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Selecting an Airborne Particle Counter

Choosing a particle counter depends on various factors such as monitoring environment, communications, desired flowrate, and the particle sizes of interest. This article will identify which features to focus on and provide a guide to select the right counter for your application.

Terminology

All airborne particle counters sample air at a specified volumetric flowrate which is defined as the speed of air being pulled through the particle counter. The flowrate units are usually in cubic-feet-per-minute (CFM) or liters-per-minute (LPM). Particle counters are calibrated to sample at their specified flowrates, and sizing accuracy is dependent on that flowrate.

To meet classification standards, particle counters sample defined volumes of air which provide qualifiable, statistical significance to particle count data.

Standards and Certification

A portion of **Table 1** from the ISO 14644-1:2015, *Classification for Air Cleanliness by Particle Concentration*[1] standard is provided below. The ISO standards prescribe limits for common sizes of particles such as 0.1, 0.3, and 0.5 µm. Modern cleanrooms consistently meet ISO Class 5 or Class 6 certification, if not better.

TABLE 1 Maximum Allowable Particle Concentrations

Classification	Maximum Particle Size	Total Particles	Sample Volume
ISO 5	0.1 µm	100,000	1 m^3
	0.3 µm	10,200	
ISO 6	0.1 µm	1,000,000	
	0.3 µm	102,000	

Source: ISO 14644-1:2015, Table 1.

The ISO 14644-1:2015 standard is based on volume sampled, not flow rate. Thus, a 1 CFM particle counter must sample for 35 minutes to equate to a total of 1 cubic meter of air. Faster flowrates can achieve ISO specifications in less time; a particle counter with a flowrate of 50 LPM can sample one cubic meter in only 20 minutes.

Monitoring a cleanroom in accordance with ISO cleanroom classifications requires the particle counter's maximum concentration specification to exceed ISO limits. For example, to monitor a Class 5 cleanroom for 0.1 µm particles, the maximum concentration of the counter must be greater than 100,000 particles per cubic meter (2,841 particles per cubic foot). Using a 0.3 µm particle counter to monitor the same Class 5 cleanroom requires a particle counter maximum concentration value of greater than 10,200 particles per cubic meter (290 particles per cubic foot). These are easily achievable limits with most modern particle counters.

Note: There is no ISO specification for 0.1 µm particle counts higher than ISO Class 6, so a 0.1 µm particle counter is not required for those applications.

Solutions to aid in attaining cleanroom certification are listed in Table 2 and featured in Figure 1.

TABLE 2 Cleanroom Certifying Solutions

Particle Size	Flowrate	Product
0.1 µm	1.0 CFM	Lasair® III 110 Aerosol Particle Counter
0.3 µm	1.0 CFM	Lasair Pro 310C Aerosol Particle Counter
0.5 µm	3.56 CFM	Lasair Pro 5100 Aerosol Particle Counter

FIGURE 1 LASAIR III 110 (LEFT) AND LASAIR PRO (RIGHT)

Frequent or Continuous Cleanroom Monitoring

Frequent Monitoring

In demonstration of compliance with ISO, frequent monitoring requires sampling at specified time intervals not exceeding 60 minutes during operation. After the certification process, manifold systems are the least expensive solution for sustained clean room monitoring and can be installed during or after the cleanroom construction process. Standalone particle counters may be installed at any time for critical areas in the clean room. The Air Manifold II system includes either 16 or 32 sampling ports with a single line that connects to a single particle counter, allowing semi continuous monitoring of larger spaces. There are also smaller manifolds like the ParticleSeeker manifold which includes 10 ports and specializes in nanoparticle transport for operation in conjunction with the NanoAir 10 CPC for monitoring critical areas closer to the process. Both manifolds can sequentially sample from each port, send the samples to the particle counter, then repeat the process making them great options for frequent monitoring. However, since a manifold cycles through many sample points, a particle event can go unnoticed if the particle counter is not currently monitoring the appropriate port.

FIGURE 2 AIR MANIFOLD 16 PORT SYSTEM (TOP, GREY INSTRUMENTS) AND NANOAIR & PARTICLESEEKER SYSTEM (BOTTOM, BLACK INSTRUMENTS)

Continuous Monitoring

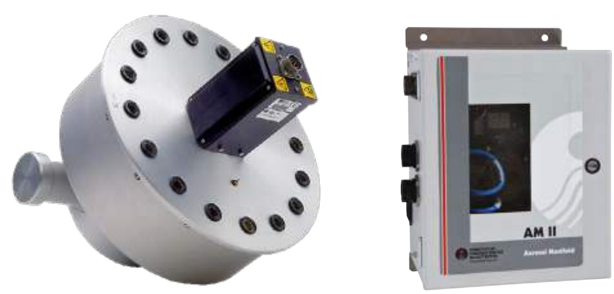
In critical locations, continuous monitoring is needed. Continuous monitoring requires constant sampling. This method constantly gathers data, so events are not missed. Sample intervals can be any duration. Shorter sample intervals will give better time resolution but will provide vast quantities of data that could overwhelm a system (minimum sample intervals can be set to 1 second); it can be important to optimize. Typical time intervals range from one minute to ten minutes. Instruments like the IsoAir Pro-Plus, AirNet II, Lasair III 110 Inline, and NanoAir 10 offer continuous monitoring as they are designed for 24/7 continuous particle counting in a fixed location. These counters can be combined depending on the monitoring coverage needed. Overall, if a location is important enough to require constant filtration or purge gas, it is important enough to have continuous monitoring to validate control measures are effective. These instruments are featured in **Figure 3**.

(A) **(B)** **(C)** **(D)**

FIGURE 3 ISOAIR PRO E PARTICLE COUNTER (A), AIRNET II PARTICLE COUNTER (B), LASAIR III 110 INLINE PARTICLE COUNTER (C), NANOAIR 10 PARTICLE COUNTER (D)

Choosing between continuous and frequent cleanroom monitoring is a choice of economics and infrastructure. Dedicated particle counters are the best method to detect particle excursions, but at a high cost per sample point. If short-duration events are not critical and there is a greater need for trending only, a manifold system can be an effective and economical solution. However, manifold systems cannot reliably transport and count particles much larger than 5 µm due to particle losses by inertial effects. Some additional Particle Measuring Systems continuous and frequent monitoring options are featured in **Figure 4**.

(E) **(F)**



(G)

FIGURE 4 HANDILAZ MINI II PARTICLE COUNTER (E), LASAIR III 110 PARTICLE COUNTER (F), AIR MANIFOLD 16 PORT SYSTEM (G)

Communication Options and Proper Connections

If a cleanroom offers network ports (Ethernet 10Base-T or 100Base-T), select a particle counter with networking capability (TCP/IP). If the cleanroom relies on serial communications, select a particle counter with RS-232 or RS-485 communication protocols. In other cases, simpler solutions like communication via 4-20 mA output can be used. 4-20 mA can be used to tie directly into Supervisory Control and Data Acquisition (SCADA) systems. It can be important to also consider the protocol that is acceptable over TCP/IP. Some instruments can communicate via protocols like Modbus or OPC over TCP/IP, which can then be tied directly into advisory systems like Facility Monitoring Systems (FMS) or SCADA systems. **Figure 5** exhibits some of these communication avenues with Airnet II particle counters.

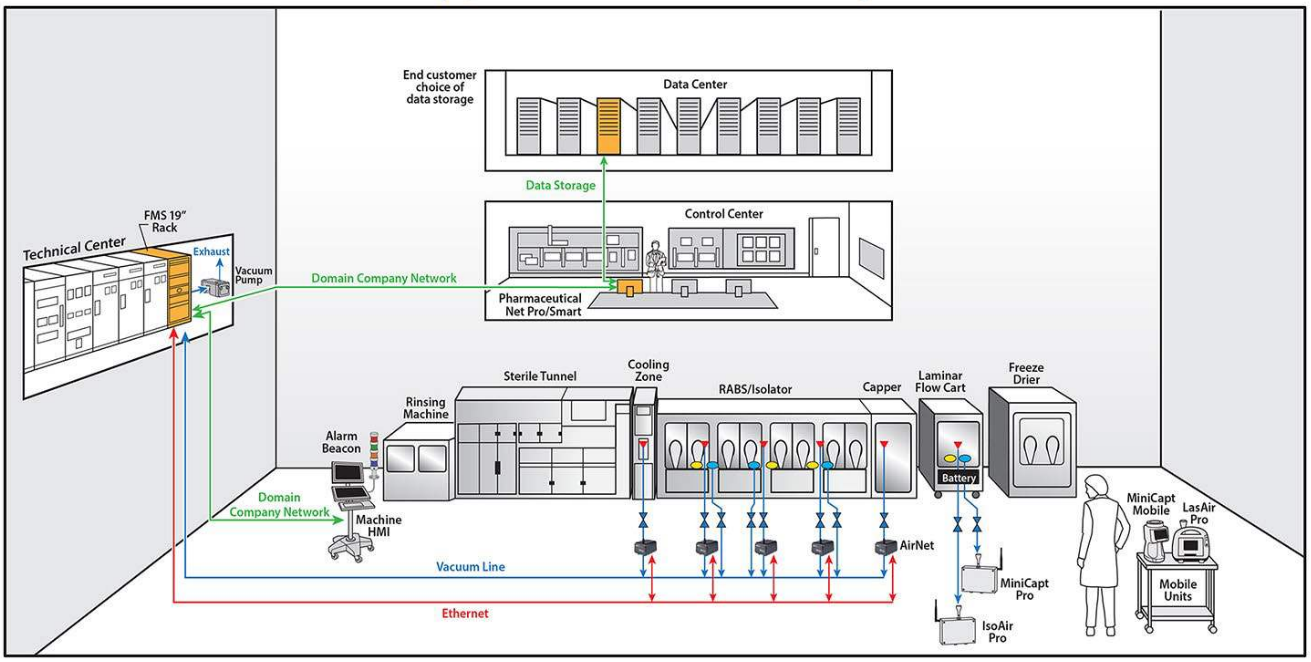


FIGURE 5 BLUEPRINT OF AIRNET II PARTICLE COUNTERS IN CLEANROOM SETTING WITH FMS SYSTEM AND CONNECTION POINTS

At this point, it is important to consider if you need a portable instrument (like a Lasair Pro) which has a screen to provide information at the particle counter verses a sensor instrument without a screen where data can only be seen after being extracted from the particle counter on a software system. When setting up for particle contamination monitoring, not only is access to proper communication wiring essential but also other instrument connections to ensure access to include vacuum. Primarily, portable particle counters contain internal blowers while others require vacuum hookups for proper operation. **Table 3** features some of Particle Measuring Systems portable and non-portable options including those with internal blowers or that require vacuum hookups.

TABLE 3 Cleanroom Monitoring Solutions

Product	Frequency	Smallest Particle Size	Flowrate (CFM)	Communication - Data Output	Portable or Non-Portable	Internal Blower or Vacuum Connection
Lasair III 110	Continuous	0.1 µm	1.0	✓ TCP/IP ✓ RS-232 ✓ 4-20 mA (4 out) ✓ TTL/Pulse output ✓ USB data download	Portable	Internal Blower
Lasair III 110 Inline	Continuous	0.1 µm	1.0	✓ TCP/IP ✓ RS-232 ✓ 4-20 mA (4 out) ✓ TTL//Pulse output	Non-portable	Vacuum Needed
Lasair III 110 with AM II 16/32 Manifold	Frequent	0.1 µm	1.0	✓ TCP/IP	Non-portable	Internal Blower
HandiLaz Mini II	Continuous	0.2 µm	0.1	✓ None	Portable - Handheld	Internal Blower
Airnet® II 201/301	Continuous	0.2 µm or 0.3 µm	0.1	✓ TCP/IP ✓ RS-232 ✓ 4-20 mA (3 out)	Non-portable	Vacuum Needed
Airnet II 310/510	Continuous	0.3 µm or 0.5 µm	1.0	✓ TCP/IP ✓ RS-232 ✓ 4-20 mA (5 out)	Non-portable	Vacuum Needed
Lasair Pro Family	Continuous	0.3 µm or 0.5 µm	1.0, 1.77, or 3.56	✓ TCP/IP ✓ USB data download	Portable	Blower
IsoAir Family	Continuous	0.3 µm	1.0	✓ TCP/IP ✓ PMS TCP/IP ✓ 4-20 mA	Non-portable	Internal Blower
NanoAir10	Continuous	0.01 µm	0.1	✓ TCP/IP ✓ Serial USB ✓ 4-20 mA	Non-portable	Vacuum Needed
NanoAir10 with ParticleSeeker Manifold	Frequent	0.01 µm	0.1	✓ TCP/IP ✓ 4-20 mA	Non-portable	Vacuum Needed

Monitoring Locations

After choosing the monitoring method, the next step is to determine how many monitoring locations or particle counters are needed. The total number of locations (N_L) required by ISO can be calculated by dividing the area of the cleanroom (in m^2) by 1,000. Then, multiply this number by 27. See the equation below for the calculation of the minimum total number of sample locations.

$$N_{\mathrm{L}} = 27 \times \left(\frac{A}{1\ 000} \right)$$

For example, inserting a typical cleanroom area (***A***) of 9290 m^2 (100,000 ft^2), we can determine N_L is 251. This means ISO requires 251 monitoring locations. These locations should be evenly distributed and mounted at a work height of 76 cm (30 in).

Keep in mind the ISO 14644-1:2015 standard only applies to cleanroom certification. Cleanroom operators should evaluate their processes and the sensitivity of their product to contamination to determine the number of sampling locations required. Our advice is to monitor where it counts. Measure where your product is exposed and where contamination will cause damage. In the case of semiconductor manufacturers that use SMIF pods or FOUPs, the wafers are exposed in the minienvironment, so monitoring efforts should be focused there. Monitoring should be concentrated where the risk is the highest. In the case of minienvironments, this is often near the load ports where wafers are loaded and unloaded. This is where products like Airnet II and NanoAir 10 instruments come in; they are designed to be small enough to fit into areas with limited space like inside of minienvironment or inside tools for monitoring as close to the process as possible. A simplified example layout of NanoAir10 and ParticleSeeker for Point of Use (PoU) sampling is featured in Figure 6.

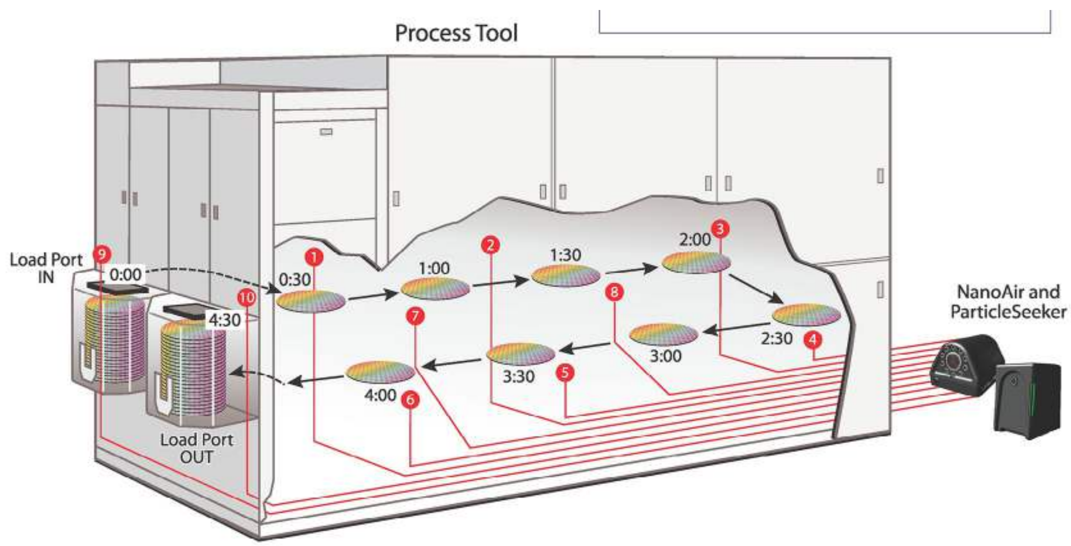


FIGURE 6 POINT OF USE SAMPLE LOCATIONS CLOSE TO THE PROCESS VIA PARTICLESEEKER MANILFOD IN CONJUNCTION WITH NANOAIR 10 PARTICLE COUNTER

Minienvironments

A substantially important location to monitor for contamination is in minienvironments designed to keep product clean and stable during development and transport. To isolate the product from contamination during transport between tools, minienvironments are often classified as ISO Class 1 or Class 2. Within these classifications, most instruments can easily remain under the maximum concentration limits extrapolated in Table 4.

TABLE 4 Maximum Allowable Particle Concentrations

Classification	Maximum Particle Size	Total Particles	Sample Volume
ISO 1	0.1 µm	10	$1\ m^3$
	0.3 µm	---	
ISO 2	0.1 µm	100	
	0.3 µm	10	

Source: ISO 14644-1:2015, Table 1.

Minienvironment particle data often follows trends in differential air pressure, so an instrument's ability to correlate particle and differential pressure data provides trend analysis, yield improvements, and accurately scheduled preventative maintenance cycles. Published minienvironment particle data[2] shows particle concentrations clustered near 0.4 µm. Since the cost of a particle counter increases as the sensitivity increases from 0.2 µm to 0.1 µm, the most cost-effective continuous monitoring solution is a 0.2 µm particle counter with an inclusive differential air pressure (DAP) probe. For validation and certification, a 0.1 µm counter is recommended for ISO Class 1 and Class 2 minienvironments.

When monitoring minienvironments, it is important to consider that 0.1 µm or 0.2 µm instruments do not tell the whole story. Nanoparticles can have a major impact on yield and cause defects. Just because a location does not have any 100 nm particles does not mean it is clean. Table 5 features ratios of particles that are 100 nm (0.1 µm) and greater to particles that are 10 nm and greater; this reveals great concentration of nanoparticles in these minienvironments. Monitoring to lower sizes can be important. Table 6 features solutions to monitoring minienvironments.

TABLE 5 Particle Concentration Ratios at Specific Locations in Lithography Hood

Location	>100 nm	>10 nm	10 nm/100 nm Ratio
Etch	243	459879	1893
Chemical Hood	224	2028	9.1
Coater/Developer	545	8551	15.7
Stocker	326	17560	53.9

TABLE 6 Minienvironment Monitoring Solutions

Minienvironment Class	Particle Size	Flowrate	Product
ISO Class 1 or 2	0.2 µm	0.1 CFM	Airnet II 201
	0.1 µm	1.0 CFM	Lasair III 110 Aerosol Particle Counter
	0.01 µm	0.1 CFM	NanoAir 10 Condensation Particle Counter

Because minienvironments can be rich in nanoparticles, it is important to understand how nanoparticles move and how we can detect them. Counting particles in the nanometer size range encounters new complications due to Brownian motion. Because these particles approach the size of air molecules, they can diffuse out of and upstream against bulk air flow. In addition to complications of getting the nanoparticles to the particle counter, they are small enough to yield a limited light scattering signal introducing another complication in their detection. When this is the case, a condensation particle counter will grow nanoparticles to a size detectable by an optical particle counter. In these cases, NanoAir 10 particle counters are the desired particle counter when detecting particles in the 10 nm and greater range. To learn more about how CPCs works, watch the YouTube Video "How does a Condensation Particle Counter Work?" or read the FAQ paper for the NanoAir 10 and ParticleSeeker instruments, "Condensation Particle Counter and Manifold FAQ".

In clean room environments focusing on nanoparticle detection, the concentration of nanoparticles is often at a specific point in product development. This means that a point of use particle counter that can detect nanoparticles is desired. When NanoAir 10 unit is paired with the ParticleSeeker nanoparticle manifold, tubing can route nanoparticles from the point of use through the manifold to the NanoAir 10 counter for detection of MPPS between AMCs and traditional OPCs as displayed in **Figure 7**.

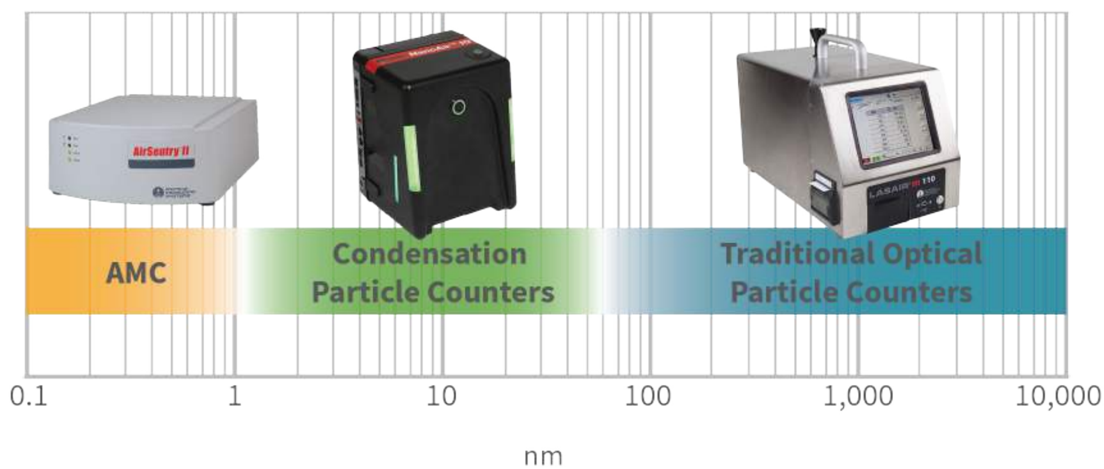


FIGURE 7 NANOAIR 10 MONITORS THE MOST PENETRATING PARTICLE SIZES THROUGH FILTERS AND THOSE PARTICLES GENERATED BY CLEAN ROOM PROCESSES IN THE SIZE RANGES BETWEEN AMCS AND TRADITIONAL OPTICAL PARTICLE COUNTERS (0.01 UM – 2.5 UM).

Filter and Valve Testing

Depending on the level of accuracy required, testing filters may require specialized particle counters. Aerosol spectrometers employ more than thirty-two channels for particle size distinction and resolution. While expensive, spectrometers provide the most detailed information regarding particle sizes and distributions. Standard 0.1 µm or 0.3 µm particle counters can easily monitor filters and valves and are usually installed upstream and downstream of the filter or valve. This technique provides accurate filter efficiency data and alarming for contamination problems but may not be desirable for testing valves.

Filters use an efficiency rating specified at the most penetrating particle size (MPPS). Standard specifications dictate the filter's efficiency at a specific MPPS and velocity. High Efficiency Particulate Air (HEPA) filters have a minimum filtering efficiency of 99.99% at 0.3 µm, and Ultra Low Penetration Air (ULPA) filters have a minimum filtering efficiency of 99.999% at 0.12 µm. Detecting penetrating particles requires a particle counter with at least 0.3 µm sensitivity for HEPA filter testing and 0.1 µm sensitivity for ULPA filter testing.

Valve testing procedures are outlined by SEMATECH. By nature, valves tend to trap and shed particles, so sampling particles from a valve can provide unreliable data. Therefore, because some of the particles detected may be generated by the process and others may come from the valve, valve cleanliness reports are difficult to generate; solutions are offered in Table 7.

TABLE 7 Filter and Valve Monitoring Solutions

Filter Type	Particle Size	Flowrate	Communication	Product
ULPA/HEPA	0.1 µm	1.0 CFM	TCP/IP	Lasair III 110
	0.3 µm	1.0 CFM		Airnet II 310
	0.3 µm	0.1 CFM		Airnet II 301
	0.01 µm	0.1 CFM		NanoAir 10

Lab Testing

Lab testing applications do not typically need to meet ISO cleanroom requirements. These applications seek a specific number of particle counts within a certain size range, and this number defines whether the lab components will pass or fail. Particle counter selection is dependent on the components being tested in the lab, so the lab must define the critical particle size limit (in µm) and the acceptable maximum concentration limits. High flow rates are often desirable as they increase throughput, reduce sampling times, and gather more data. Since lab tests focus on sub-micrometer contamination, the choices narrow for particle counters. These solutions are featured in Table 8.

TABLE 8 Lab Testing Solutions

Particle Size	Flowrate	Product
0.1 µm	1.0 CFM	Lasair III 110
0.3 µm	1.0 CFM	Lasair Pro 310C
0.3 µm	1.78 CFM (50 LPM)	Lasair Pro 350L
0.5 µm	3.56 CFM (100 LPM)	Lasair Pro 5100
0.01 µm	0.1 CFM	NanoAir 10

Harsh Environments

Harsh environments (such as pharmaceutical labs, cleanroom make-up air handling (MUAH) units, fan decks, or aerospace launch facilities) require special particle counters that are isolated from the environment but still provide accurate air sampling. Particle counters developed for harsh environments are often housed in NEMA-rated enclosures. These enclosures isolate the sensitive optics and electronics, while providing an external probe for monitoring particle concentrations and are featured in Table 9.

Pharmaceutical manufacturers are only interested in 0.5 µm and 5.0 µm particles. Some particle counters offer screen/data configurations that only display/print these specific channels; the Lasair® Pro family, Airnet® II series, and IsoAir® series provide this functionality. If a pharmaceutical lab contains heavy concentrations of hydrogen peroxide H_2O_2, a particle counter with resilient counting and high maximum sampling concentrations, such as the Airnet II 510 XR, is recommended.

MUAHs, fan decks, and launch systems require robust enclosures that can withstand conditions outside normal room environments. Appropriate particle counters have enclosures made from stainless steel or Kydex®, which provide superior resistance to damaging external conditions, but have proven reliability in particle counting. Some of the instruments that meet these conditions include the IsoAir 310P and the Airnet II series.

TABLE 9 Harsh Environment Monitoring Solutions

Cover Material	Particle Size	Flowrate	Communication	Product
Stainless Steel 316L	0.1 µm	1.0 CFM	Ethernet	Lasair III 110
Stainless Steel 316L	0.5, 5.0 µm	1.0 CFM	Ethernet	Airnet II 510s, 510s XR
Stainless Steel 316L	0.3, 0.5 µm	1.0 CFM	Ethernet	IsoAir 310P
Polycarbonate	0.3 µm	1.0 CFM	Ethernet	Airnet II 310
Polycarbonate	0.3 µm	0.1 CFM	Ethernet	Airnet II 301
Polycarbonate	0.5 µm	1.0 CFM	Ethernet	Airnet II 510 XR
Polycarbonate	0.3 µm	50 LPM	Ethernet	Lasair Pro
Polycarbonate	0.5 µm	100 LPM	Ethernet	Lasair Pro

Counting Particles in Gases

Measuring particles in compressed gases requires a different series of considerations and safety measures. First, we need to determine whether the gas is reactive like hydrogen or oxygen and what pressure range at which the unit will operate. Reactive gases require a special particle counter stored inside a containment vessel designed to withstand moderate levels of overpressure to avoid exposure and reactions/explosions of these gases. Usually, containment vessels are backfilled with nitrogen, an inert gas that neutralizes small volumes of reactive gases. It may be possible to monitor other reactive gases after careful evaluation for compatibility between the particle counter's wetted materials with the sample gas. Additional safety precautions for high pressure gas sampling should be taken such as leak monitoring, purge flow monitoring, and any other safety measure to ensure proper operation.

Sampling gases at pressure is preferred to avoid particle losses. Therefore, products like the Particle Measuring System's High Pressure Gas Probe (HPGP) has mass flow controllers to provide constant, volumetric flowrates when connected to gas line pressures between 40 - 150 psig. Particle sizing can differ with pressure and the composition of gas, so gas particle counters must account for these variables. A gas constant entered into the instrument's data system provides correction factors for different gases and allows the mass flow controller to increase or decrease the flowrate based on the chemistry of the sampled gas.

If the gas is reactive and falls within the specified pressure range, you may sample the gases using a High-Pressure Gas Probe (HPGP). The HPGP-101-C offers 0.1 µm sensitivity, 0.1 CFM flowrate, and a containment vessel to confine overpressures of 3200 psig. If there is a gas you would like to measure particles in, contract Particle Measuring Systems to consult if the HPGP can used. The HPGP also does not waste any gas used for testing as the gas after particle counting can be filtered then put back into the high pressure gas line.

FIGURE 8 HPGP-101-C ULTRA HIGH PURITY GAS PARTICLE COUNTER

Non-reactive gases such as argon, helium, neon, nitrogen, and xenon have different monitoring requirements as they are not explosive or dangerous. The option with the lowest initial cost is connection from a standalone particle counter to a high-pressure diffuser (HPD) which drops the gas being sampled to atmospheric pressure for the subsequent standard particle counter. They come in 0.1 CFM and 1 CFM flow rates and are considered accessories to standard optical particle counters. The HPD III from Particle Measuring Systems accommodates pressures from 40 - 125 psig. One thing to note with HPD units is that excess gas will be vented into the ambient so for expensive gases they can be wasteful from a cost perspective and proper ventilation should be implemented in smaller rooms. Figure 9 features an HPD III accessory connected to NanoAir 10 instrument.

FIGURE 9 NANOAIR 10 PARTICLE COUNTER WITH HPD III ACCESSORY

Dedicated gas particle counters should be used for critical applications and any measurement of reactive gases. HPDs should be used for less critical applications or occasional monitoring of non-reactive gases. **Table 10** features some use cases of the above mentioned particle counters.

TABLE 10 Gas Monitoring Solutions

Gas Type	Purpose	Particle Size	Flowrate	Pressure Range	Product
Reactive	Dedicated sampling at pressure	0.1 µm	0.1 CFM	40 - 150 psig	HPGP-101-C
Non-reactive	Dedicated, occasional, periodic testing, or trend monitoring	0.1 µm	1.0 CFM	40 - 100 psig	HPGP-101-C or Lasair III 110 with HPD II-100
Non-reactive	Dedicated, occasional, periodic testing, or trend monitoring	0.3 µm	1.0 CFM	25 - 100 psig	HPGP-101-C or Lasair Pro with HPD III

Conclusion

While the purchasing choices may seem endless, evaluating your application will help you focus on your requirements. Using the basic guidelines provided in this article will help you purchase the ideal counter to meet your requirements without paying for features you do not need.

References

1. ISO 14644-1, *Cleanrooms and Associated Controlled Environments*. 2015.
2. High-yield manufacturing: Particle Monitoring in Minienvironments; *CleanRooms Magazine*, April 2004.