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**Particle Detection Efficiency of Three Particle  
Counters: Aerodynamic Particle Sizer 3321,  
Lighthouse SOLAIR 3350, and Met One GT-526S**

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<b>14. ABSTRACT: (Limit 200 words)</b> Many airborne particle detectors are available for laboratory use as reference detectors. These particle detectors are designed differently based on the application and have various and, in some cases, adjustable airflow rates. This study focused on experimentally determining the detection efficiency of three particle detectors: the Aerodynamic Particle Sizer (APS) 3321 (TSI, Inc.; Shoreview, MN), the SOLAIR 3350 (Lighthouse Worldwide Solutions, Inc.; Medford, OR), and the GT-526S (Met One Instruments, Inc.; Grants Pass, OR). The APS, SOLAIR, and Met One instruments were tested at 1, 100, and 1 L/min airflow rates, respectively. The Met One instrument has an adjustable airflow rate with a maximum of 2.83 L/min. An inkjet aerosol generator (IJAG) was used to generate particles in four sizes (1.91, 2.65, 4.22, and 7.68 μm) at eight particle-generation rates (1–500 particles/s). Six replicate tests were conducted at each test condition. The APS, SOLAIR, and Met One detectors had average detection efficiencies of 97.75, 377.96, and 93.19%, respectively. The efficiency of the SOLAIR detector was closer to 100% for higher IJAG particle-generation rates. The results indicated that the Met One detector could be an alternative to the APS for determining low-concentration aerosols when a larger air sample volume is required.					
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## **PREFACE**

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# **PARTICLE DETECTION EFFICIENCY OF THREE PARTICLE COUNTERS: AERODYNAMIC PARTICLE SIZER 3321, LIGHTHOUSE SOLAIR 3350, AND MET ONE GT-526S**

## **1. INTRODUCTION**

Intentional and accidental releases of harmful aerosols pose threats to both soldiers and civilians; therefore, it is important to monitor the hazardous particles in air. Aerosol detectors and samplers identify and alert to the presence of threat agents in the air. Fielded detectors and samplers must be checked periodically using simulant aerosols in controlled environments to establish their functionality, quantify any degradation, and identify their limits of detection. New or developmental items also must be tested to determine their functionality and to compare them with existing technology. Precise measurements of particle sizes and concentrations are needed to identify the particle detection efficiencies of these systems. Validated reference aerosol particle detectors are needed that can accurately assess particle size and concentration, identify the challenge conditions, and provide comparisons with the system under test. Many reference particle detectors are available for use in laboratory and field settings. These particle detectors are designed for different applications and have various and, in some cases, adjustable airflow rates. In addition, these detectors use different detection technologies (such as time of flight or light scattering) to detect and measure particles in air.

The Aerodynamic Particle Sizer (APS) 3321 (TSI, Inc.; Shoreview, MN) is a common laboratory reference instrument that measures particle size and concentration very accurately. However, it is also expensive, and it may not be suitable for use as a reference for low concentration (<1 particle/L range) aerosol tests because it has a low airflow rate through the measurement region (1 L/min). Instruments with higher airflow rates are available, but their particle detection efficiencies have not been validated in our laboratory. Two such instruments are the SOLAIR 3350 (Lighthouse Worldwide Solutions, Inc.; Medford, OR) and the GT-526S (Met One Instruments, Inc.; Grants Pass, OR). Testing was conducted to assess the particle counting efficiencies of APS, SOLAIR, and Met One instruments using eight concentrations of four monodispersed particle sizes and to determine whether these high-airflow instruments can be used to accurately detect low to high concentrations of particles in air.

## **2. MATERIALS AND METHODS**

Testing was conducted in a clean room (Figure 1) containing high-efficiency particulate air (HEPA) filters on the roof to filter the air that was blown into the room. This room provided a particle-free environment for particle detector and particle counter testing. Three aerosol particle counters were tested in this study: APS 3321, SOLAIR 3350, and Met One GT-526S. Four sizes of solid sodium hydroxide (NaOH) particles were generated using an inkjet aerosol generator (IJAG; U.S. Army Combat Capabilities Development Command Chemical Biological Center; Aberdeen Proving Ground, MD) and delivered to the inlet of each particle counter so their relative detection efficiencies could be evaluated. Solid NaOH particles are suitable for this test because the NaOH solution does not clog the IJAG cartridge during aerosol generation, and the solid particles do not break apart in high-airflow conditions within the

particle detectors. Tests were conducted using four NaOH particle sizes ( $1.91 \pm 1.45$ ,  $2.65 \pm 1.15$ ,  $4.22 \pm 1.19$ , and  $7.68 \pm 1.12$   $\mu\text{m}$ ) and eight IJAG particle-generation rates (1, 5, 50, 100, 200, 300, 400, and 500 particles/s). The IJAG generated monodispersed aerosols with a geometric standard deviation (GSD) of  $<1.2$ , but the particle size (number mean diameter [NMD]) shifted slightly from day to day. The standard deviation provided with the particle size is related to the change in size on different days. In addition, these IJAG-generated particles provided different concentrations to each instrument because of different airflow rates, as shown in Table 1.



Figure 1. Clean room.

Table 1. Aerosol Challenge Concentrations Observed by Each Particle Detector

IJAG Generation Rate (Particles/s)	Challenge Concentration (Particles/L)		
	APS 3321 (1 L/min Flow Rate)	SOLAIR 3350 (100 L/min Flow Rate)	Met One GT-526S (1 L/min Flow Rate)
1	60	0.6	60
5	300	3	300
50	3,000	30	3,000
100	6,000	60	6,000
200	12,000	120	12,000
300	18,000	180	18,000
400	24,000	240	24,000
500	30,000	300	30,000

## 2.1 IJAG

The IJAG was developed to enable testing of aerosol detection instruments with different particle sizes and concentrations. Particles can be generated on demand, either one at a time with a push of a button or at a constant generation rate of 1–500 particles/s. Generated particles travel downward and are delivered directly into the intake flow of the detector being tested. The IJAG system is composed of three principal components: the dispenser, controller, and computer (Figure 2). The first component, the dispenser, is the heart of the system. The dispenser is a tubular device that contains the inkjet cartridge (mounted on top), the light-scattering detector (below the cartridge), and the oven. The IJAG system includes a ThinkJet 12-nozzle printer cartridge (HP Inc.; Palo Alto, CA) filled with a dilute aqueous NaOH solution at a concentration that yields the appropriate final particle size when dry.

The second component, the controller, provides the dispenser with airflows, electrical power for the oven, and pulses to fire the cartridge nozzles. It also provides signal processing for the light-scattering detector. The third component, a computer, operates the IJAG through the controller via a Personal Computer Memory Card International Association (PCMCIA) card. The IJAG program uses feedback from the light-scattering detector to adjust the nozzle firing rate and achieve the desired particle-generation rate, even if one (or more) cartridge jet becomes nonfunctional. This cartridge produces nearly monodispersed primary droplets that result in dry, monodispersed particles. A HEPA-filtered carrier flow, typically 1 L/min, transports the particles through the 300 mm (~1 ft) long drying oven that is heated to approximately 72 °C. It takes about 3 s for a particle to travel the length of the dispenser and exit through a 15.8 mm (0.622 in.) diameter outlet tube. The IJAG-generated larger primary droplets are counted using the light-scattering system. Based on the counts, the generation rate can be altered to produce the desired number of final particles.

For this test, the IJAG generated four different sizes of monodispersed NaOH particles at 1, 5, 50, 100, 200, 300, 400, and 500 particle/s generation rates. NaOH particles are solid when dry and do not split into smaller particles in high-airflow conditions. Liquid Tween 80 (Croda; Princeton, NJ) particles were used in previous tests, but Tween 80 particles may split into smaller droplets in high-airflow conditions; therefore, they were not suitable for this counting efficiency test. The IJAG computer software controlled the particle generation rate, generation time, and firing nozzle selection. Six repetitions were conducted for each combination of generation rate, particle size, and particle counter. For each test, the IJAG generated particles for 30 s. This means that at a 1 particle/s generation rate, the IJAG generated around 30 particles in 30 s, and at a 500 particle/s generation rate, the IJAG produced about 15,000 particles in 30 s. The IJAG output tube was carefully connected to the particle detectors to completely eliminate any losses in the tubing and connectors.

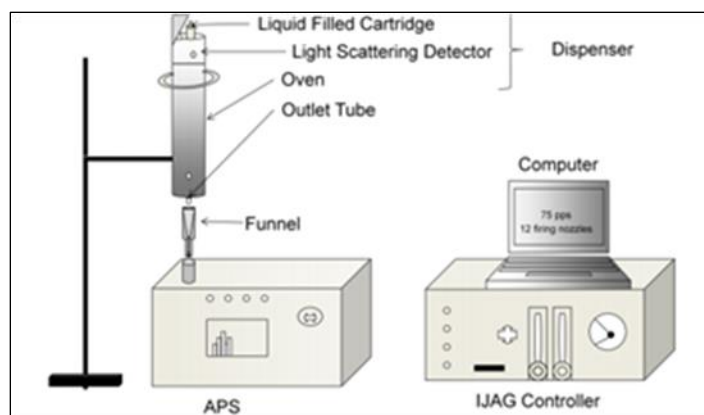


Figure 2. Experimental setup for challenging the APS 3321 instrument with IJAG-generated particles.

## 2.2 APS 3321

The APS 3321 instrument aerodynamically sizes particles between 0.5 and 20  $\mu\text{m}$  and also uses light scattering to count particles presumed to be between 0.3 and 0.5  $\mu\text{m}$ , which have scattering intensities too marginal to permit time-of-flight sizing. The total aerosol flow rate into the APS instrument inlet is 5 L/min. This flow is split: 1 L/min of sample flow passes through the inner inlet tube and thence into the detection region, and the remaining 4 L/min is filtered and serves as sheath flow. The sheath flow confines the sample flow to the center of an acceleration nozzle, which is located just ahead of a split laser beam. The particle size is determined by the time of flight of particles between the two laser beams.

The APS 3321 instrument coincidence error is <5% for a particle size of 0.5  $\mu\text{m}$  diameter and a concentration of  $10^3$  particles/ $\text{cm}^3$  ( $10^6$  particles /L), and <10% for a particle size of 10  $\mu\text{m}$  and a concentration of  $10^3$  particles / $\text{cm}^3$  (TSI, 2006). Particle density and shape affect the aerodynamic particle size measured by the APS instrument as a consequence of non-Stokesian effects for nonspherical particles (Cheng et al., 1993).

The IJAG-generated particles were delivered directly to the APS 3321 instrument's inner nozzle using a custom-made funnel for particle size distribution and count measurements (Kesavan et al., 2014). The IJAG generated particles for 30 s, and the APS instrument sampled the aerosols for 40 s to completely capture all of the generated particles. The total count, NMD, and GSD were recorded to determine the particle size distribution and detection efficiency.

## 2.3 Lighthouse SOLAIR 3350

The Lighthouse SOLAIR 3350 instrument is a portable particle counter with a 100 L/min airflow rate. The SOLAIR instrument uses laser diode technology to collect scattered light and thereby measure the number and size of particles between 0.3 and 25  $\mu\text{m}$ . Light scattered by the particles is collected and focused onto a photodiode that converts light bursts into electrical impulses. The pulse height is a measure of the particle size. The SOLAIR

instrument records data in eight particle channels: 0.3, 0.5, 0.7, 1.0, 3.0, 5.0, 7.0, and 10.0  $\mu\text{m}$ . It has a 50% counting efficiency for 0.3  $\mu\text{m}$  particles, but that increases to 100% for particles larger than 0.45  $\mu\text{m}$ . A funnel (Figure 3) was connected to the inlet of the SOLAIR instrument, and the IJAG output tube was centered and placed about a 1/2 in. into the funnel. The IJAG generated particles for 30 s, and the SOLAIR instrument sampled the particles for 40 s to completely capture all the generated particles. Total counts and the individual particle channel counts were recorded for each generation rate and particle size.

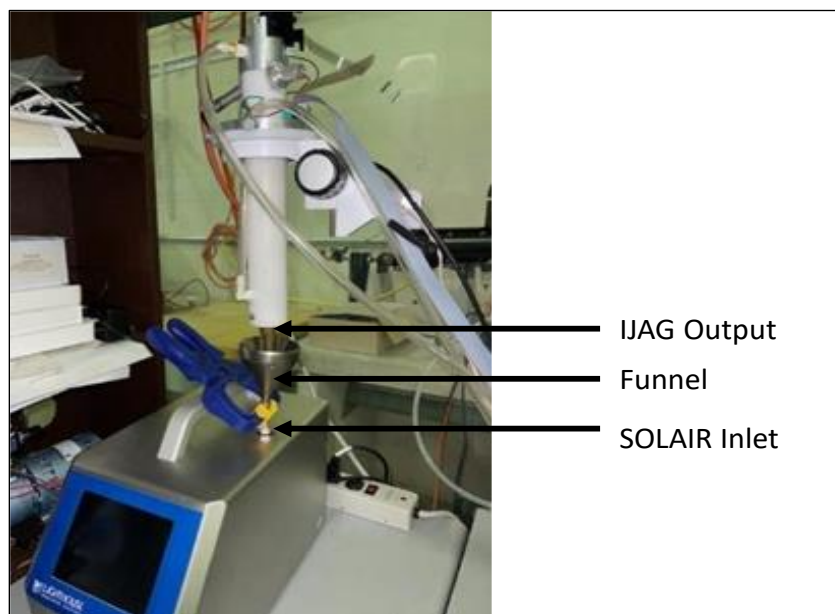


Figure 3. Experimental setup for challenging the Lighthouse SOLAIR 3350 instrument with IJAG-generated particles.

## 2.4 Met One GT-526S

The Met One GT-526S is a battery-operated, handheld particle counter. The light source is a 780 nm laser diode, and the scattered light from particles is collected to count and size the particles. The Met One instrument has an adjustable flow rate with a maximum of 2.83 L/min and can detect concentrations in the range of 0 to 105,900 particles/L (3,000,000 particles/ft<sup>3</sup>). The Met One instrument has six channels for sizing particles between 0.3 and 10.0  $\mu\text{m}$ , and these channels can be configured to factory-calibrated standard sizes or user-defined custom sizes. This study used the factory standard bins to size particles: 0.3, 0.5, 1.0, 2.0, 5.0, and 10.0  $\mu\text{m}$ . The Met One instrument collects one sample at a time, and the sample time is adjustable from 1 to 999 s. The operating temperature of the unit is 0–50 °C, and the storage temperature is –20–60°C.

For this test, a funnel was placed at the end of the IJAG (Figure 4) to create a small opening that fit just inside the Met One instrument's inlet tubing. The Met One instrument was adjusted to sample at a 1 L/min airflow rate to match the aerosol flow of the IJAG. This allowed the IJAG output to be connected directly to the Met One instrument. The Met One inlet

tubing was kept completely vertical to prevent any particle loss in the tubing. The IJAG generated particles for 30 s, and the Met One instrument sample time was set for 40 s so it could completely count all of the generated particles. Total counts and the individual particle channel counts were recorded for each test.

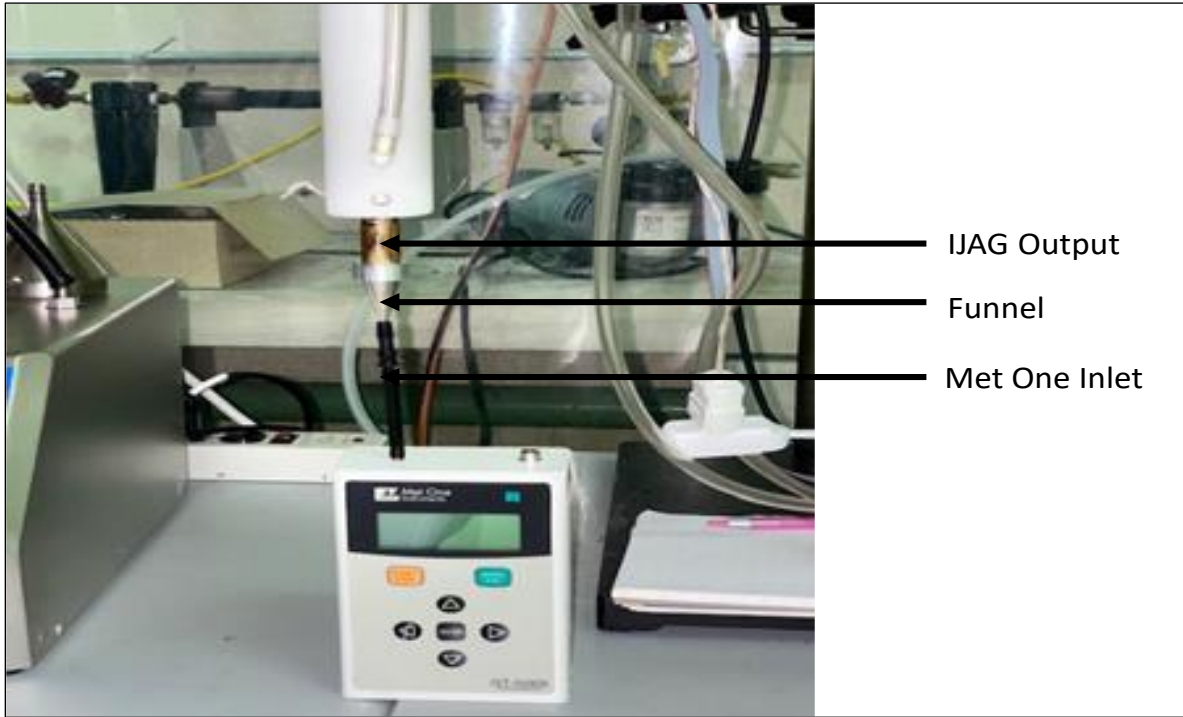


Figure 4. Experimental setup for challenging the Met One GT-526S instrument with IJAG-generated particles.

## 2.5 Testing

The test protocol consisted of testing the APS and another particle counter together. The IJAG-generated particles were first delivered to the APS 3321 and then to the second instrument (SOLAIR 3350 or Met One GT-526S). Testing was conducted with four monodispersed particle sizes and eight IJAG particle-generation rates. Six repetitions were conducted for each condition.

The particle counting efficiency of each instrument was determined by comparing the number of particles detected by the instrument with the number of particles produced by the IJAG:

$$\text{Particle counting efficiency} = 100 \times \left( \frac{\text{Particles detected by the detector}}{\text{Particles generated by the IJAG}} \right) \quad (1)$$

A 100% particle-counting efficiency meant the instrument counted the exact same number of particles that the IJAG produced. A <100% particle-counting efficiency indicated that the instrument was not able to count all of the particles generated. A >100% particle-counting

efficiency meant the particle detector was either detecting particles that were not actually produced or counting incorrectly, which are issues that could occur for many reasons.

The counting efficiency was averaged for each particle size and each generation rate. The counting efficiency of the SOLAIR 3350 instrument was closer to 100% for high IJAG particle-generation rates, so the counting efficiency for the SOLAIR instrument was averaged for IJAG particle-generation rates of 100–500 particles/s for each particle size. Because the instruments had significantly different airflow rates, the counting efficiency was also calculated and plotted as a function of aerosol concentration.

### **3. RESULTS**

#### **3.1 APS Model 3321 Results**

The APS 3321 was tested with both the SOLAIR 3350 and the Met One GT-526S instruments; therefore, two sets of APS data were collected for the total counts and particle sizes. Number geometric means and standard deviations from the APS were averaged to determine the four particle sizes of the solid NaOH test particles. The four sizes used in these tests were 1.91, 2.65, 4.22, and 7.68  $\mu\text{m}$ . The detection efficiencies for each particle size and each generation rate are provided in Table 2 and Figure 5. The average detection efficiency for each particle size is provided in Table 3 and Figure 6. The overall APS counting efficiency for all generation rates and all particle sizes is 97.75%. Figure 5 shows the APS detection efficiencies compared with the SOLAIR and Met One detection efficiencies for all four particle sizes and all eight generation rates. The APS was nearly 100% efficient every time and the standard deviations were very small. The low generation rate (1 particle/s) was the exception; APS efficiency was in the high 80 to low 90% range for all four particle sizes at this generation rate. Table 3 shows the APS efficiency for each particle size. There was little difference among the efficiencies; however, the APS had the highest efficiency for 2.65  $\mu\text{m}$  NaOH particles.

#### **3.2 Lighthouse SOLAIR 3350 Instrument Results**

Particle counting efficiencies for each particle size and generation rate are provided in Table 2 and Figure 5. The average particle counting efficiencies for each particle size averaged for all generation rates and specifically for 100–500 particle/s generation rates are provided in Table 3 and Figure 6. The SOLAIR 3350 particle detector had >100% efficiency for most generation rates and particle sizes. However, the greatest overage was at the lowest generation rate (1 particle/s), as shown in Figure 5. The efficiency decreased almost exponentially from the 1 to 100 particle/s generation rates and then plateaued near 100% for the remaining generation rates. This trend was observed for all four particle sizes. The particle-counting efficiency was 135.94% for the 100–500 particle/s IJAG particle-generation rates, as shown in Table 3.

### 3.3

### Met One GT-526S Results

Particle-counting efficiencies for each particle size and generation rate are provided in Table 2 and Figure 5. The average particle-counting efficiencies for each particle size averaged for all generation rates are provided in Table 3 and Figure 6. The Met One GT-526S particle counter had an overall relative detection efficiency of 93.19% (Table 3). It had the highest counting efficiency for the 4.22  $\mu\text{m}$  NaOH particle and the lowest efficiency for the 7.68  $\mu\text{m}$  particle. (Table 3). As shown in Figure 5, the counting efficiency for the Met One instrument was uniform over all eight generation rates.

Table 2. Detection Efficiency

IJAG Particle Generation Rate (Particle/s)	Detection Efficiency (%)			
	1.91 $\mu\text{m}$ Particles	2.65 $\mu\text{m}$ Particles	4.22 $\mu\text{m}$ Particles	7.68 $\mu\text{m}$ Particles
APS 3321				
1	91.94 $\pm$ 4.99	93.33 $\pm$ 3.58	93.06 $\pm$ 7.55	85.67 $\pm$ 7.69
5	97.56 $\pm$ 1.83	98.39 $\pm$ 1.59	97.22 $\pm$ 1.80	95.62 $\pm$ 2.96
50	99.65 $\pm$ 0.46	99.83 $\pm$ 0.20	99.18 $\pm$ 0.84	98.33 $\pm$ 0.49
100	99.67 $\pm$ 0.22	99.26 $\pm$ 0.79	98.41 $\pm$ 0.77	97.16 $\pm$ 1.27
200	99.53 $\pm$ 0.23	99.25 $\pm$ 0.28	98.15 $\pm$ 1.13	98.73 $\pm$ 0.83
300	99.01 $\pm$ 0.37	98.90 $\pm$ 1.08	98.74 $\pm$ 1.17	99.03 $\pm$ 0.45
400	99.35 $\pm$ 0.15	99.34 $\pm$ 0.17	98.56 $\pm$ 1.12	98.96 $\pm$ 0.36
500	99.02 $\pm$ 0.61	99.34 $\pm$ 0.18	98.84 $\pm$ 0.61	99.03 $\pm$ 0.32
SOLAIR 3350				
1	8281.67 $\pm$ 4564.79	2901.67 $\pm$ 2344.48	2018.33 $\pm$ 818.34	585.91 $\pm$ 64.81
5	453.71 $\pm$ 102.19	425.48 $\pm$ 253.62	743.67 $\pm$ 662.26	340.56 $\pm$ 37.31
50	214.65 $\pm$ 82.34	371.37 $\pm$ 128.01	204.69 $\pm$ 121.62	234.00 $\pm$ 23.09
100	138.57 $\pm$ 41.70	231.65 $\pm$ 74.68	147.97 $\pm$ 61.74	183.62 $\pm$ 17.39
200	119.16 $\pm$ 28.60	93.58 $\pm$ 14.83	138.43 $\pm$ 18.02	174.95 $\pm$ 4.99
300	100.32 $\pm$ 14.59	81.32 $\pm$ 11.40	128.94 $\pm$ 10.75	175.61 $\pm$ 8.77
400	85.72 $\pm$ 11.39	92.72 $\pm$ 15.67	152.85 $\pm$ 15.75	162.78 $\pm$ 7.74
500	90.04 $\pm$ 28.44	91.94 $\pm$ 8.83	164.75 $\pm$ 9.69	164.03 $\pm$ 6.92
Met One GT-526S				
1	86.31 $\pm$ 19.65	104.44 $\pm$ 11.67	96.63 $\pm$ 10.03	85.50 $\pm$ 15.37
5	99.44 $\pm$ 1.29	99.56 $\pm$ 7.72	94.46 $\pm$ 2.86	88.00 $\pm$ 2.46
50	93.40 $\pm$ 9.10	94.65 $\pm$ 0.95	92.53 $\pm$ 1.48	91.13 $\pm$ 4.69
100	91.00 $\pm$ 5.65	92.71 $\pm$ 2.98	96.43 $\pm$ 1.32	92.23 $\pm$ 2.00
200	92.31 $\pm$ 3.91	90.07 $\pm$ 4.41	94.91 $\pm$ 3.51	90.08 $\pm$ 1.85
300	94.95 $\pm$ 2.08	93.83 $\pm$ 1.54	95.37 $\pm$ 2.89	88.18 $\pm$ 6.30
400	94.55 $\pm$ 2.01	92.63 $\pm$ 0.98	95.64 $\pm$ 2.15	89.90 $\pm$ 0.70
500	90.74 $\pm$ 0.54	92.84 $\pm$ 1.01	96.14 $\pm$ 2.85	91.43 $\pm$ 1.27

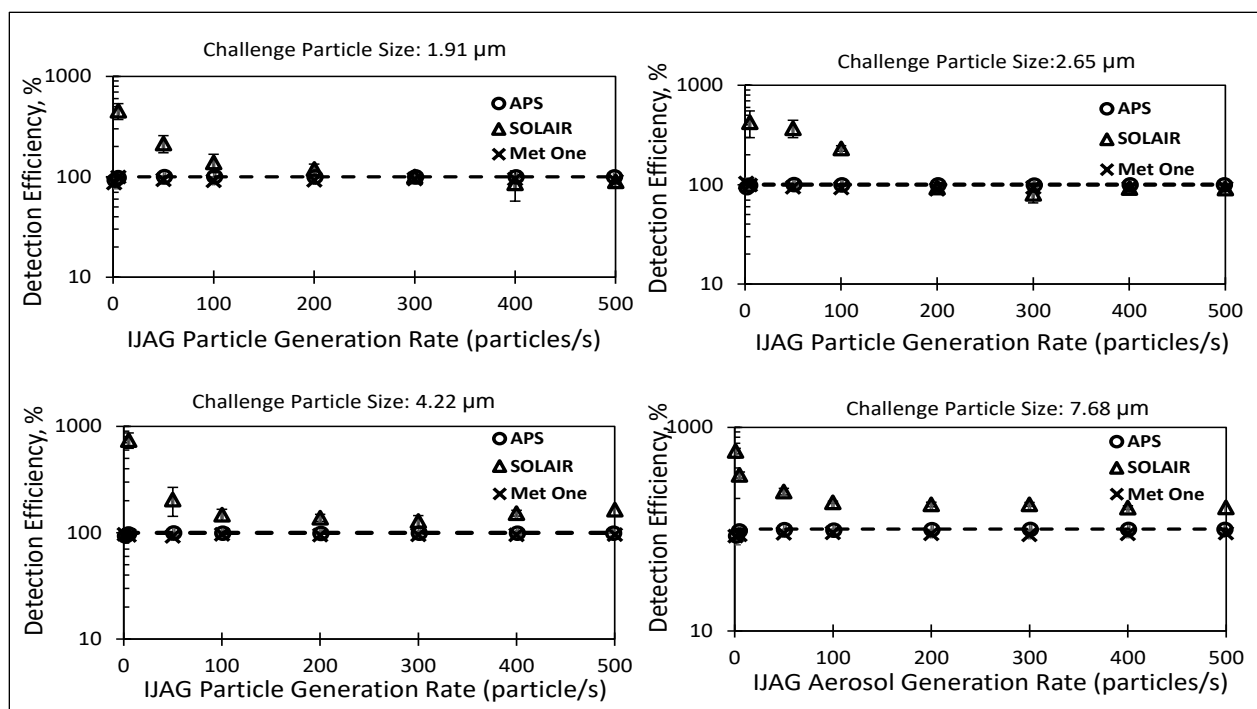


Figure 5. Relative detection efficiencies of APS 3321, SOLAIR 3350, and Met One GT-526S instruments for four particle sizes and eight IJAG particle-generation rates. The standard deviation for the SOLAIR instrument at a 1 particle/s IJAG particle-generation rate for 1.90, 2.65, and 4.22  $\mu\text{m}$  particle sizes ranged from 818.34 to 4564.79; this is not shown in the graph because it would make the range of the y axis very large.

Table 3. Average Detection Efficiency for Each Particle Counter and Each Particle Size\*

Particle Counter	Counting Efficiency (%)				
	1.91 $\mu\text{m}$ Particles	2.65 $\mu\text{m}$ Particles	4.22 $\mu\text{m}$ Particles	7.68 $\mu\text{m}$ Particles	Average <sup>†</sup>
APS	98.22 $\pm$ 1.11	98.45 $\pm$ 0.98	97.77 $\pm$ 1.88	96.57 $\pm$ 1.80	97.75 $\pm$ 1.44
SOLAIR <sup>‡</sup>	260.48 $\pm$ 609.25	536.22 $\pm$ 356.44	462.46 $\pm$ 214.77	252.67 $\pm$ 21.28	377.96 $\pm$ 300.46
SOLAIR <sup>§</sup>	106.76 $\pm$ 21.96	118.24 $\pm$ 63.59	146.59 $\pm$ 13.68	172.18 $\pm$ 8.76	135.94 $\pm$ 27.00
Met One	92.84 $\pm$ 4.40	95.09 $\pm$ 3.91	95.26 $\pm$ 3.39	89.56 $\pm$ 4.33	93.19 $\pm$ 4.01

\*The counting efficiencies for all generation rates were averaged for APS 3321, SOLAIR 3350, and Met One GT-526S instruments. In addition, the counting efficiencies for generation rates of 100–500 particles/s were averaged for SOLAIR.

<sup>†</sup>Average counting efficiencies for all test particle sizes.

<sup>‡</sup>All generation rates.

<sup>§</sup>100–500 particles/s generation rates.

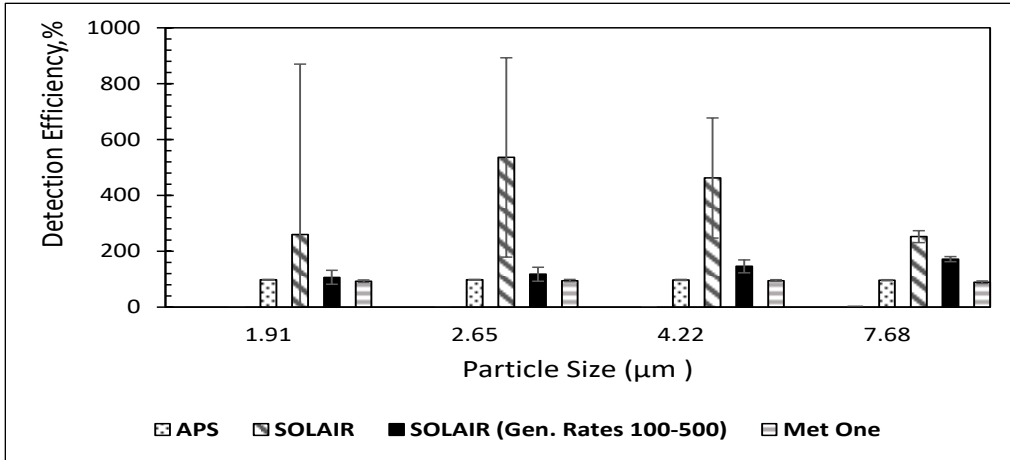


Figure 6. Average relative detection efficiencies of APS 3321, SOLAIR 3350, and Met One GT-526S particle detectors for the four particle sizes. Graph includes SOLAIR efficiencies for all generation rates and only 100–500 particle/s generation rates.

Because the three particle detectors sampled very different particle concentrations, the counting efficiency data were also plotted as a function of aerosol concentration, as shown in Figure 7. The results indicated that the SOLAIR 3350 was challenged with lower aerosol concentrations as compared to the APS 3321 and Met One GT-526S, as shown in Figure 7. However, all three detectors were tested at 60 and 300 particle/L particle concentrations. Figure 7 indicates that the counting efficiency of all three instruments may be similar for a 300 particle/L concentration; therefore, the counting efficiency at this concentration was evaluated further. The 300 particle/L concentration was produced at a 5 particle/s IJAG generation rate for the APS and Met One instruments but a 500 particle/s rate for the SOLAIR instrument. *T*-test results indicated that the counting efficiencies of the APS and Met One instruments were similar ( $p = 0.199$ ) for the 300 particle/L concentration, but the counting efficiency of the SOLAIR instrument was significantly higher ( $p < 0.05$ ), as shown in Figure 8.

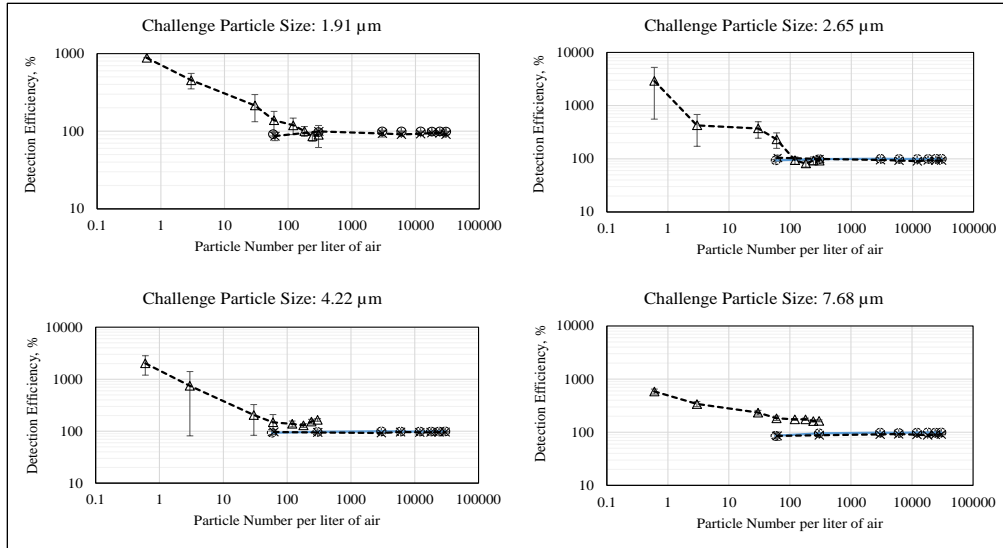


Figure 7. Detection efficiency as a function of aerosol concentration. APS results are provided by the circle, SOLAIR results are provided by the triangle, and Met One results are provided by the X.

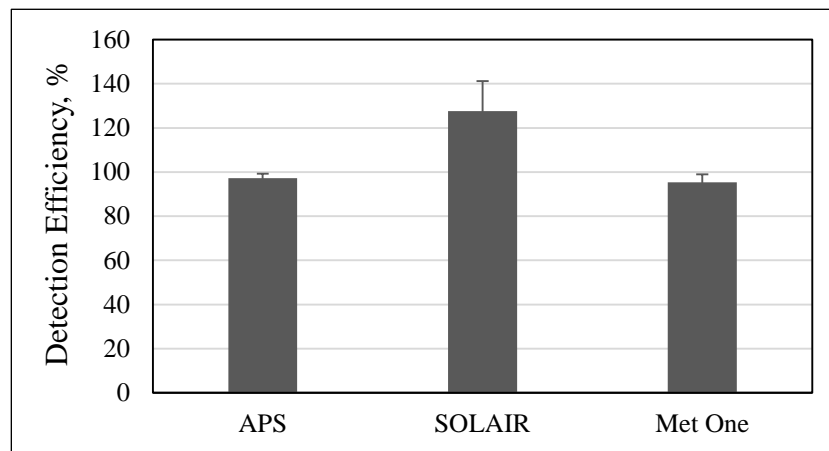


Figure 8. Particle detection efficiency of APS 3321, SOLAIR 3350, and Met One GT-526S instruments for 300 particle/L concentration.

#### 4. CONCLUSIONS

This study evaluated the counting efficiency of APS 3321, SOLAIR 3350, and Met One GT-526S particle counters using IJAG-generated particles. The counting efficiency of each instrument was assessed as a function of the IJAG particle-generation rate and the particle concentration in air. Because the particle counters had very different airflow rates (1 L/min for the APS and Met One instruments and 100 L/min for the SOLAIR instrument), the aerosol concentrations measured by the instruments were very different.

The APS 3321 instrument had the best detection efficiency for all four particle sizes and all generation rates (97.75% overall average efficiency). The SOLAIR 3350 particle counter had detection rates significantly >100% for lower concentrations but closer to 100% for higher concentrations. The Met One GT-526S instrument had a 93.19% average detection efficiency. There appears to be no correlation between particle size and counting efficiency across the three particle counters; each particle counter had the most accurate counting efficiency at a different particle size, as shown in Table 3. The APS detected the 2.65  $\mu\text{m}$  particles most accurately, whereas the SOLAIR instrument detected the 7.68  $\mu\text{m}$  particles most accurately, and the Met One instrument detected the 4.22  $\mu\text{m}$  particles most accurately.

The APS 3321 had the lowest flow rate (1 L/min), and the results had very small standard deviations. The Met One GT 526S instrument had a slightly higher airflow rate (2.83 L/min) and slightly greater standard deviations, and the SOLAIR 3350 instrument had a 100 L/min airflow rate and large standard deviations. After many trials and manipulations, it is unclear why the SOLAIR counted the particles inaccurately. It could be because of a problem with the internal light-scattering system, or the instrument might need recalibration. The results indicate that the Met One particle counter is suitable for counting particles in low-concentration environments if a large sample volume is required. The particle counting efficiencies of other available particle counters should also be tested, to determine whether they are suitable for use in laboratory tests as reference instruments.

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## ACRONYMS AND ABBREVIATIONS

APS	aerodynamic particle sizer
GSD	geometric standard deviation
HEPA	high-efficiency particulate air
IJAG	inkjet aerosol generator
NMD	number mean diameter



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