Basic Guide to Particle Counters and Particle Counting

Without measurement there is no control.

PARTICLE MEASURING SYSTEMS®
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Particle Counters and
Particle Counting

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Particles

The physical nature, origin, and behavior of particles are described in this section.

Types and Sources

Generally, there are three types of particles:

- Inert organic
- Viable organic
- Inert inorganic

Inert organic particles come from non-reactive organic material, which is material derived from living organisms and includes carbon-based compounds. Viable organic particles are capable of living, developing, or germinating under favorable conditions; bacteria and fungi are examples of viable organic compounds. Inert inorganic particles are non-reactive materials such as sand, salt, iron, calcium salts, and other mineral-based materials.

In general, organic particles come from carbon-based living matter, like animals or plants, but the particles are not necessarily alive. Inorganic particles come from matter that was never alive, like minerals. A dead skin cell is an inert organic particle, a protozoan is a viable organic particle, and a grain of copper dust is an inert inorganic particle.

Particles are produced from a large variety of sources. Inert particles usually develop when rubbing one item against another, such as the dust produced when you cut through a piece of wood. Humans shed many thousands of inert particles through the continuous sloughing of dead skin and large quantities of viable particles through other natural processes. Electric motors generate inert particles when their wire brushes rub against the rotating components. Plastics, when exposed to ultraviolet light, slowly release inert particles.

Size

In the context of contemporary manufacturing methods, the smallest particles are so small that they cannot be considered destructive contamination. These small particles are many times smaller than an atom, and are called subatomic particles. The next larger family of particles is atoms, followed by molecules, which are groups of atoms.

Molecular contamination is of particular interest in semiconductor manufacturing environments that follow Moore's Law. In 1965, Gordon E. Moore (co-founder of Intel Corporation) stated that the number of transistors on an integrated circuit doubles about every two years. With fixed real estate in the integrated circuit, the only way to double the number of transistors is to shrink their size. These transistors are quickly shrinking towards molecular sizes, and molecular contamination can limit the manufacturing efficiency.

After molecular contamination, various manufacturing applications concentrate on particles measured in µm (micrometers). These particles range in size from well under 1 µm (1/1000 [10^{-3}] of a millimeter or 1 millionth [10^{-6}] of a meter) to about 100 µm.

Comparatively speaking, 25,400 µm equals one inch, a single grain of salt measures about 60 µm and human hair measures between 50 and 150 µm. The average human eye cannot see particles smaller than 40 µm.

It is particles larger than 100 µm and smaller than 0.01 µm that are of little interest to most modern manufacturing processes because particles larger than 100 µm are easily filtered and particles smaller than 0.01 µm are too small to cause damage.

In addition, the International Organization for Standardization (ISO) does not provide classifications for particles smaller than 0.1 µm (called ultrafine particles) nor particles larger than 5.0 µm (called macroparticles). **Table 1** lists some common particles and their relative sizes.

Table 1 Common Particle Sizes

Particle Content	Particle Size (in µm)
Hair	50 – 150 µm
Visible	50 µm
Flu virus	0.07 µm
Pollen	7 – 100 µm
Sneeze particles	10 – 300 µm
Dust	0.1 – 100 µm
Bacteria	1.0 – 10 µm

There are several different ways to measure a particle. **Figure 1** shows the standard methods used. A sphere, modeled in **Figure 1** as dashed lines, represents the equivalent polystyrene latex sphere (PSL) particle. PSLs are synthetic particles used to calibrate particle counters and test filters.

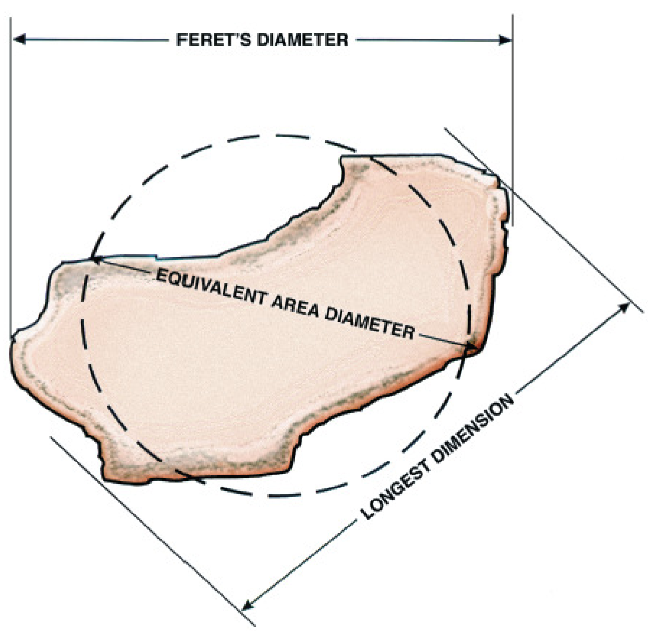

Figure 1 Particle dimensions

The scientific term for each type of measurement is useful in different contexts, especially in microscopy. Feret's Diameter is the measured distance between theoretical parallel lines that are drawn tangent to the particle profile and perpendicular to the ocular scale. Particles falling onto a surface will adopt their most mechanically stable state, which means they will present their largest area to the observer and as a consequence their longest dimension.

Some particles may change in size. A viable organic particle, such as a paramecium, is a microorganism that, like most animals, is made mostly of water. If the paramecium becomes desiccated (dried up) it will be much smaller than it was when it was hydrated (full of water).

Particle size is relevant in manufacturing. Depending on the clean process, specific particle sizes may cause damage. In the semiconductor industry sub-µm particles affect the number of producible chips. In the disk drive industry particles can damage the read/write heads. In the pharmaceutical industry, larger particles can affect a drug's interaction with the body. Because we rely on filters to remove most of the particulate contamination, knowing the relevant particle size allows you to purchase filters with the correct pore size to remove the contamination and increase productivity.

Bell Curve Distribution (Gaussian Distribution)

Realistically, particle standards seldom size exactly within a particular size channel. Using 3.0 µm particles as an example, most particles are a little bigger or a little smaller than 3.0 µm. We call 3.0 µm the nominal size of the particle because it is convenient (instead of calling them, for example, "2.547 µm to 3.0582 µm particles"). The amount a particle differs from the nominal size is the variance. The variance is equal to the squared value of the standard deviation.

If you precisely measure a number of particles at a nominal size of 3.0 µm and graph the results, the graph will look like **Figure 2**.

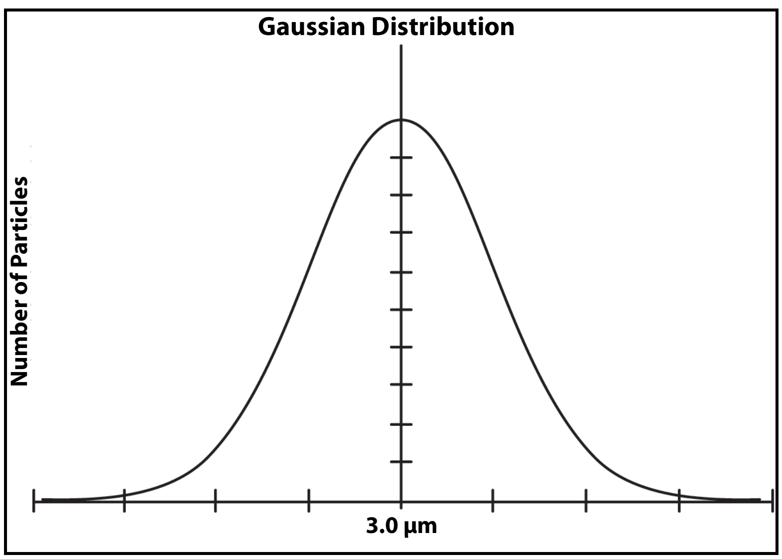

Figure 2 Gaussian (Bell curve) distribution

On the graph, most of the particles are centered at 3.0 µm, with lesser numbers of particles larger or smaller than 3.0 µm. In a particle counter, those particles that are smaller than the nominal size (to the left of the peak) will be sized and counted in the smaller particle size bin. The particles at or larger than the nominal size (at the peak and to the right of the peak) will be sized at the nominal size.

Concentrations

Typically, in a standard cubic foot of indoor air we can expect 1,000,000 particles larger than 0.5 µm. Comparatively speaking, a cubic foot of air over the middle of the ocean or high mountains contains only 34 particles or 169 particles (respectively) larger than 0.5 µm.

In liquids, a single milliliter of a cleanroom's ultrapure water source contains fewer than one particle larger than 0.05 µm. Yet, a milliliter of drinking water may contain 1,200,000 particles larger than 0.05 µm. Humans produce significant particle concentrations, shedding about 1 ounce of skin particles per day. The simple process of exhaling air can produce several thousand particles, especially from smokers. **Figure 3** shows how human activity generates particles.

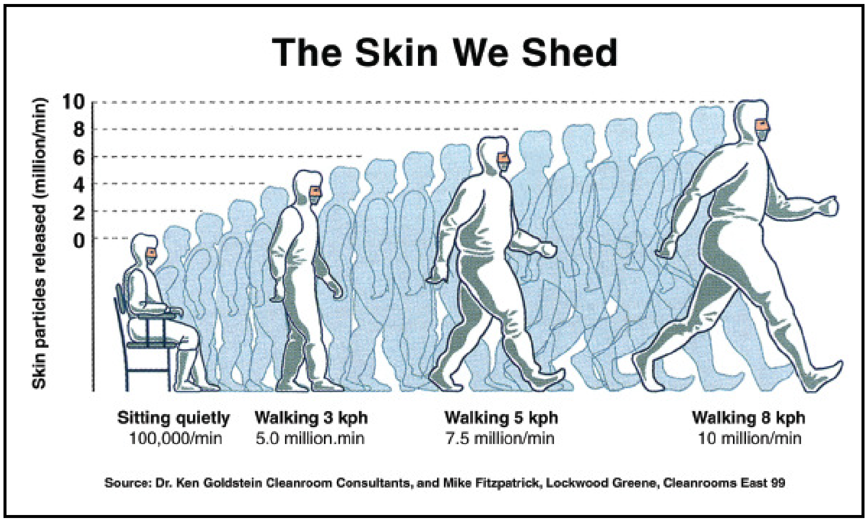

Figure 3 Particle generation

Distributions

Airborne and liquid particles within ambient conditions follow a common sizing distribution. The airborne particle distributions follow ISO 14644 Cleanroom Standards that assume Power Law Distribution.

The Power Law Distribution correlates data from one particle sizing channel to the next. If plotted on a log-log graph, the data will yield a straight line; similarly, plotting data on a standard XY-axis graph produces an exponentially decreasing line.

Subsequent particle studies have shown distributions for airborne particles proportional to $1/(\text{diameter})^{2.1}$. Liquid particle distributions range from $1/(\text{diameter})^{2}$ to $1/(\text{diameter})^{4.5}$, but $1/(\text{diameter})^{3}$ is used as a standard for most ambient liquid distributions.

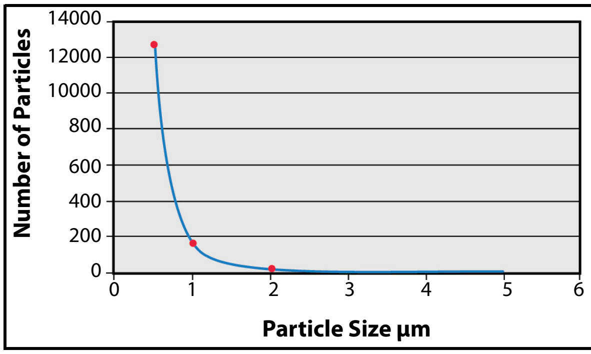

Figure 4 Ambient particles (XY axis plot)

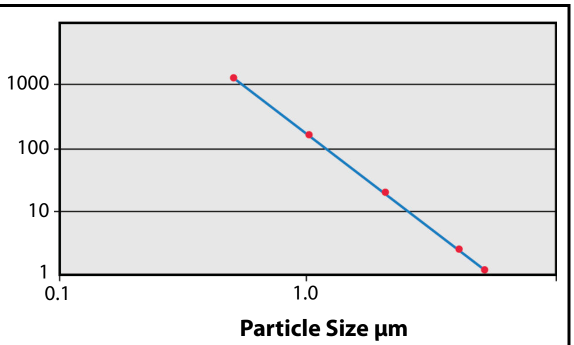

Figure 5 Ambient particles (log-log plot)

Power Law Distribution formula example:

- Testing drinking water shows 20 particles/mL > 2.0 µm
- Use the liquid particle distribution formula $1/(\text{diameter})^3$
- The formula can calculate how many particles are > 0.5 µm:
  - (number of particles > 2 µm)* [1/(ratio of particle diameters)^3]
  - (20)* [1/(0.5 µm /2.0 µm)^3]
  - 1280 particles > 0.5 µm
- The drinking water contains 20 particles/mL > 2.0 µm, and 1280 particles/mL > 0.5 µm.

Materials

Almost anything can generate particles under the right circumstances. In a cleanroom, the most prolific particle generators are usually people. People generate particles by shedding skin cells, emitting perfume/colognes/hair sprays, losing hair, breathing, sneezing, etc.

All particles can be classified according to their grouping:

- *Particle:* a single particle with similar material throughout.
- *Aggregate:* a group of particles held together by strong atomic or molecular forces. The particles' attractive forces are comparable to those that bond a chunk of concrete.
- *Agglomerate:* a group of particles held together by weaker forces of adhesion or cohesion. The particles' attractive forces are comparable to those that bond a dirt clod.
- *Flocculate:* a group of particles held together by the weakest forces. The particles' attractive forces are comparable to dust sitting on a table.

Particle Mechanics

Particles exhibit certain tendencies. They move through the air (and other media) by ballistic forces or diffusion. Particles may accumulate on surfaces due to gravity and electrostatic adhesion. In liquids, particles may adhere to air bubbles, cling to the walls of a duct or container, or agglomerate into a larger mass.

Relative Importance of Gravity vs. Other Forces

Like all matter, particles are influenced by gravity and other forces, which may include centrifugal or electric forces. In the presence of gravity and absence of other forces, particles larger than a few micrometers will quickly settle onto surfaces or sample tubing walls. Conversely, sub-micrometer particles can remain suspended in air currents for a long time. However, if particles are influenced by centrifugal or electrical forces, the particles may resist gravity, travel greater distances, or become attracted to optics. A simple example of particle attraction to optics is a TV screen. The screen attracts dust (particles) due to high energy electrical forces. The tendency of particles to settle onto surfaces is known as the settling coefficiency derived from Stokes' Law. Stokes' Law is an equation that relates forces (drag) to the settling velocity of smooth, rigid spheres in viscous fluids of known density and viscosity. Using these concepts of physics, the settling efficiencies can be shown as follows:

Table 2 Settling Velocity

Particle Size (µm)	Settling Velocity (in cm/sec)
0.0037	---
0.01	6.95×10^{-6}
0.1	8.65×10^{-5}
1.0	3.5×10^{-3}
10.0	3.06×10^{-1}
100	2.62×10^{-1}

Movement

Ballistic forces: Particles ejected from a tool or process may cause them to move against the prevailing airflow and not evenly distribute within the environment. Gradually, particles will migrate towards lower pressure areas, but due to the continued particle contribution from the tool or process, ambient particle distributions seldom occur.

Diffusion: Imagine dumping red dye into a bucket of clean water. After a while, the entire bucket of water becomes a uniform red color. This phenomenon is diffusion and still occurs when a gas or liquid appears motionless. Particles suspended in a fluid (liquid or gas) are moved by several forces: currents, thermal variation, and Brownian motion.

Currents: Currents are the laminar (smooth) and turbulent (rough) movements of air or fluids. Currents result from pressure differences, with movement shifting from an area of high pressure to an area of low pressure. Particles suspended in a laminar flow tend to remain in that part of the fluid. In air, lateral (side-to-side) movement is called advection, and vertical (up and down) movement is convection.

Thermal variation (thermophoresis): Temperature differences in a fluid contribute to currents, particularly convective (vertical) currents. Simply, thermophoresis describes particle motion in a temperature gradient as particles move from a hot region towards a cooler region.

Brownian motion: Small particles suspended in gas or liquids come into contact with gas molecules. These molecules bump into a small particle and alter the small particle's trajectory. The particle's path, which has been altered by molecules, is called *Brownian motion*. Warming a fluid causes the molecules to be more energetic, collide more frequently, and move farther apart from other molecules and therefore increases Brownian motion.

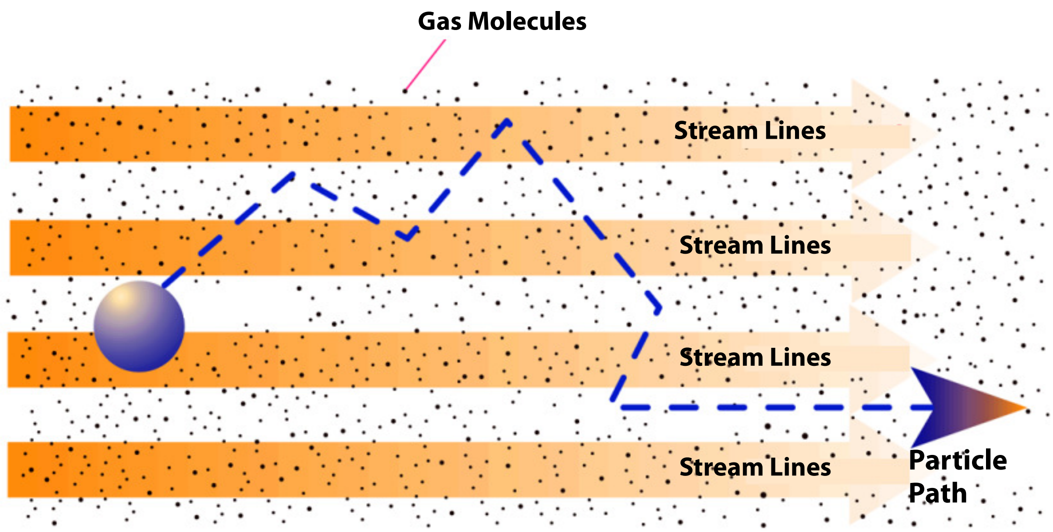

Figure 6 Brownian motion

Adhesion

Many forces act upon a particle and remove it from its free (diffused) state. The primary adhesive forces are described below.

Electrostatic adhesion: Rubbing a balloon against your hair creates a layer of static electricity on the balloon. This creates electrostatic adhesion. Similarly, particles may carry static electricity causing them to attract to surfaces that carry opposite charges.

Agglomeration: Agglomeration occurs when particles bond firmly together. In liquids, particles tend to agglomerate onto gas bubbles.

Accretion: Accretion defines the growth of particle matter as particles attach to each other. Electrostatic adhesion or other "sticky" forces contribute to particle accretion, and under certain conditions two particles stuck together are called a doublet.

Friction: Particles can bond to a rough surface where movement, or friction, is not strong enough to dislodge them.

Movement and Adhesion Cycle

Diffusion and adhesion coexist in a continuous cycle: particles circulate, become trapped, break free, and re-circulate. This cycle creates constantly changing values for the number and sizes of particles. Therefore, particle detectors analyze a volume of fluid and may correlate the data to particle concentrations per unit volume.

Transporting Particles through Tubing

Manifold systems collect particles from separate areas and transport the samples to a particle counter located elsewhere. Usually, a tube or duct provides remote sample gathering, but when sample media within a tube travels from a remote location to a particle counter, two things happen:

- Some pressure is lost
- Some particles adhere to the tubing

There are many factors that affect particle mobility within tubing. **Table 3** describes pressure losses as a function of distance, using a system standard of 3 CFM airflow per sample point. Brief descriptions of the terminology follow the table.

Table 3 Air Pressure Loss at Distances

Diameter (ID)	Reynolds Number	Pressure Loss (psi/meter)	Gas Velocity (meter/second)
4 mm	9150	0.980	40.35
5 mm	7360	0.340	25.90
6 mm	6130	0.150	18.00
1/4 in	5780	0.110	16.00
7 mm	5250	0.070	13.20
8 mm (5/16 in)	4585	0.040	10.10
9 mm	4070	0.020	8.00
3/8 in	3865	0.016	7.20
10 mm	3670	0.013	6.50

Inside Diameter: The inner diameter of a tube, designated ID.

Reynolds Number: The ratio of inertial (resistant to change or motion) forces to viscous forces that is used for determining whether a flow will be laminar or turbulent. The Reynolds Number accounts for flows within a tube influenced by shape, inner smoothness, straightness, fluid viscosity, ambient air pressure, and temperature.

Pressure Loss: Air pressure decreases proportionately to the length of tube. Thus, if 10 psi of air pressure enters a tube 20 meters long and 7 mm wide, the pressure at the other end will measure 8.6 psi.

Gas Velocity: The speed at which gas travels through the line.

Particle Loss

To minimize particle loss in tubing, the tubing should always lie flat (if possible) with minimal bends. If tubing bends are required, the *bend radius* (which is measured to the inside curvature) should not be less than 6 inches. Also, the tubing diameter and materials should be conducive to particle transport.

Bev-A-Line® conductive polymer 3/8" ID tubing is commonly installed with aerosol manifold systems and offers superior particle transport at a reasonable cost. Some tubing materials are not always available, or affordable, so based upon reducing particle losses, the following list of tubing material types is in order of preference:

1. Stainless steel
2. Conductive polymer
3. Polyester
4. Vinyl (if plasticizer does not interfere)
5. Polyethylene
6. Copper
7. Glass
8. Teflon
9. Aluminum

Environments

The use of specialized environments and filtration to control the effects of particles on production is described in this section.

Cleanliness in Manufacturing

Many modern high-technology processes demand cleanliness. Specifically, they demand an absence of particulate contamination. A few examples can best explain this.

Example One

In the semiconductor manufacturing industry, we commonly refer to semiconductors as “integrated circuits” (ICs), “microchips,” or “chips.” An IC is a flat piece of silicon etched with very small traces (flat wires) that form transistors and other components. Transistors may operate as a switch or an amplifier for signals (voltage, current, or power).

IC traces are so close together (30 nanometers [nm] apart and shrinking) that a particle lying across a trace would cause a short circuit. Semiconductor manufacturers need to filter airborne particles equal to and larger than 30 nm; particles smaller than 30 nm are not big enough to cause a short circuit. However, as traces grow closer together, there will be a demand for more-sensitive monitors.

ICs are multi-layered devices, with each layer being extremely thin. So for manufacturing purposes, an IC’s effective surface area is equal to the following:

Area (IC Surface) = length x width x number of layers

The density of IC surface areas compounds the likelihood that stray particles could destroy the entire chip. Controlling or eliminating particle contamination within the production environment is a semiconductor manufacturer’s primary concern.

Example Two

The pharmaceutical industry commonly manufactures *parenteral* drugs. Parenteral (injectable) drugs must be free of particles that could infect the body – either human and animal.

Particles that can negatively affect the body tend to be larger than 2.0 or 3.0 µm and the pharmaceutical company, like the semiconductor manufacturer, must manage the production environment to eliminate particle contamination.

Typically, pharmaceutical companies determine *process cleanliness* by monitoring 0.5 µm particles and determine *product sterility* by monitoring 5 µm particles. In contrast, semiconductor manufacturing tends to concentrate on particles from 0.3 µm down to 0.05 µm.

Controlling Particle Contamination

There are three ways to control particles:

- Eliminate existing particles in the manufacturing environment
- Prevent or restrict the importation of new particles into the manufacturing environment
- Prevent the generation of new particles within the manufacturing process

Filtration

Filtration is essential to controlling particle contamination. There are two steps to filtration: directing the particles to the filter and trapping them inside the filter. Directing particles to the filter is more difficult.

Directing particles to the filter requires us to think about particles in the context of a typical manufacturing facility. A facility has an enormous number of particle traps (areas where particles accumulate), large surface areas, and abundant sources of contamination. The optimal method for particle management preserves laminar flow wherever possible, so that as many particles as possible are swept into the filters. Unfortunately, it is not always possible to preserve laminar flow.

Trapping particles inside the filter utilizes four principles: sieving, impaction, electrostatic force, and Brownian motion. The filter media has gaps, or *pores*, to allow air or liquid to pass (sieve), while fibers within the filter trap larger particles (impaction). Electrostatic forces carry an opposite charge from particles that helps trap particles onto a charged plate or fiber. Still, some smaller particles may slip through small pores and resist impaction, but their random movement (Brownian motion), does not allow them to escape the filter. All of these principles combine to make a filter more efficient as it ages.

Filters become more efficient as particles gradually fill the gaps in the filter media, so fewer areas are available for particles to slip through. However, the increased contamination creates less area for the fluid to pass through, creating greater pressure across the filter and eventually severely limiting flow through the filter. Once a filter reaches saturation (completely full of particles) it must be replaced. Sometimes the filter media can be purged (cleaned) and reused. Figure 4 shows a filter's media and the relative scale of 25 µm.

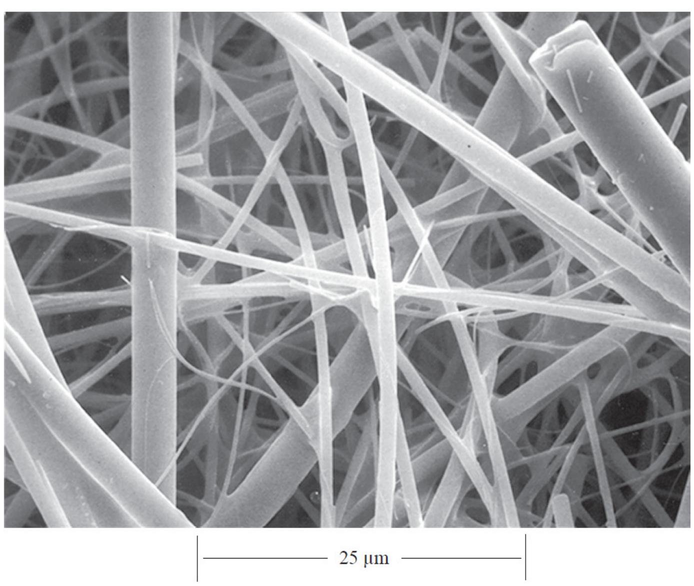

Figure 7 Filter media

Filter media have become very sophisticated and are made from synthetic fibers, membranes (Gore-Tex®), porous plastics, or ceramics. Common air filtration standards are as follows:

HEPA (High-Efficiency Particulate Air) filtration is the industry standard for ultraclean or ultrapure manufacturing environments. HEPA filters typically remove 99.99% of particles equal to, or larger than the filter's specification, which is usually 0.3 µm. HEPA filtration is an integral part of HVAC (Heating/Ventilation/Air Conditioning) systems.

ULPA (Ultra Low Penetration Air) filtration removes 99.9997% of particles equal to, or larger than 0.12 µm. Ultraclean process environments require UPLA filters.

In the past, particle contamination studies required using a microscope to count and measure particles within the filter. The technique was time consuming, labor intensive, and did not provide real-time particle monitoring. Today, sophisticated particle counting instrumentation performs filter analysis.

Cleanrooms

"Clean" process environments must remain unfailingly clean, so merely filtering the factory's air is inadequate. To minimize particle contamination it is important to build separate environments, called cleanrooms, that allow particle limits to be maintained at measurable and controllable levels. Cleanrooms achieve these great cleanliness levels by maximizing laminar airflow and minimizing particle traps. Laminar airflow is air moving in one direction, which allows particles to be swept away from an area. Particle traps are areas where particles gather and escape laminar airflow. Careful cleanroom designs can minimize these areas.

In efficient cleanrooms, filters installed in the ceiling allow filtered air to pass down toward the floor. The floor tiles have small holes that allow the air to pass under the floor, where air-returns (air ducts) transport the air back to the ceiling filters. This filtration process can exchange the cleanroom's entire volume of air more than thirty times per hour, resulting in the cleanest environment possible while minimizing the advective movement of particles.

Further contamination reduction in a cleanroom requires personnel to wear protective gowns, hair and beard covers, hoods, overshoes, and gloves. These are affectionately referred to as *bunny suits*. In the cleanest environments, personnel wear bunny suits fitted with helmets and respirators that filter exhaled air. Cleanroom apparel is extremely important in microcontamination control to contain the particles emitted by people.

Minienvironments and Isolators

The most technologically advanced cleanrooms employ minienvironments. These are miniature cleanrooms (measuring a few meters across) that isolate product from external contamination sources. Minienvironments include their own air fans, filters, temperature and humidity controls, internal robotic arms, or integral rubber gloves. Due to their size, minienvironments are significantly less expensive than cleanrooms and their usage is growing. A factory can install minienvironments in a lower grade cleanroom instead of spending large sums of money building a state-of-the-art facility to achieve the same results.

Classification of Cleanrooms and Minienvironments

The US Federal Standard 209E, published in 1963, defined cleanroom classification and monitoring within the United States. The European Committee for Standardization, in cooperation with the International Organization for Standardization (ISO), developed standards for Europe. Different standards caused confusion, so in 1992, the American National Standards Institute (ANSI) and Institute of Environmental Sciences and Technology (IEST) petitioned ISO to develop an international standard.

ISO developed new standards for cleanroom classifications and monitoring and published them under ISO 14644. In November 2001, the United States adopted ISO 14644 standards and officially cancelled FS-209E. Table 4 compares cleanroom classifications for FS-209E and ISO 14644-1.

ISO 14644-1 establishes standard classes of air cleanliness for cleanrooms and clean zones based on specified concentrations of airborne particulates. An ISO Class 1 cleanroom has no more than 10 particles larger than 0.1 µm in any given cubic meter of air. An ISO Class 2 cleanroom would be ten times dirtier than a Class 1 cleanroom, and an ISO Class 3 cleanroom would be ten times dirtier than a Class 2, and so forth. The specific allowable particle limits per ISO Class are shown in **Table 4** .

Table 4 ISO Classification vs. Maximum Particle Concentration Allowed

ISO Class	Approx. FS209 Class	<---------------------- Certification Particle Size (µm) ------------------>					
		0.1	0.2	0.3	0.5	1.0	5.0
1	---	10	2	---	---	---	---
2	---	100	24	10	4	---	---
3	1	1,000	237	102	35	8	---
4	10	10,000	2,370	1,020	352	83	---
5	100	100,000	23,700	10,200	3,520	832	29
6	1,000	1,000,000	237,000	102,000	35,200	8,320	293
7	10,000	---	---	---	352,000	83,200	2,930
8	100,000	---	---	---	3,520,000	832,000	29,300
9	---	---	---	---	35,200,000	8,320,000	293,000

Standards for Cleanrooms

In 1984, the Institute of Environmental Science and Technology drafted IES-RP-CC-006-84-T, which is a method for testing cleanrooms. The measurement techniques within the testing parameters include the following:

- Airflow velocity and uniformity
- Filter integrity
- Airflow parallelism
- Cleanroom recovery time
- Airborne particle counting
- Particle fallout rate
- Cleanroom pressure and contaminant
- Induction rate
- Lighting and noise levels
- Temperature and relative humidity
- Vibration

The National Environment Balancing Bureau (NEBB) expands this standard and offers a third-party certification program. While the NEBB certification program provides useful information, NEBB is not required for cleanroom certification.

Cleanroom Evaluation and Certification

Cleanroom certification occurs after facility construction or significant physical changes. Certification guarantees the facility has met the requirements for a statistically-valid maximum concentration of specified-size airborne particles. Cleanroom certifications may occur in any of three different stages:

As Built: A cleanroom certified "ISO Class X, As-Built Facility" defines a cleanroom fully constructed and operational, with all services connected and functioning, but has no production equipment or operating personnel within the facility. This certification is most common because any failures can be immediately addressed, and corrected, by the cleanroom designers and builders.

At Rest: A cleanroom certified "ISO Class X, At-Rest Facility" defines a cleanroom fully constructed and operational, with production equipment installed and operating (or operable), but has no personnel within the facility. This certification demonstrates continued compliance from the "As Built" certification. Cleanrooms that were constructed but sat idle, or cleanrooms that were modified, would require "At Rest" certification.

Operational: A cleanroom certified "ISO Class X, Operational Facility" defines a cleanroom in normal manufacturing operations, including equipment and personnel. This certification may occur after a partial—or full—complement of equipment is installed within the cleanroom. The intent is to demonstrate continued cleanroom compliance and maintain cleanliness standards. Cleanroom management personnel will determine if, and when, the cleanroom should meet "Operational" certifications.

Deposited Particles

Cleanroom certifications do not require evaluation of particle deposition on surfaces; cleanroom certifications only evaluate freely moving particles in the air. However, deposited particles can have the greatest impact on high-technology manufacturing processes.

In order to evaluate particle deposition, a facility may collect particles deposited upon a *witness plate*. A witness plate is a flat, particle-free object made from the same materials as the product being manufactured (for example: if you make ABS plastic products, you should use ABS plastic witness plates).

Several witness plates are placed throughout the cleanroom, and the plates are left to gather particle deposition. After a set period of time, testing personnel gather the witness plates and count the particles deposited. Counting witness plate particles usually requires optical microscopy or surface analysis particle counters.

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Particle Detection

The technology of particle counters and the most common methods of detecting, counting, and measuring particles are described in this section.

Background

Cleanroom monitoring is an ongoing process. Continuously monitoring the air quality ensures the filtration system is working properly and that no unknown particle generators exist.

In the early days of clean manufacturing processes, test filters captured particles. Later, lab personnel used microscopes to confirm the number and size of the captured particles. Sometimes, the person counting the particles could determine the composition of the particles (e.g. copper dust). Negating the time-consuming efforts, microscopy is still the best way to learn specific information about particles, but does not offer instantaneous contamination data. Microscopy reveals *historic,* not *current,* particle events.

In the mid-1950s, military applications spawned the development of the first particle counting instruments. These devices made it possible to monitor instantaneous particle levels and provide quick notifications when contamination levels exceeded limits. Instead of waiting days for particle analysis, which could allow thousands of defective products to pass through a process, the particle counter provided data in minutes.

Gradually, this technology spread to other sectors of manufacturing and confidence grew in the new particle counter technology. Process engineers monitoring real-time particle contamination levels started to develop processes that were more efficient, with less damaged product.

Today, the particle counter continuously improves productivity by providing detailed particle contamination levels, trends, and sources. Manufacturing personnel use particle data to understand causes of contamination, precisely schedule cleanroom maintenance cycles, correlate contamination levels with manufacturing processes, and fine-tune each step of production.

Optical Particle Counters

Most people are familiar with the sight of dust flickering in a sunbeam. Four principles are necessary to see the dust: sunlight (illuminates the dust), dust (reflects the sunlight), air (carries the dust), and your eye (sees the dust, or more accurately, sees the light reflected by the dust). An optical particle counter (OPC) uses the same principles but maximizes the effectiveness. Particle counters use a high-intensity light source (a *laser*), a controlled air flow (*viewing volume*), and highly sensitive light gathering detectors (a *photodetector*).

Theory of Operation

Laser optical particle counters employ five major systems:

1 *Lasers and Optics*: A laser is the preferred light source because the light is a single wavelength, meaning only one "color" of high-intensity light. Common lasers appear red, green, or near-infrared. The first lasers were ruby rods. These were replaced by glass tubes filled with a gas or mixture of gases. Helium-Neon lasers (HeNe) were commonly used in particle counters but have been gradually replaced by solid-state laser diodes. Currently, laser diodes are most common because they offer constant power outputs, smaller size, lighter weight, lower cost, and longer MTBFs (Mean Time Between Failure).

Optics collimate and focus the laser light so that it illuminates the particle sampling region, which is called the viewing volume. Additional optics collect the scattered light and transmit the light to a photodetector.

2 *Viewing volume:* The viewing volume is a small chamber illuminated by the laser. The sample medium (air, liquid, or gas) is drawn into the viewing volume, the laser passes through the medium, the particles scatter (reflect) light, and a photodetector tallies the scattered light sources (the particles).

3 *Photodetector:* The photodetector is an electric device that is sensitive to light. When particles scatter light, the photodetector identifies the flash of light, and converts it to an electric signal, or pulse. Small particles scatter small pulses of light, and large particles scatter large pulses of light. An amplifier converts the pulses to a proportional control voltage.

4 *Pulse Height Analyzer:* The pulses from the photodetector are sent to a pulse height analyzer (PHA). The PHA examines the magnitude of the pulse and places its value into an appropriate sizing channel, called a bin. The bins contain data about each pulse and this data correlates to particle sizes.

5 *Black box:* The black box, or support circuitry, looks at the number of pulses in each bin and converts the information into particle data. Often, computers will display and analyze data.

Comments Regarding Laser Particle Counters

1. Particle counters do not count particles

Particle counters count pulses of scattered light from particles, or in some cases, they count the shadows cast by backlit particles. The amount of light a particle scatters, or eclipses, can vary with several different factors, including the following:

- The shape of the particle: Particles are seldom smooth and spherical like the PSL particles used in particle counter calibrations. Often, particles are flakes of skin or jagged fibers. When they float through the viewing volume sideways, they will scatter a different amount of light than if they travel through lengthwise.
- The albedo (reflectivity) of the particle: Some particles are more reflective (e.g., aluminum) than others, which causes more scattered light onto the photodetector. The photodetector produces a larger pulse and the particle counter thinks the particle is larger than its actual size. Conversely, some particles are less reflective (e.g., carbon) and the particle counter thinks a smaller particle passed through the viewing volume.

2. Particle counters do not count every particle within a volume

For instance, in a 5,000 ft^2 cleanroom with 12 foot ceilings, a 1.0 cubic-foot-per-minute (CFM) particle counter will analyze only 1/60,000 (or 0.0000167%) of the total room air in one minute.

In an hour, the particle counter will count sixty times more air, which is equivalent to only 0.001% of the total room's volume. Considering only a small volume is sampled, particle counters should sample enough of the media (air, liquid, or gas) to statistically represent the entire volume. This is called statistical significance and is a valid representation of the entire volume. ISO provides a specific formula, based upon sampling volumes, to determine when a sample meets statistical significance.

The sampling techniques appear simple, but particles never truly diffuse (evenly distribute) within a sample volume. Particles tend to stay in laminar flow, accumulate inside turbulent flow, stick to surfaces, and rise in warm air. Although cleanrooms minimize these particle traps and problems, there will always be areas where particles congregate.

Types of Particle Counters

There are several varieties of particle counters. The primary differences depend upon the medium in which particles are suspended: air, liquid, gas, vacuum, or atmospheric/ meteorological.

Airborne

Airborne particle counters measure air contamination in HEPA-filtered cleanrooms for disk drive assemblies, pharmaceutical manufacturers, small test benches, rocket launch facilities, and hundreds of different controlled air applications.

Liquid

Liquid particle counters measure contamination in a wide range of fluids including drinking water, injectable drugs, transmission fluids, and hydrofluoric acids. Some liquid particle counters require an accessory called a *Sampler.* A sampler communicates with the particle counter, automatically extracts a precise volume of liquid, and, programmed with the counter's specific delivery rate, dispenses the liquid to the particle counter. Some liquid counters directly connect into plumbing lines or use pressurized gases to eliminate bubbles in chemicals.

Gas

Gas particle counters measure contamination suspended in gases. These gases may be either inert or volatile, and either dry (anhydrous) or contain trace water vapors. Usually, the gas particle counter's design provides contamination measurements at pressures ranging from 40 – 150 psig.

Vacuum

Vacuum particle counters fill a niche market where processes occur under negative pressures (vacuum), which offer unique challenges. Particles do not exhibit predictable movement in vacuum, so specialized particle counters must depend upon a particle's momentum for detection.

Atmospheric/Meteorological

One of the original particle counter applications, atmospheric (or meteorological) particle counters examine atmospheric contamination like pollution or provide detailed weather studies. These instruments measure water droplets, ice crystals, condensation nuclei, or contamination drift from oil fires and volcanic eruptions.

Variations of Particle Counter Technologies

Several technological variations can be used when designing a particle counter. The application dictates the variant technology employed in the particle counter. In addition, the lasers chosen for variant technologies are selected for their particle-sizing proficiency.

A laser's intensity is not uniform. Specifically, a laser is more intense at the center than at the edges. The laser's intensity illustrates a Gaussian or bell-shaped distribution. Some particle counters use special optical masks to view only the laser's center portion. Figure 5 illustrates an actual laser beam mapped onto a grid. The laser's intensity levels rise to a peak (the white and red areas), which is the center of the laser beam.

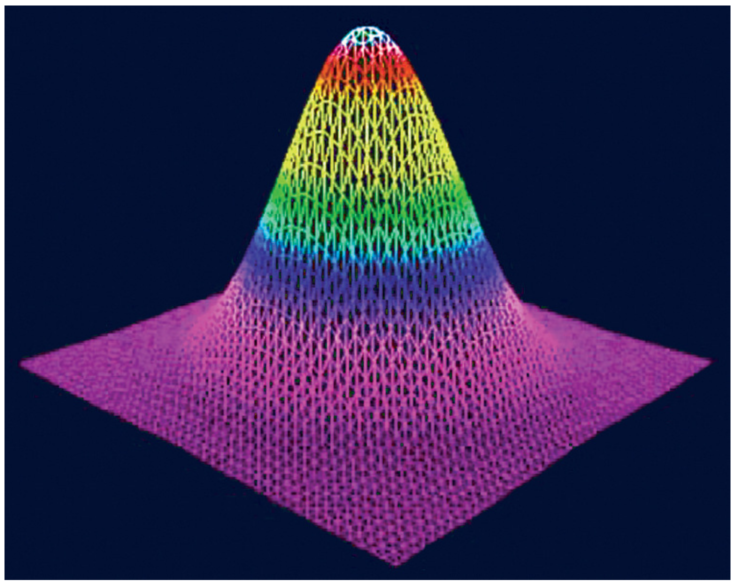

Figure 8 Laser profile (courtesy of CrystaLaser)

Scattering vs. Extinction

Both scattering and extinction technologies use a laser to illuminate a viewing area. Scattering particle counters measure a particle's reflected (scattered) light as it passes through the viewing region. Extinction particle counters illuminate the entire viewing volume and measure a particle's shadow (areas where light is extinct) as it passes through the viewing region. Extinction technology is only used in liquid particle counters that size particles larger than 2.0 µm. If scattering technology was used for large particles, the photodetector would be blinded by the intense scattered light.

Volumetric vs. Non-Volumetric

Volumetric particle counters examine the entire sample volume for particles. Non-volumetric particle counters look at only a small representative portion of the entire sample volume. Typically, non-volumetric particle counters have higher flow rates that allow more total volume to be sampled; conversely, they sacrifice some differentiation in particle size channels, which is called *resolution*. Volumetric particle counters usually sample liquid more slowly, but provide many particle sizing channels and better resolution.

Spectrometer vs. Monitor

As previously mentioned, the laser beam's intensity is not uniform throughout the beam's profile. Spectrometers use only the center of the laser beam, and monitors use the full width of the laser beam.

Spectrometers use the center portion of the laser beam because the laser's intensity is consistent there. Consistent light sources provide greater accuracy in particle detection, so a spectrometer may easily discern slight differences in particle sizes and offer better resolution.

Monitors use the entire laser beam, so they cannot perceive small differences between particle sizes. Illustrated in Figure 6, a particle passing through the laser beam's edge will be subject

to lower-intensity light than the same particle passing through laser beam's center. The relative pulse amplitudes, shown below the diagram, illustrate a particle's pulse and the noise floor (background electrical noise). As shown, the same particle will create different pulse amplitudes depending upon where it enters the laser beam. Similarly, a larger particle passing at the beam's edge may provide the same pulse amplitude as a small particle passing through the beam's center. Consequently, monitors include only a few sizing channels, with enough distance between channels to account for this sizing error.

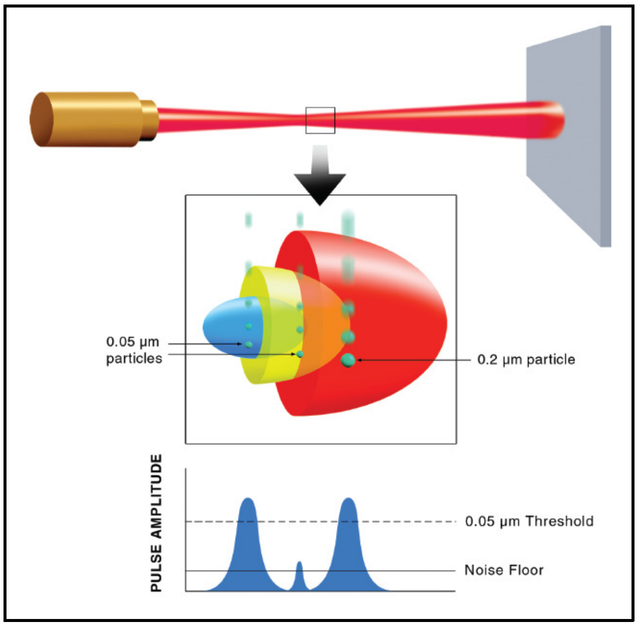

Figure 9 Laser intensity and sizing errors

Choosing between Spectrometers and Monitors:

Given a specific light intensity, small particles scatter a small (dim) amount of light and large particles scatter a large (bright) amount of light.

In a perfect design, a particle passing through a laser beam will first emit a dim flash of light as it enters the beam, slowly brighten as it reaches the beam's center, and grow dimmer as the particle exits the beam. In the real world, since particles do not have an inclination towards the beam's center, they are just as likely to transit the edge of the beam, resulting in a dim flash.

Unless the "viewed" portion of the laser (the part visible to the photodetector) is limited to the center of the beam, it is impossible for the pulse height analyzer to determine if a dim flash was caused by a small particle transiting the center of the beam or a large particle transiting the edge of the beam. Thus, the particle counter's ability to accurately measure particle sizes is limited by the technology employed.

Spectrometers use focusing or masking techniques to limit the viewing region to the center portion of the laser beam. Also, they require smaller sample volumes and lower flow rates because it is easier to determine a particle's size if it passes slowly through a laser beam. This technology provides specific particle sizing data. The spectrometer's precise sizing accuracy makes it the preferred instrument to conduct filter studies, analyze specific particle contamination issues, illustrate mono-dispersed particle challenges, and verify the accuracies of less precise particle counters.

There are many applications where precise sizing of specific particles is of no consequence. These applications only require general particle information, so a particle monitor is appropriate. Plus, considering any given particle size sensitivity, a monitor samples larger volumes at higher flow rates, which provides more particle data. For example, monitors are the preferred instruments for multi-point monitoring of a deionized (DI) water system or a factory's integrated piping system.

Condensation Particle Counters

All automated particle counting techniques are limited by the smallest particle size they can detect. That is, we reach a point where the particle is so small, the scattered light is indistinguishable from background noise. Background noise is similar to electrical static and is a by-product of electrical operations. When the particle is too small to be distinguished from background noise, special particle counters grow particles to larger sizes, which enables detection. These particle counters are called Condensation Particle Counters (CPCs).

A CPC contains a reservoir of volatile liquid, such as butyl alcohol. The sample air flows through a warm chamber where alcohol vapor mixes with the sample air. Next, the sample air and alcohol vapor flow through a cold condensing chamber, where the alcohol vapor becomes super-saturated and condenses upon the particles. Using this technique, microscopic droplets of alcohol can surround particles as small as 0.01 µm and grow to particle/alcohol droplets measuring between 1 – 2 µm. This particle size is easily detected.

The CPC's design diffuses all excess alcohol onto the condensing chamber's walls so the droplets will not add to the particle counts. Similar to optical particle counters, CPCs for smaller detectable particle diameters are more complex and require more maintenance.

There are some disadvantages of a CPC versus an OPC: CPCs require periodic refilling of the alcohol reservoirs, the butyl alcohol has an unpleasant odor, non-butyl alcohol CPCs use an expensive fluorocarbon liquid, and if a CPC accidentally spills, no data output will occur until the flooded parts return to normal. In many environments (ISO Class 6 or dirtier), a CPC would detect so many particles that it could not count fast enough, so the data would be erroneous. Also, unlike an OPC, a CPC cannot report particle size information. Since a CPC grows all particles to the same diameter, it can only report a particle's presence and not its size!

NanoVision Technology

The next major advance in detector technology brings optical particle counters into the digital age. This novel approach couples a high power laser with a high-density two-dimensional array of high-efficiency detector elements to digitally image the light scattered by particles as they travel through the measurement capillary. High-efficiency detector elements exhibit a high photon-to-signal yield. A digital imaging approach is similar to traditional diode array approaches, where noise is spread over an array of detector elements. The difference is that NanoVision Technology uses a significantly larger number of detector elements. Distribution of background noise in combination with high-efficiency detector elements results in a very high signal-to-noise ratio.

This digital imaging approach offers other distinct advantages over traditional analog-to-digital signal processing methods. Most notably, signal discrimination; the light scattered by a particle exhibits a predictable and repeatable fingerprint that travels in the direction of the flow. The particle size range (40 – 125 nm) is much smaller than the laser wavelength of 808 nm. Therefore, the digital image is a picture of the light scattered by the particle, or a fingerprint, and not an image of the particle itself. Utilizing proprietary signal processing electronics and software it is possible to discern the light scatter fingerprint of a particle from both background molecular scatter and other sources of background noise such as random high-energy photons. Traditional analog-to-digital signal processing approaches have no mechanism for discerning these non-particle events from actual particles.

The particle fingerprints are a result of Rayleigh scattering. Rayleigh scattering is an elastic scatter, or scatter in all directions, from the particle. The amount of light scattered is dramatically reduced as the particle size diminishes. Water molecules in 1 mL scatter approximately two times more light than theory predicts will scatter from a 50 nm particle. Additionally, capillary walls, and possible contamination on those walls contributes significantly to the background light scatter. Analog techniques can only go so far to extract the signals from small particles out of the background noise. Both cell walls and molecular scatter are important limiters to sensitivity.

The ability to digitally image the illuminated region of the capillary allows portions of the sample region to be ignored. Light scattered from capillary walls or contamination on these walls does not affect other areas of the sample volume. Additionally, a proprietary signal-normalizing calibration procedure can be utilized to compensate for differences in signal strength from different regions of the sample cell. Because of this, there is zero sample volume growth with the digital imaging approach. Particle size resolution is approximately 5%, which is similar to volumetric based approaches. Sensitivity, however, is improved to 40 nm in liquid chemicals, and with future development, 30 nm detection in ultra-pure water is expected.

Using Particle Counters

In order to effectively use a particle counter, it must be handled, installed, and operated correctly. Following a few guidelines ensures the instrument is working correctly and taking statistically valid samples.

Particle counters are not like other common testing instruments.

- Particle counters include lasers, specialized optics, printed circuit boards (PCBs), and painstakingly-aligned sampling regions.
- They are extremely sensitive to environmental stresses like vibration, EMI (electro-magnetic interference), heat/cold extremes, and dirt.
- Particle counters are high-performance, sensitive electronic instruments.

Guidelines for Handling Particle Counters

First, an operator should always read the particle counter's manual. The manual provides the best suggestions for operating the particle counter; failure to learn the proper installation procedures could be costly in both time and money.

Unpacking

Many particle counters are manufactured and packaged within cleanroom-type environments. Do not remove the plastic bag covering the particle counter until the instrument is inside the environment where it will be used. This is especially true if the particle counter will operate in a cleanroom. Observing this guideline will minimize the particle counter's exposure to dirt and moisture which contaminate the optical surfaces.

Installation

The installation area should be free of vibrations from other equipment and at normal room temperature (70°F/21°C). Place the particle counter on a clean, level surface near a source of grounded, conditioned AC power. Avoid placing the instrument in an electrically noisy environment (with lots of voltage spikes from electric motors, relays, transformers, etc.). Electrical noise can cause false particle counts.

Storage

Before storing a particle counter, if applicable, drain any corrosive chemicals (in liquid particle counters) and replace them with freeze-proof windshield wiper fluid. Wrap the particle counter in a plastic bag (before removing it from the clean environment), seal, and label the bag. The label should list the type of particle counter, the date, the reason for storage, the serial number, and the calibration due date. Then when needed again, the particle counter will be ready for shipping back to a calibration/repair facility.

Instrument File

You should consider keeping a file that shows the date the instrument was placed in service, the date calibration is due, the amount of time it is used, the date of any preventive maintenance (optical cleaning, etc.), dates of any mishaps/damages, and notes about any unusual performance experienced by operators.

Maintenance

Particle counters need routine maintenance that typically includes cleaning the optical surfaces. Over time, optical surfaces accumulate dirt that can scatter laser light; in liquid particle counters, this is called *DC Light*. DC Light is a measurement of direct current (DC) correlating to the amount of scattered laser light passing through liquids or containment surfaces. Excessive DC light can result in diminished sensitivity and/or false particle counting. To avoid this, follow the instructions that came with your particle counter because, with most instruments, cleaning may be performed by the user. Carefully follow the directions, and if you are unsure of what you are doing, do not proceed. Contact the manufacturer for further instructions.

Applications of Particle Counters

How particle counting equipment can be used is described in this section.

Trend Tracking

It is seldom useful to know how many particles are in a room; it is more useful to know if the room's contamination is increasing or decreasing over time. This is called *trend tracking*, and particle counters provide detailed particle contamination trend analysis. That is, they monitor gradual or sudden changes in the environment's contamination levels. This information can tell the operator if there is a filtration problem, if a tool or process is dirty, or if someone left a door or valve open. There are more sophisticated applications for particle counters. These will be discussed later.

Statistically Valid Sampling

This important concept, discussed earlier, is worth repeating. A statistically valid sample is a sample of media that is representative, in both content and characteristics, of the media under test. Particle counts may be higher within convection currents or settle onto surfaces, but in general, the principles of diffusion show that sampling from one area of a room will provide similar data to another area of the room.

Data Normalization

A particle counter samples media at a constant flow rate and counts the particles in the media.

The data collected by the particle counter are viewable in two ways:

Raw Counts: The total number of particles in a specific size channel. Raw counts are not calculated as a function of the sample volume, so the data does not report volumetric contamination values. This data is useful in some applications, as well as in calibrating the instrument.

Normalized Counts: The total number of particles divided by the sampled volume. Normalized counts correlate particle counts to sample volumes, so the data reports particle concentrations per unit volume (ft^3, m^3, ml, and so forth).

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Hardware and Accessories

This different kinds of particle counters and their associated hardware are described in this section. In addition, specific applications for each type of particle counter are discussed.

Airborne Particle Counters

Airborne particle counters detect and measure particle contamination in air. Typically, they monitor particle contamination in clean environments, such as cleanrooms or minienvironments. In addition to monitoring air within a room, airborne particle counters can monitor particles in the air inside a large processing tool.

Filter efficiency monitoring is another common application. The particle counter samples air as it enters and exits the filter. *Filter efficiency* is the ratio of particles trapped by the filter to the total number of particles found in the air upstream of the filter. If unattended testing is desired, the particle counter can include alarms for acceptable particle limits and send a notification when the filter fails efficiency tests.

Cleanroom monitoring, verification, and testing are the most common applications for airborne particle counters. These particle counters sit near a process under test and constantly gather data. When contamination rises above the particle counter's programmable limits, an audible and/or visual alarm alerts the manufacturing personnel.

In any application, a particle counter should sample enough media so that it provides statistically valid data. Specifically, if sampling a large cleanroom, the particle counter should sample several different locations within the room. ISO documents offer suggestions for the number of sample locations:

Number of sample locations = $Area(m^2)$

Therefore, if a cleanroom measures 10,000 square feet, first convert to square meters, next find the square root, then round up.

$$
\begin{aligned}
&Area\ (m^2) = ft^2 \text{ x } 0.092903 \\
&\Rightarrow 10{,}000\ ft^2 \text{ x } 0.092903 \\
&\Rightarrow 929.03\ m^2 \\
&\Rightarrow \sqrt{929.03\ m^2} \\
&\therefore\ 30.48 \cong 31\ sample\ locations
\end{aligned}
$$

Effective monitoring of this cleanroom should include thirty different sampling locations.

Alternatively, one can perform cleanroom testing using one of the following methods:

- Using an Aerosol Manifold (described below)
- Moving the particle counter from location to location
- Demonstrating that a statistically valid sample can be taken at a single location

Selecting a particular airborne particle counter requires some decisions. Channel sizes range from 0.06 µm at the smallest to several hundred µm at the largest, and depending upon the model, the number of channels and size range is either preset or programmable. Other features include different flow rates, statistics processing, automated certification modes, and almost any feature to meet most airborne particle applications.

Handheld Airborne Particle Counter

Handheld airborne particle counters are slightly larger than a person's hand and commonly used to pinpoint and isolate contamination sources. They may employ a probe at the end of a hose that emits different tones (like a Geiger counter or metal detector) corresponding to particle concentrations.

Handheld particle counters are ideal for troubleshooting.

These instruments typically have much lower flow rates than other portable particle counters.

Figure 10 HandiLaz Mini particle counter

Aerosol Manifolds

Aerosol manifolds use a single particle counter to take air samples from many different locations. The aerosol manifold is a device that is usually controlled by a particle counter with several incoming air hoses from the locations where air is sampled, and one outgoing air hose connected to the particle counter. The manifold uses a large pump, providing 100 CFM of air flow, to direct particles from all ports to the particle counter. Sequentially, the particle counter samples from one location, then after a period of time (usually one minute), the manifold steps to the next incoming hose, and repeats the process.

Well-designed manifolds minimize particle loss in transport tubing and limit cross-contamination. Cross-contamination occurs when particles leak from one sample port to another.

Figure 11 shows the basic parts of an aerosol manifold system.

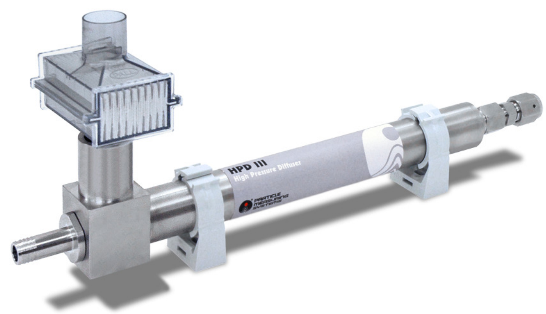
Figure 11 Aerosol Manifold (lower right), Pump (lower left), and Control Box (top)

Sampling Probes

Sampling probes (SPs) attach to the end of the sample tube. Cleanroom air often has laminar flow with velocities ranging from 45 to 90 ft/minute. Some probes are sized to provide velocity equalization between the particle counter and the room air; these sample probes are referred to as isokinetic. Thus, the SP captures particles at the same velocity as the sample air, providing accurate normalized particle counts.

Figure 12 Sample Probe (top), and tubing adapter fitting (bottom)

High Pressure Diffusers



Standard airborne particle counters sample air at 1.0 ft^3/minute and 1.0 atmosphere (14.6959 psi).

High pressure diffusers (HPDs) reduce pressures (25 – 100 psi) from pressurized gas systems, so the gases can be analyzed by an airborne particle counter. However, HPDs should analyze only inert pressurized gases.

Figure 13 HPD III High Pressure Diffuser aerosol monitoring accessory

HPDs exhaust some pressurized gases into the room, so if these gases are not inert, serious injury could result.

Environmental Sensors

Environmental sensors can measure temperature, relative humidity, differential air pressure, air velocity, etc. The particle counter and/or Facility Monitoring System (FMS) interpret the environmental probe's data and display it in a readable format.

Liquid Particle Counters

Liquid particle counters count particles in almost every kind of liquid: water, hydrofluoric acid, petrochemicals, and injectable drugs are common applications. Often, they monitor filter efficiencies or quality control devices in batch sampling applications.

Liquid Samplers

Liquid samplers extract a precise liquid volume, then, using a fixed delivery rate, send the sample to a liquid particle counter. Non-pressurized liquids are a common application for liquid samplers, including tests within beakers or vials.

If incorrectly used, a liquid sampler can produce cavitations and create bubbles within the liquid. Bubbles are a problem because they can accumulate particles (agglomeration) and bubbles appear as large particles (usually, greater than 1.0 µm).

Some liquid samplers reduce or eliminate effervescence (bubbling) through compression. The liquid sampler includes a chamber that holds the liquid sample, while pressures (> 30 psi) compress the bubbles and eliminate them from the liquid.

Figure 14 SLS-1040 Syringe Sampling System with UltraChem® Particle Counter

Viewing Modules

Viewing modules for liquids are analogous to those for vacuum particle counters; they provide a method for monitoring particles without diverting the flow.

Corrosives and Plumbing

Counting particles suspended in liquid, especially corrosive liquids, requires particle counters with internal, wetted surfaces that will not dissolve or release toxic gas when sampling corrosives.

Optics

- *Fused Silica:* A material similar to glass, fused silica is compatible with most chemicals except hydrofluoric acid.
- *Sapphire:* Compatible with most chemicals used in the semiconductor industry, including hydrofluoric acid.
- *Magnesium Fluoride:* Compatible with most chemicals, except ammonium fluoride and hydrogen peroxide.

Plumbing

- *Polyvinylidene Fluoride (PVDF):* A thermoplastic used in many sample cells, but not recommended for long-term use with acetone.
- *Perfluoroalkoxy (PFA) Teflon®:* A fluoropolymer used in some sample cells, PFA Teflon is porous to some chemicals. Other materials include Teflon, KalRez® (an expensive O-ring material) and Kel-F.

Chemical Compatibility

Before you put any chemical into a liquid particle counter, consider these important points:

- Make certain the chemical is compatible with the wetted surfaces of the particle counter, liquid sampler, and all accessory plumbing (including the tool plumbing).
- Make certain the chemical will not react with any chemical residue from the previous sample.
- If you have any questions regarding chemical compatibility, please contact the particle counter manufacturer.

Gas Particle Counters

Gas particle counters determine the purity of various gases, both inert and reactive. A gas particle counter is a specialized airborne particle counter that counts particles under pressure. Some gas particle counters can sample at cylinder pressures (up to 150 psi), while others are suitable for reduced line pressures.

Acquiring and analyzing representative gas samples can be difficult. Challenges in semiconductor factories include connecting the particle counter to the gas supply. Typically, the gas supply originates from a processing facility outside the semiconductor factory, with large diameter stainless steel pipes transporting the gas from the supply to the factory. If the application requires analyzing particles in the gas before they reach the semiconductor factory, a sampling port must be added to the gas supply pipes where the particle counter can extract samples.

Still, semiconductor gas does not contain many particles, so gravity and diffusion can make it hard to capture statistically-valid samples of the few particles that are present. The preferred method for capturing particles requires a pipe fitting, with the sample tube connected to the fitting and inserted into the center of the pipe's diameter. Usually, additional gas particle counters are placed near the points-of-use as a final check on gas quality.

Some applications use gas analysis systems consisting of a "homemade" HPD connected to an airborne particle counter. Few homemade diffusers work at all. Their failure to zero-count when sampling filtered gas and the randomness of the particle counts are all problems Particle Measuring Systems' engineers overcame before high pressure diffusers were ready to market.

Gas Particle Counter vs. Airborne Particle Counter with HPD

When deciding whether to use a high-pressure gas particle counter versus an airborne counter with a high pressure diffuser, consider the following:

- Cost of the gas (HPDs consume more gas than they analyze)
- The desired sample flow rate (most HPDs only accept pressures to 100 psig)
- Instrument footprint (due to internal plumbing, gas particle counters are larger than airborne particle counters)
- Particle size/instrument sensitivity
- Data display options

The particle counter manufacturer can provide suggestions regarding the correct choice for your pressurized gas application.

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Data Integration

This section describes how particle detection technologies work together to manage contamination.

Facility Monitoring Systems

A facility monitoring system (FMS) provides data communications and a central monitoring location for all particle counters, samplers, manifolds, environmental sensors, and other microcontamination assessment equipment. The FMS collects and analyzes particle data, and correlates the data to events, such as door or valve openings, filter failures, or flow problems.

A sample pharmaceutical manufacturing facility with cleanrooms (shown in Figure 9) illustrates commonly used particle counters working within the FMS. A detailed explanation of the components follows.

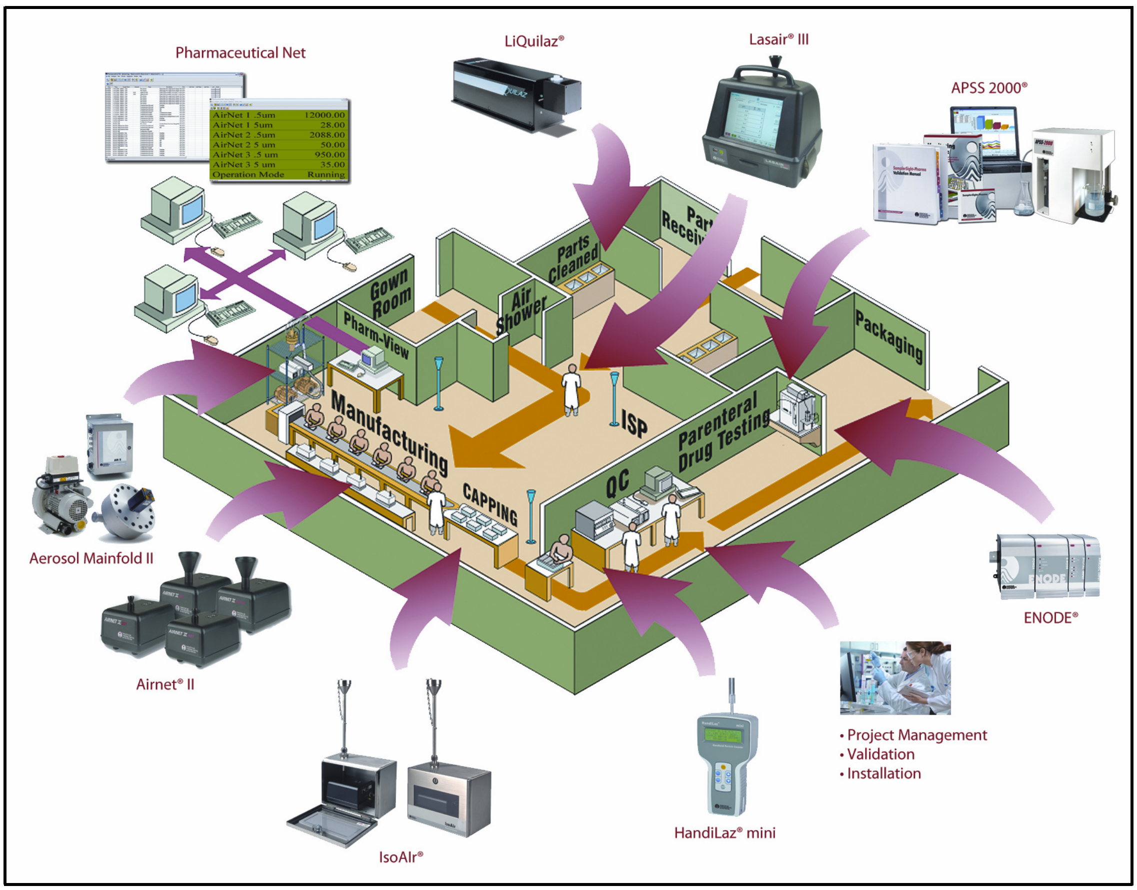

Figure 15 Pharmaceutical manufacturing facility

Facility Management Systems Software (Pharmaceutical Net or Facility Net)

Facility Management Systems (FMS) software allows the operator to receive status from all connected devices. The software has features to trigger alarms, generate reports and graphs, analyze data, perform statistical processes, and notify users (through email or paging systems) of problems within the facility.

Each particle counting device connects to the FMS computer. In **Figure 15** on page **6-35**, Particle Measuring Systems Pharmaceutical Net (Facility Net) software serves as a central control station for each device and manages all collected data. Other computers connected to the FMS network can see the data in real-time.

In addition, Facility Net software can perform the following:

- Analyze particle data
- Track particle trends
- Trigger local and/or remote alarms if the following problems occur:
  - Maximum particle counts exceed limits
  - Temperatures exceed minimum/maximum values
  - Relative humidity exceeds minimum/maximum values
  - Calibration expiration
  - Particle averages exceed limits

LiQuilaz® (Liquid Particle Counter) for Parts Cleaning and Acid Baths

In this part of the facility, process liquids or an acid bath requires testing. Monitoring the liquid's filter efficiency requires two liquid particle counters, but monitoring the acid requires a corrosive liquid sampler. Calculating filter efficiency is a comparison between the amount of particle contamination in the liquid prior to filtration and the amount after filtration. This testing determines when the filters need to be replaced, if a hole has developed in the filter media, and if the liquid is too dirty to use.

Lasair® III Portable Counter (Airborne Particle Counter)

This airborne counter can determine localized particle sources, certify the cleanroom, spot-check HEPA filters, or determine general air purity in the facility. Periodic facility inspections require checking every filter, so an airborne particle counter is imperative.

APSS-2000 (Liquid Particle Counter)

An APSS-200 syringe sampling system is designed to size and count suspended particulate matter in a wide range of liquids. This system samples from small batches, follows all current USP test <788> requirements, and can adapt to future regulatory changes. Unlike semiconductor applications, where sub-µm particles affect product, parenteral applications require particle counters that detect particles larger than 2 µm. The APSS-2000 has a particle size range of 2 – 125 µm.

ENODE® (I/O Controller)

ENODE is a modular Ethernet (networking) device that directly integrates into Facility Net software. The ENODE monitors digital and analog inputs, alarm output contacts (digital or relay), and sends the data to the software for analysis. Inputs may include temperature, relative humidity sensors, or electronic switches that notify the software when a process door is open. The ENODE device is the solution for a wide range of monitoring and control applications.

Project Management, Validation, and Installation

Each contamination system must have people who understand the particle data and provide support to the areas suffering high particle contamination. Validation and installation occurs in the early phases of system integration, with validation performed by an external agency and installation performed by either internal or external sources. Continual management of the contamination control system provides requires expertise and commitment from personnel responsible for improving the processes.

HandiLaz® Mini (Handheld Airborne Particle Counter)

Handheld particle counters, like the HandiLaz Mini shown in **Figure 10** on page **5-30**, are ergonomically designed to fit in the palm of your hand. Handheld particle counters are rugged, dependable, and provided tremendous value for cost-conscious users who need to pinpoint and isolate localized sources of particle contamination.

IsoAir® (Airborne Particle Counter)

Areas that directly process chemicals or drugs use IsoAir sensors to identify breakdowns in critical zone protection. These compact, simple to install sensors provide unparalleled performance in a chemically resistant, easy to disinfect, stainless steel box.

Figure 16 IsoAir 310P Aerosol Particle Sensor

Manufacturing and Quality Control (QC)

Certain assembly, test, and packaging operations are conducted within an ISO Class 5 Cleanroom environment. Aerosol manifolds, isokinetic sampling probes, and particle counters effectively monitor these areas for cleanliness standards.

Airnet® II (Airborne Particle Counter) and AM-II (Aerosol Manifold)

The particle counters and manifold, along with isokinetic probes, monitor the ISO Class 4 or 5 (FS-209e Class 10 or 100) cleanrooms along with the ISO Class 6 (FS-209e Class 1000) equipment space area. An aerosol manifold can economically monitor many different areas or several points in the same area, ensuring statistically valid samples.

Figure 17 Air Net II 4-Channel Particle Sensor

Aerosol manifolds (see **Figure 11** on page **5-30**) are not suitable for all applications because they exhibit a certain amount of particle loss and inter-sample delay. Particle loss occurs because the manifold's sample lines can be lengthy (up to 125 feet). Particles larger than one µm do not travel very far, so gravity or tubing bends will cause them to stick to the tubing's inner wall. Intersample delays occur when the manifold switches from one sample port to another. Particle events can escape detection while the manifold is switching sample ports.

Glossary

accretion
: The tendency for particles to stick together.

advection
: The horizontal transport of particles through air or liquid.

aerosol
: A suspension of particles and water vapor in air.
: A system of solid or liquid particles suspended in gas medium.

agglomeration
: To gather into a mass, such as particles sticking to a gas bubble in liquid.

albedo
: The reflectivity or shininess of a particle.

anhydrous
: Lacking water; dry.

bin
: An electronic storage place for the electrical pulse generated by a photodetector; sometimes called a channel.

Brownian motion
: Brownian motion is the random movement of small particles due to collisions with molecules; generally, Brownian motion influences particles equal to or smaller than 0.1 µm diameter.

cavitation
: The formation of bubbles in a liquid, often caused by rapidly filling a sample syringe or the movement of a pump impeller.

class
: The quality of a cleanroom, expressed in the maximum number of 0.5 µm particles per cubic foot (or meter, in the ISO system).

cleanroom
: A manufacturing environment that is designed to minimize particle contamination by use of filters, protocols and design.

coherent light
: A beam of light whose photons have the same optical properties (wavelength, phase, and direction).

convection
: The vertical transport of particles in air or liquid.

currents
: Movements of a fluid in a given volume.

diffusion
: The action whereby particles migrate from an area of greater concentration to an area of lesser concentration.

doublet
: A pair of particles that are stuck together.

electrostatic adhesion
: The tendency of particles to stick to things as a result of static electricity.

extinction
: Technique of particle counting based on backlighting the viewing volume and analyzing the shadows cast by particles.

Federal Standard 209
: Obsolete US Government regulations that defined how cleanrooms were classified.

fluid
: Any liquid or gas.

FMS
: Facility Monitoring System: a system of computer hardware, software, and cables that monitors and controls all particle-counting equipment in a facility.

HEPA filter
: High Efficiency Particulate Air filters that remove 99.99% of particles larger than 0.3 µm.

in-situ
: Latin word for in-position, and describes a class of particle counter that looks at a small portion of the sample volume.

laminar flow
: In fluids, a smooth, layered flow.

LASER
: Light Amplification by Stimulated Emission of Radiation, which is a high-intensity coherent light.

liquid
: A fluid that is not gaseous or solid.

macroparticles
: Particles larger than 5.0 µm.

microcontamination
: Particles that are detrimental to a manufacturing process.

µm, micrometer
: Unit of measure equal to 10^{-6} meter (1/1000 of a millimeter).

minienvironment
: A miniature cleanroom.

monitor
: A type of particle counter that uses the full laser beam width to count particles.

normalization
: The formatting of data to make it useful by giving it volume context.

nm, nanometer
: Unit of measure equal to 10^{-9} meter (one billionth of a meter).

organic
: Arising from living matter, either animal or vegetable.

particle counter
: A device that counts particles.

particles
: Very small pieces made of diverse substances.

photodetector
: A device that detects light and converts the light into electrical pulses.

pulse height analyzer
: A device that collects electrical pulses and correlates them to relative particle sizes; Abbreviation: PHA.

raw counts
: Particle counts that are not normalized for the sample volume.

scattering
: The reflection of light by a particle transiting a laser beam; one method of optical particle counting; C.f. extinction.

spectrometer
: A type of particle counter that uses only the center of the laser beam to count particles.

statistically-valid
: A small sample with particle content representing the entire volume.

thermal variation
: Temperature irregularities in a volume of fluid that contribute to the fluid's movement.

trend tracking
: The use of a particle counter to follow long-term trends in microcontamination within a given volume.

turbulent flow
: Non-smooth movement of air or fluid.

ULPA filter
: Ultra Low Particulate Air filters that remove 99.9997% of particles larger than 0.12 µm.

ultrafine particles
: Particles smaller than 0.1 µm.

vacuum
: The absence of gas or liquid in a given volume.

viable
: Living.

viewing module
: A small chamber with windows that is installed in a conduit and allows a laser beam to shine through.

viewing volume
: The volume of air or liquid that passes through a particle detection system.

volumetric
: A type of particle counter that examines the entire sample.

witness plate
: A test surface placed in a clean environment that collects particles for later measurement.