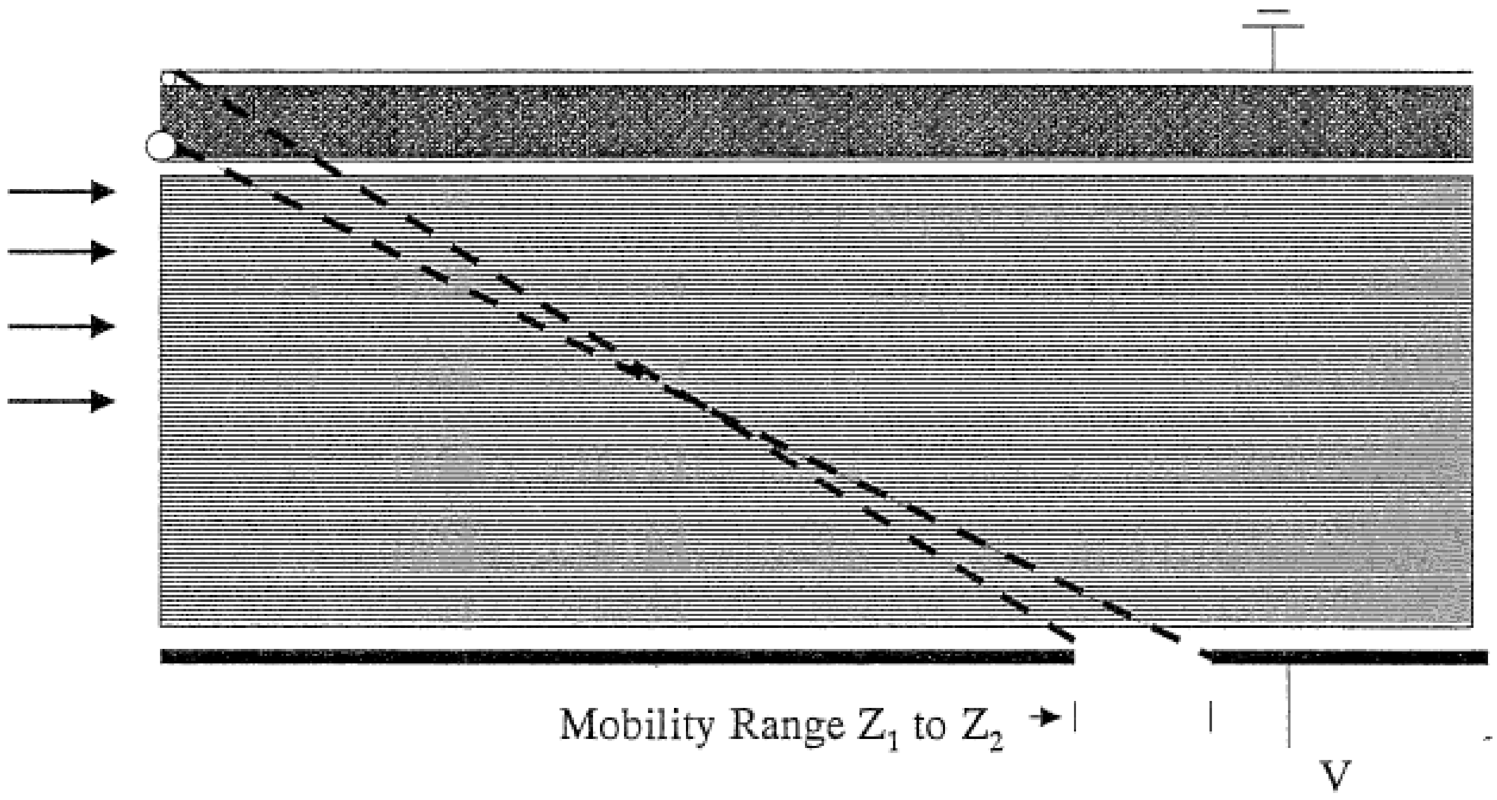
Residue Particles残留的颗粒



PSL AerosolsPSL气溶胶

- Common for Cleanroom Applications常用于洁净室应用
- NIST traceable PSLs are expensive可溯源到NISTPSL粒子非常贵
- PSLs are easy to aerosolize, but output concentration is variable容易雾化，但输出浓度变化大
- Limited by residue at small sizes 在小的粒径区有残留
- Not available in large sizes没有大的尺寸的颗粒
- PSL gives excellent optical response 光学反应上性能优秀
- Used as calibration aerosol for particle counters用作计数仪的校准气溶胶

Electric Mobility Classification
电纤移分类



Points to Remember

- Standards are required to verify and calibrate instruments and devices
- A Standard aerosol can be either poly or mono disperse
- R&D standards are more precise and are for laboratory use
- Industrial standards are easier to produce and are widely used

Points to Remember cont'd.

- Poly-disperse aerosols are commonly generated by atomization, nebulization or mechanical means
- Only a few techniques are available to generate very tight, mono-disperse aerosols
- NIST traceable PSLs are generated in small quantities and are very expensive
- PSL concentration output is variable
- Residue particles can be a problem in small sizes

Discussion

Photometer Testing Standards & Practices

光度计测试标准和实践

What is a “Filter” Testing Standard?过滤器测试标准

- A DOCUMENTED and Universally Accepted method of obtaining a Qualitative Performance Measurement

  一个可记录的广泛接受的方案，得到一个可量化的测量

Why are Standards Necessary?标准必需什么

- They establish consistent methodology建立一致性
- Provide a guide for understanding and compensating for variables encountered during practical application提供一个指导对理解和补偿在实践中

How Does this Affect Filter Testing?

- A Test Standard defines methods and limits
  - Aerosol characteristics气溶胶特性
  - System Operating Conditions系统操作条件
  - Testing protocols测试条文
    - Allowable Challenge Concentrations允许挑战性浓度
    - Sampling Rate取样速度
    - Maximum “Allowable” Leakage最大的允许的泄露
    - Scanning Speed扫描速度

Standards & Recommended Practices Organizations标准及建议操作组织

- AACC (American Association for Contamination Control)
- 美国污染控制协会
- ISO (International Organization for Standardization)
- 国际标准组织
- BNL (Brookhaven National Laboratory)
- ASTM (American Society for Testing and Materials)
- EN (European Norm)
- IEST (Institute of Environmental Science & Technology)
- ANSI (American National Standards Institute)
- ASME (American Society of Mechanical Engineers)
- DOE (Department of Energy)

Filter Testing Standards

- CS-IT (1968) Standard for HEPA filters
- CS-2T (1968) Standard for Laminar Flow Clean Air Devices - Installation Leak Test (filter and gaskets)
- CS-2T (1968) Standard for Laminar Flow Clean Air Devices - Induction Leak Test (seams and joints)
- 14644-3 (2005) Cleanrooms & Associated Environments, Annex B- Test Methods (Informative)
- IH62300 (2001) In-Place HEPA Filter testing, Section 6.2 Equipment
- EN-1822-2 High Efficiency Air Filters (HEPA & ULPA)-Part 2: Aerosol Production, Measuring Equipment, Particle Counting Statistics
- IES-RP-CC001 HEPA & ULPA Filters
- IES-RP-CC006 Testing Cleanrooms
- IES-RP-CC007 Testing ULPA Filters
- IES-RP-CC034 HEPA & ULPA Filter Leak Tests
- Fed Std 209E (1992 by IEST) Most referenced in “Filter” industry was replaced by ISO 14644-1 & 2 in November 2001
- NSF 49:2008 (Annex A:2008) Biosafety Cabinetry: Design, Construction, Performance & Field Certification-Performance Tests
- NSF 49:2008 (Annex F:2008) Biosafety Cabinetry: Design, Construction, Performance & Field Certification-Field Tests
- ASME N509 (2008) Nuclear Power Plant Air-Cleaning Units & Components)
- N510 (2007) Testing of Nuclear Air Treatment Systems
- N511 (2007) In-Service Testing of Nuclear Air Treatment Heating, Ventilating and Air-Conditioning Systems

DOE-HDBK-1169, DOE Handbook Nuclear Air Cleaning Handbook, Section 8.6.1 In Place

Industries Using Photometry光度计行业

- Pharmaceutical制药
- Non-pharmaceutical 非制药
  - Civilian
    - Nuclear Power核电厂
  - Military
    - Nuclear Weapons 核武器
    - Chemical Weapons化学武器
    - Biological Weapons生物武器

Photometer vs. Discrete Particle Counter光度计和计数仪

- 1968 CS-1T Standard for HEPA Filters
- 1968年cs-1THEPA测试标准

Photometer光度计

•Upstream challenge aerosol must be at least 27ug/l
•Maximum Leakage = 0.01%
•Scanning rate = 2 inches per second @ 1 inch from filter face

Particle Counter

•No defined method

Photometer vs. Discrete Particle Counter

- 1968 CS-2T Standard for Laminar Flow Clean Air Devices
  - Installation Leak Test (for filter & gaskets)

Photometer

•Upstream challenge aerosol must be at least 27ug/l
•Maximum Leakage = 0.01%
•Scanning rate = 2 inches per second @ 1 inch from filter face

Particle Counter

•No defined method

Photometer vs. Discrete Particle Counter

- 1968 CS-2T Standard for Laminar Flow Clean Air Devices
  - Induction Leak Test (for seams & joints)

Photometer

•Ambient aerosol must be at least 10 E^3 above FF
•Maximum Leakage = >FF
•Scanning rate = 2 inches per second @ 1 inch from joint or seam within clean zone

Particle Counter

•Ambient aerosol must be >300K particles/ft3
•Maximum leakage >100 counts
•Scanning rate = 2 inches per second @ 1 inch from joint or seam within clean zone

Photometer vs. Discrete Particle Counter

- 2005 ISO 14644-3 Cleanrooms & associated controlled environments, Test methods
  - Installed Filter System Leakage
  - 2005年 ISO 14633-3标准

Photometer光度计

•Upstream challenge aerosol of between 20 & 80ug/l
•上游在20-80ug/L间
•Maximum Leakage = 0.01%
•最大的泄露是0.01%
•Scanning rate = 2 inches per second @ 1 inch from filter face扫描速度是每秒2英寸，距过滤器面1英寸

Limitations限制

•Efficiency < 99.997% @ MPPS
•Oil aerosols allowed油气溶胶允许
•Ability to achieve required concentrations 可得到需要的浓度

Particle Counter 计数仪

•Upstream challenge aerosol (Too much detail to list here @ 6 pages) sufficiently high that N_p >2 & <10
•上游气溶胶浓度足够高
•Maximum leakage = 0.01%
•最大的泄露0.01%
•Scanning rate ≤ 3.14 inches per second (varies depending on probe dimensions, N_p, sample rate扫描速度是每秒小于3.14英寸（探头尺寸不同而不同）

Photometer vs. Discrete Particle Counter

- 2005 ISO 14644-3 Cleanrooms & associated controlled environments, Test methods
  - Containment Test 2005 年ISO 14644-3标准

Photometer

•Upstream challenge aerosol of between 20 & 80 ug/l

•上游在20ug/L-80之间

•Maximum Leakage = 0.01%

•Scanning rate ≤ 2 inches per second at 2 inches from joint, seal or mating surfaces

Limitations

•Efficiency < 99.997% @ MPPS

•Oil aerosols allowed

Particle Counter

•The greater of:

- ambient count X $E10^3$
- > 3.5 $E10^6$ particles/m^3

•Maximum leakage = ≤ ambient count X $E10^{-2}$

•Scanning rate ≤ 2 inches per second at 2 inches from joint, seal or mating surfaces

Photometer vs. Discrete Particle Counter

- 2001 IH62300:2001 In-Place HEPA Filter testing

Photometer

- Upstream challenge aerosol 10^4 greater than ambient
- Maximum Leakage = 0.03%
- Duct measurement-No scan

Particle Counter

- No defined method

Photometer vs. Discrete Particle Counter

- IEST-RP-CC006 Testing Cleanrooms

Photometer

•Upstream challenge aerosol of between 10 to 20 ug/l
•Maximum Leakage = 0.01%
•Scanning rate = 2 inches per second @ 1 inch from filter face

Particle Counter

•3 x E10^8 #/m3 @ particle size of interest (10 counts per Appendix B, Exp. 1)
•Maximum Leakage = 0.01%
•Scanning rate =
$[(C_c)(L_s)(F_s)(D_p)] \div [(60)(N_p)]$
Result 3.3 ft/min @ 1 in or 0.65 inches per second
(Appendix B, Exp. 1)

Photometer vs. Discrete Particle Counter

- IEST-RP-CC034 HEPA & ULPA Filter Leak Tests IEST测试标准

Photometer

•Upstream challenge aerosol of between 10 to 90 ug/l
•Maximum Leakage = 0.01%
•Scanning rate = 2 inches per second @ 1 inch from filter face

Particle Counter

•2.8 x E10^8 #/m3 @ particle size of interest *(10 counts per Appendix G, Exp. 1)*
•Maximum Leakage = 0.01%
•Scanning rate = [(2.8)(108)÷1000][(0.0001)(28.3)(1.25)÷(60)(10)]

Result = 1.25 cm/s @ 1 in or 0.5 in/sec
(Appendix G, Exp. 1)

Photometer vs. Discrete Particle Counter

- 2008 NSF 49 Biosafety Cabinetry
- 2008年NSF 49 生物安全柜

Photometer

•Upstream challenge aerosol of at least 10 ug/l

•上游大于10ug/L

•Maximum Leakage = 0.01%

•最大的泄露是0.01%

•Scanning rate = 2 inches per second @ 1 inch from filter face 扫描速度是每秒2英寸，距过滤器面1英寸

Particle Counter

- No defined method 无计数仪描述

Points to Remember!

- Photometer & particle counter results are not likely to correlate due to the different weighting of the technology used.
  - Photometry response is mass weighted while particle response is number weighted.
- Filter testing process is the same regardless of photometer or particle counter use.
  - Measure upstream challenge
  - Measure downstream penetration by scanning or point sampling
  - Calculate penetration

Points to Remember!

- Filter testing process complexity varies between photometers and particle counters.
  - Challenge concentration
    - Photometers: Variable range of 10-100 ug/l with 10-30 ug/l being typical (Std defined)
    - Particle counters: Variable range of 3.0 $E10^5$ to 3.0 $E10^8$ (Std defined, calculated to achieve desired N_p)
  - Measure Downstream
    - Photometers :0.01% leakage maximum while scanning rate of 2 inches /second in most cases (Std defined)
    - Particle counter: 0.01% leakage maximum in most cases while scanning at a calculated, statistically, determined rate (Std defined)

Points to Remember!

- Calculate Penetration
  - Photometer: Ratio of upstream challenge to downstream expressed as a percent
  - Particle counter: Ratio of upstream challenge to downstream expressed as a percent

Points to Remember!

- Each technology has design strengths and weaknesses which decide where its use is “reasonable” in filter leakage testing.
  - Photometer
    - Aerosol generator for upstream challenge “oil” aerosol
    - No diluter necessary for Upstream measurements
    - Consistent & essentially “Calculation Free” test method
    - Limited to systems with efficiencies ≤99.997%
    - Typically consistent results among multiple units
    - Robust “core” technology
  - Particle counter
    - Aerosol generator required in most cases, but at a lower output
    - Use of solid or liquid aerosol possible
    - Ability to test systems to 99.9999% efficiency
    - Diluter required for upstream sampling
    - Unit to unit result consistency difficult to achieve
    - More sensitive detection system results in less-robust instrument

Discussion

Hands On Demo: Photometer Filter Leak Scanning

Review and Discussion

Thank you

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