Aerosol Collection of the (Bladewerx Corporation) Breathing Zone Monitor and Portable Workplace Monitor

(Derived from LA-UR-06-1861)

Murray E. Moore[1]

Trevor J. Kennedy[1]

Paul J. Dimmerling[1]

(1) RADIATION PROTECTION DIVISION; GROUP RP-2.
LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM 87545

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ABSTRACT

The Radiation Protection Group at the Los Alamos National Laboratory has a wind tunnel capable of measuring the aerosol collection efficiencies of air sampling devices. In the fall of 2005, the group received an internal Los Alamos request to perform aerosol collection efficiency tests on two air samplers manufactured by the Bladewerx Corporation (Rio Rancho, New Mexico). This paper presents the results from tests performed in the wind tunnel facility at a test velocity of 0.5 m/sec. The SabreAlert (Portable Workplace Monitor) and the SabreBZM (Breathing Zone Monitor) are both designed to detect and measure the presence of alpha emitting isotopes in atmospheres. The SabreAlert was operated at two test air flowrates of 6 and 45 liters per minute (LPM), and the SabreBZM was operated at two test air flowrates of 3 and 19 LPM. The aerosol collection efficiencies of both samplers were evaluated with oleic acid (monodisperse) liquid droplet aerosols tagged with sodium fluorescein tracer. These test aerosols varied in size from about 2.3 to 17.2 microns (aerodynamic equivalent diameter). The SabreAlert was roughly 100% efficient in aerosol collection at a flowrate of 6 LPM, and had an aerodynamic cutpoint diameter of 11.3 microns at the 45 LPM flowrate. The SabreBZM had an aerodynamic cutpoint diameter of 6.7 microns at the 3 LPM flowrate, but the SabreBZM aerosol collection efficiency never exceeded 13.6% at the 19 LPM test flowrate condition.

Keywords:
Aerosols; air sampling; personnel monitoring; airborne radioactivity.

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* To whom correspondence should be addressed:
Murray E. Moore
Los Alamos National Laboratory
Group RP-2, MS G-761
Los Alamos, NM 87545
Tel: 505-665-9661
Fax: 505-665-6071
E-mail: memoore@lanl.gov

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INTRODUCTION

The Radiation Protection (RP-2) Group at the Los Alamos National Laboratory (LANL) has a wind tunnel capable of measuring the aerosol collection efficiencies of air sampling devices. In the fall of 2005, the RP-2 Group received an internal LANL request to perform aerosol collection efficiency tests on two air samplers manufactured by the Bladewerx Corporation (Rio Rancho, NM). This paper presents the results from tests performed in the RP-2 wind tunnel facility at a test velocity of 0.5 m/sec. The SaberAlert (Portable Workplace Monitor) and the SabreBZM (Breathing Zone Monitor) are shown in Figure 1.

Figure 1. The Bladewerx SabreAlert Portable Workplace Monitor (left) and SabreBZM Breathing Zone Monitor (right).

Both of these air samplers are designed to detect the presence of alpha emitting isotopes in air. The SabreAlert air sampler weighs 2.4 kg, and is housed in a hard plastic box (10 cm * 13 cm * 18 cm, Length*Width*Height = L*W*H). The SabreBZM air sampler weighs 1.2 kg, and is contained in a soft nylon pouch (10 cm * 13 cm * 18 cm, L*W*H) that is suitable for wearing on a person's belt. The SabreAlert operates at a nominal air sample flowrate of 6 LPM, while the SabreBZM has a nominal sampling flowrate of 3 LPM.

MATERIALS AND METHODS

A schematic of the Los Alamos aerosol test tunnel is given in Figure 2. In this paper, the wind tunnel configuration only applies to test air velocities of 0.5 m/sec. The wind tunnel was fabricated as a nuclear grade HEPA filtered ventilation system (Flanders/CSC Corporation, Bath, NC). Although the wind tunnel does not currently operate with hazardous materials, it is still able to isolate the internal test atmosphere from the laboratory room atmosphere. This wind tunnel has been in operation at the RP-2 facility since early 2005, and the design and operation is based upon performance results from a previous Los Alamos wind tunnel system (Moore and Rodgers 2005).

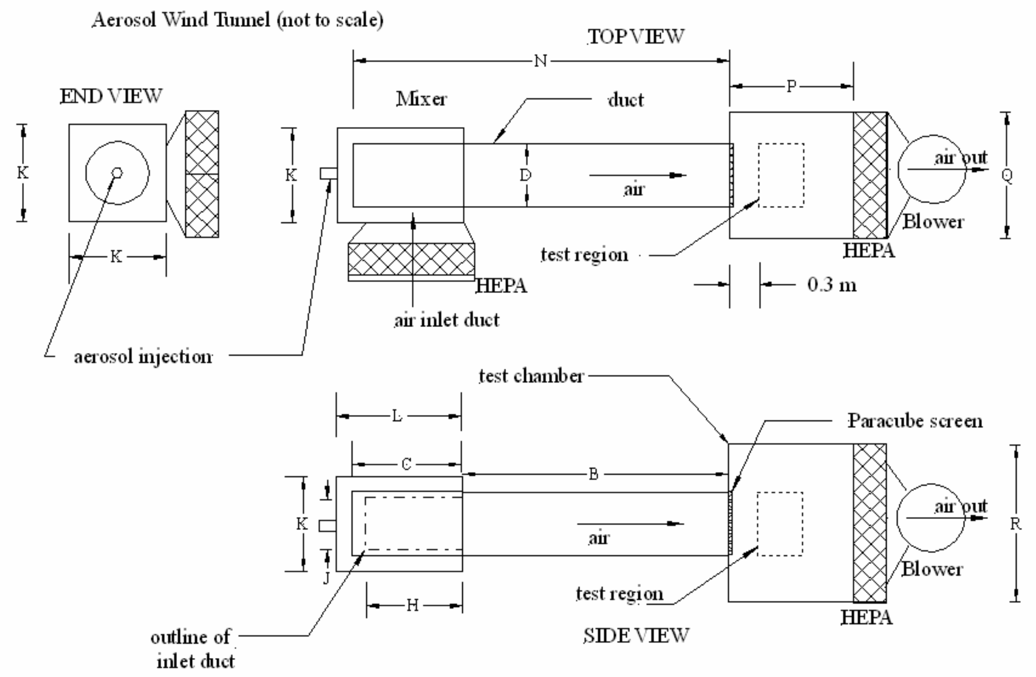


Figure 2. The Los Alamos Group RP-2 wind tunnel is able to measure the aerosol collection efficiency of air sampling devices.

Table 1. Proportions of the Los Alamos Mixer compared to the “Generic Mixer”

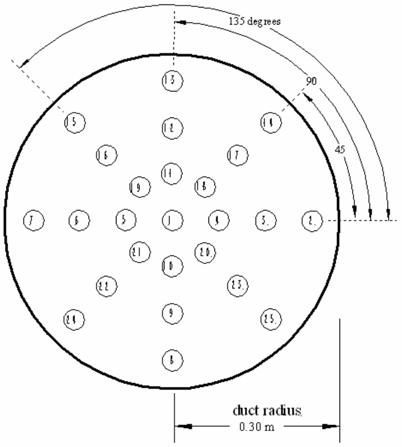
Parameter	Los Alamos Mixer	McFarland et al Generic Mixer
B	4.38D	2.5D
C	1.75D	3.0D
D	duct diameter, 0.61 m	duct diameter
G	N/A	0.17D
H	1.54D	“stack width”
J	0.83D	“stack depth”
K	1.54D	1.54D
L	(0.46D) + H	(1.83D) + H
M	N/A	0.51D
N	6.13D	N/A
P	test section length, 1.89 m	N/A
Q	test section width, 1.22 m	N/A
R	test section height, 1.52 m	N/A

The mixer section of the wind tunnel is based upon work (McFarland et al 1999) where a "generic mixer" was used to condition air flow from a building into a sampling duct placed at a right angle to the vertical exhaust duct. It should be mentioned that the configuration in this paper is slightly different from the (McFarland et al 1999) design. With reference to Table 1, there is no gap 'G' in between the 'B' and 'C' dimension, and there is also no flow element 'M'. Both of these features are in the "generic mixer", but were not present in the Los Alamos system at the time this work was performed.

In the Los Alamos wind tunnel, a plastic screen (Paracube I, American Louver Company, Skokie, IL) was installed flush to the outlet of the main flow duct, at the junction between the main flow duct and the rectangular test chamber. This extra screen was necessary to ensure uniform air velocity profiles in the wind tunnel test region. The main duct diameter (D) of the Los Alamos wind tunnel is 0.61 m, with a total duct length (N) of 3.74 m. The inside dimensions of the rectangular test chamber is 1.89 m * 1.22 m * 1.52 m (L*W*H).

Air enters into the wind tunnel through the inlet duct HEPA filter system, and then wraps around the main flow duct inside the mixer. As the air flow enters the main flow duct, it entrains the test aerosol that is being injected into the tunnel. After the air is pulled through the main flow duct into the wind tunnel test section, the air and the aerosol flow through the test section and then exit the tunnel through the second set of HEPA filters, and the air is then exhausted into the room through the blower exhaust.

The round main duct feeds into the rectangular test section. In the test section, a circular test region is defined for active testing of air sampling systems where the air velocities and test aerosol concentrations were experimentally evaluated for uniformity. The vertical plane of the test region is located 0.30 meters downstream of main duct outlet plane (this is also the location of the Paracube screen, the area of the main duct outlet plane is identical to the inside cross sectional area of the main duct). In Figure 3, twenty five measurement locations were defined for measurements with a Model 8455-03 TSI velocity probe, which sampled at 10 Hz with a sample interval of 10 seconds (or 100 data readings for each measurement location).



radius, m	Measurement index
0.00	1
0.08	4, 5, 10, 11, 18, 19, 20, 21
0.17	3, 6, 9, 12, 16, 17, 22, 23
0.25	2, 7, 8, 13, 14, 15, 24, 25

Figure 3. Velocity measurement coordinate locations for the wind tunnel test region.

In the test section, a motion control (National Instruments, Inc., Austin, TX) system was used with LabView software. An XY carriage moved the TSI velocity probe across the face of the test region (as shown in the photograph in Figure 4). The carriage was mounted on the back plane (defined by dimensions Q and R) of the test section, just upstream of the HEPA filter bank. The wind tunnel system has a structural member in between the top and bottom rows of two HEPA filters. The horizontal control carriage therefore obscured none of the flow that is not already blocked by the structural support, and the vertical motion control carriage obscures 1.7% of the total cross sectional area of the HEPA filter bank.

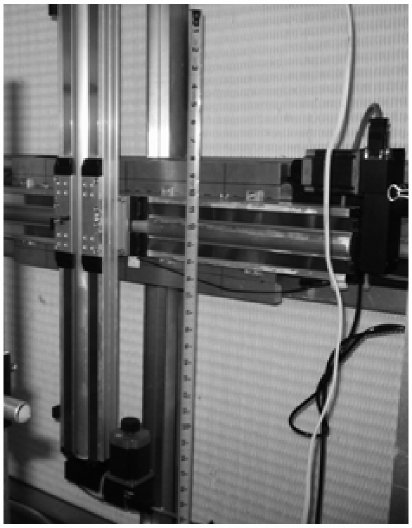


Figure 4. The motion control system in the Los Alamos wind tunnel is mounted in front of the HEPA filter bank.

For the air samplers tested in this study, the wind tunnel was operated at an average air flow velocity of 0.58±0.06 m/sec, as measured across the face of the wind tunnel test region, as shown in Figure 5. In this figure, the upper dashed line and the lower dashed line correspond to a velocity greater than and less than 10% of the mean velocity (respectively) measured at all of the 25 measurement locations. By inspection, none of the measured velocities deviate more than plus or minus 10% from the measured mean.

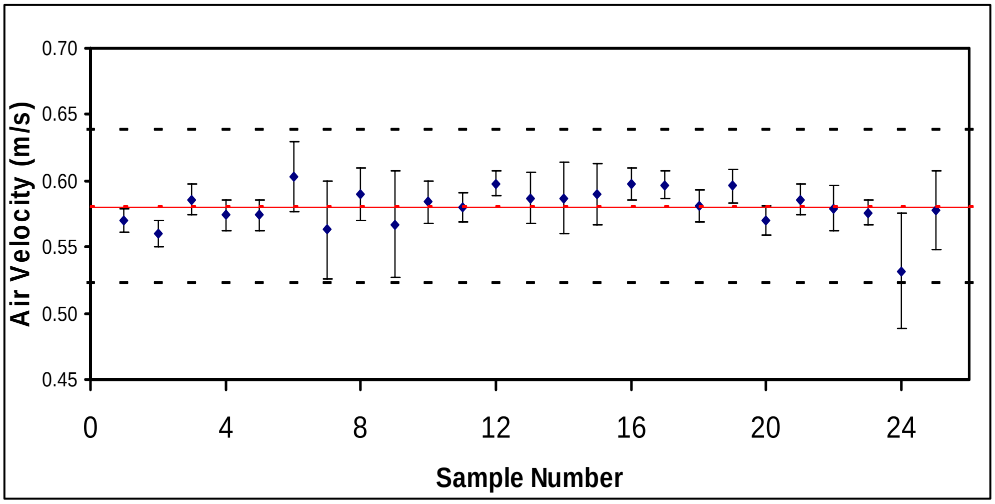


Figure 5. The mean value of a set of 25 measured air velocities is compared to an upper and lower bound of 10% of the mean of the velocities.

To measure the uniformity of the test aerosol across the face of the wind tunnel test region, five open-face filter holders (Figures 6 and 7) were mounted onto ring stands in the tunnel and were oriented to face into the oncoming airflow. As in the study detailing these open-face filter holders (Parulian et al 1996), critical flow venturis were used to control the air flow rate. The open-face filter holder (OFH) device used in this study is not currently commercially available, but was manufactured by an independent machine shop based on specifications supplied by Los Alamos National Laboratory. They are designed to provide a clamshell type closure around the (Canberra Corporation, Meriden, CT) 47 mm plastic filter holder (Figure 7). In these studies, a critical flow venturi with a nominal flow rate of 28.3 LPM was fitted downstream of the OFH.

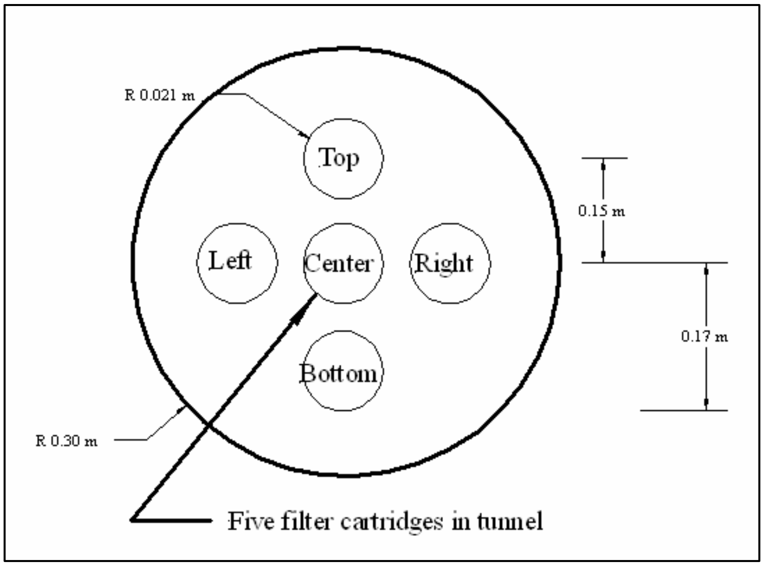


Figure 6. The filter cartridges are distributed across the test region in the wind tunnel.

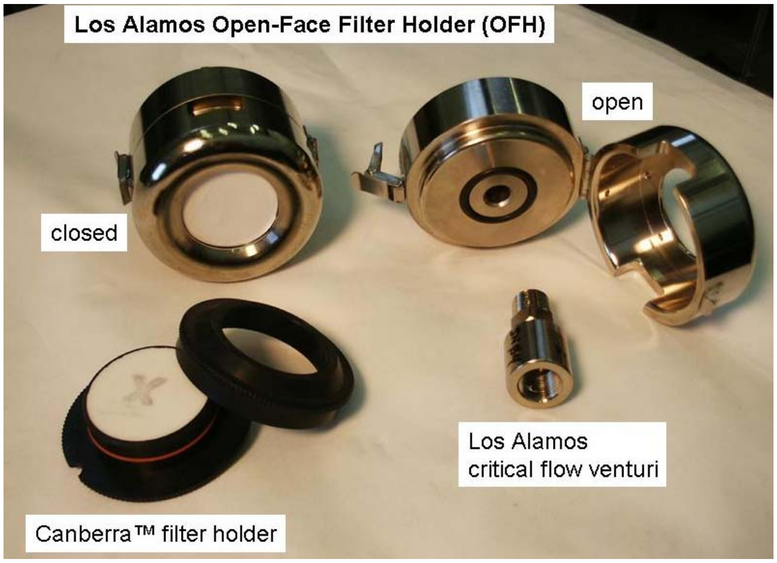


Figure 7. The Los Alamos Open-Face Filter Holder shown in both open and closed orientation. The holder is designed to be used with the Canberra 47 mm plastic filter holder. The critical flow venturi can be attached to the outlet.

Before the uniformity tests were conducted, the air flow rates were independently measured with a calibrated electronic flow meter (TSI Inc., Model 4045). In the wind tunnel test region, the five filter holders were evenly spaced in the test region, facing upstream towards the air flow. The center point of the filter holders are 0.15 meters from the center of the test region (see Figure 6). The test region itself was at a location 0.30 meters downstream from the exit plane of the main wind tunnel duct. For a filter with a 47 mm diameter, the amount of active filter exposed to the test aerosol is 42 mm diameter. The test region was therefore sampled by an array of filters that corresponds to an imaginary circle with a radius of 0.17 meters.

Figure 8 illustrates the measurements of aerosol concentration at the plane of the test region in the wind tunnel. The upper and lower bounds of the plot indicate values at plus or minus 10 percent of the average concentration of the five filters.

Figure 8. Relative aerosol concentration measured from five open face filters in the wind tunnel test region.

As seen in Figure 9, three air samplers are simultaneously placed in the wind tunnel test section: (1) the 47 mm diameter reference filter (inside the Los Alamos OFH), (2) the Bladewerx SabreAlert and (3) the Bladewerx BZM. In contrast to the reference filter, both the SaberAlert and the BZM are designed to use a 37 mm diameter filter.

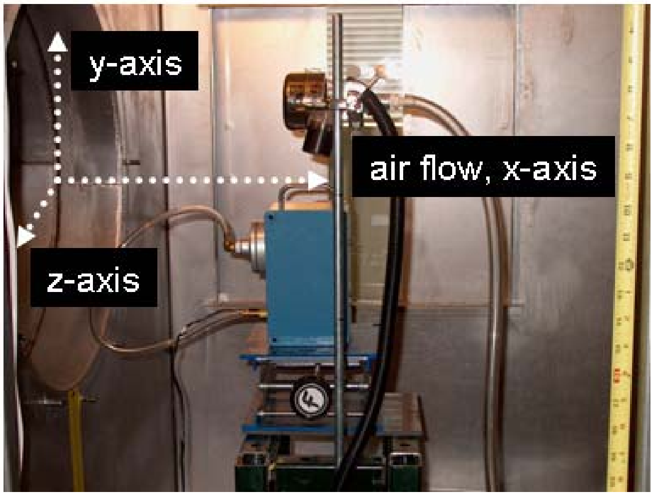


Figure 9. Three air samplers are simultaneously placed in the RP-2 wind tunnel test section for collection efficiency measurements.

The test procedure for this work is patterned after previous work (Moore and McFarland 1996) for the measurement of aerosol collection efficiencies in air sampling cyclones which uses liquid oleic acid droplets tagged with sodium fluorescein.

The sodium fluorescein compound is an ideal analytical fluorescent tracer, since it is non-toxic, it easily dissolves in water and it is detectable in a standard lab fluorometer (e.g. Turner Model 450) to levels of 20 parts per trillion.

With reference to Figure 2, test aerosol is injected at the left side of the wind tunnel, into the generic mixer. The air and the aerosol are then combined in the generic mixer, and the aerosol particles are then transported down the tunnel to the test section. In the test section, the three air samplers are situated in a vertical plane (as seen in Figure 9). The open face 47 mm filter is pointed directly into the air flow, but the SabreAlert has a tangential inlet, and its aerosol entrance is therefore facing in a normal direction to the air, and the Bladewerx BZM sampling head was clipped to a lab ring stand, and the BZM tangential inlet therefore faced directly into the air stream. The origin of the axis of the wind tunnel section is at the center point of the 0.61 meter diameter flow duct. For these tests, the three samplers were located at fixed Cartesian locations: (x,y,z), Open-Face Filter Holder (0.30, 0.05, 0.00 m), Bladewerx™ BZM (0.30, 0.05, 0.08 m) and the SabreAlert™ (0.30, 0.03, -0.10 m). Both the SabreAlert™ and the BZM were tested at the manufacturer recommended flowrates and also at a higher flowrate. Therefore, the SabreAlert was tested at 6 LPM and 45 LPM, and the BZM was tested at 2.9 LPM and 19 LPM.

When the SabreAlert and BZM samplers were tested at the low flowrates (2.9 and 6 LPM, respectively), the self-contained pumps in the respective air samplers were used. The accuracy of the 2.9 LPM and 6 LPM flowrates supplied by the pumps were confirmed in the RP-2 lab by measurement with a primary flow calibration standard (Model DC-2, BIOS International, Pompton Plains, NJ). When the SabreAlert and BZM samplers were operated at 45 and 19 LPM, respectively, the air flowrates were measured in real time by electronic mass flowmeters (TSI, Inc, St. Paul MN, Model 4045). These flowmeters were also verified to accuracy by the BIOS primary meter. The air flow through the open face 47 mm filter holder was measured in real time by a mass flowmeter (Sierra Instruments, Monterey, CA Model 730, SN 8027) that was calibrated by a volumetric gas flow meter (American Meter Co. Horsham, PA, Model AC-250).

For all of these tests, the nominal air speed in the wind tunnel was 0.5 m/sec as measured by a hot wire anemometer (TSI, Inc., Veloci-calc Model 8386A, calibrated by a primary standard pitot probe). Oleic acid aerosol was generated by a TSI Inc. vibrating orifice monodisperse aerosol generator, (VOMAG, TSI Inc. Model 3450). Measured feedstock solutions of isopropyl alcohol, oleic acid and sodium fluorescein were prepared for use in the VOMAG. A typical feedstock solution would consist of isopropyl, with a fraction of a percent (measured by volume) of oleic acid. Most of the solutions had a measured mass to volume ratio of sodium fluorescein (SFL) to oleic acid of 10 percent. However, some of the tests were run with a mass to volume ratio of 50 percent SFL to oleic acid. This 50% ratio formulation was used to generate small particles (~ 2 µm AED, aerodynamic equivalent diameter) with a higher concentration of fluorescent material.

Once a flow of test aerosol was established into the tunnel, the aerosol spectrum was measured and recorded with a TSI APS (Aerodynamic Particle Sizer). If the correct density of the aerosol particle is entered into the TSI APS software, it accurately measures the aerodynamic particle diameter of solid particles. With liquid droplets, however, the droplets are stretched and elongated in the instrument nozzle. This device does provide an excellent measure of the monodisperse nature of the aerosol, but microscopic sizing was both necessary and sufficient to measure the average AED of the oil droplets (EPA 1997).

The air samplers (reference open-face filter holder, SabreAlert, and Bladewerx BZM) were used with glass fiber filters (Fisherbrand, 0.7 µm pore, Cat. No. 09-804-142H). The air samplers were simultaneously operated in the wind tunnel facility at an air velocity of 0.5 m/sec and over a range of test AED sizes (Table 2).

Table 2. Minimum and maximum tested aerodynamic particle sizes

Sampler Airflow, LPM		Minimum AED, µm	Maximum AED, µm
BZM	3	2.3	14.5
BZM	19	2.3	17.2
SabreAlert	6	2.5	14.5
SabreAlert	45	2.3	14.5

Three replicate tests were conducted for a given air sampler flowrate and test aerosol aerodynamic particle diameter. The exposed filters from these tests were placed into pre-marked lab analysis beakers and fitted with plastic snap-top lids. Three replicate tests constituted a single "set", and generated a single data point on the graphed results. Additionally, for each "set" of tests, three blank background filters were prepared. For these background filters, the three air samplers would be opened, a clean filter would be fitted into the respective filter compartments, the air sampler would be closed or fastened, and then the sampler would be immediately opened up again. The dry "pressed" filter from each air sampler was then placed into a lab beaker. This procedure would therefore provide a quantitative measure of any fluorescent material that would possibly be transferred from one test to another through cross-contamination from the air sampler filter compartments. It should be noted that no cross contamination was ever measured.

After the test filters were placed into the lab beakers, 20 ml of purified water and 20 ml of isopropyl alcohol were added to each beaker, along with 4 to 5 drops of 0.1 M NaOH (to neutralize the solution pH and therefore stabilize the solution fluorescent response). A clean glass fiber filter was also placed in a lab beaker with the same amounts of water, isopropyl and NaOH, and this solution was used to zero the fluorometer. After a few seconds of hand-agitation of the beakers, and at least one hour of allowing the fluorescent material to be dissolved from the glass fiber filters, the liquid solutions from the beakers were sequentially poured into a glass fluorometer test cuvet. The fluorometer readings from three consecutive samples of liquid from each beaker were recorded. The relative fluorescent concentration, C, present in each measured solution was calculated by the following expression:

$$C = \frac{FL}{QT} \tag{1}$$

where: F = the fluorometer digital response.
L = the liquid volume in the respective lab beaker,
Q = the measured (actual – not standard) air sampling flowrate, and,
T = the elapsed time of the sampling test.

The fractional aerosol collection efficiency, E, is therefore:

$$E = \frac{C_{TEST} - C_{TEST-BKG}}{C_{REF} - C_{REF-BKG}} \tag{2}$$

where: C_{TEST} = the concentration from the tested air sampler,
$C_{TEST-BKG}$ = the concentration measured from the background filter that was momentarily "dry-pressed" in the sampler filter compartment,
C_{REF} = the concentration from the reference air filter, and,
$C_{REF-BKG}$ = the concentration measured from the background filter that was momentarily "dry-pressed" into the reference filter cartridge.

RESULTS

The results of the experimental tests are shown in Figure 10 and Figure 11. At a flowrate of 3 LPM, the BZM air sampler has an aerodynamic cutpoint diameter of 6.7 µm, where the sampler exhibits 50% aerosol collection efficiency. The BZM sampler has very unfavorable aerosol collection efficiency characteristics at the 19 LPM flowrate condition. The highest measured efficiency was 13.6% at 2.3 µm, and the efficiency decreased to virtually zero percent at the larger particle sizes.

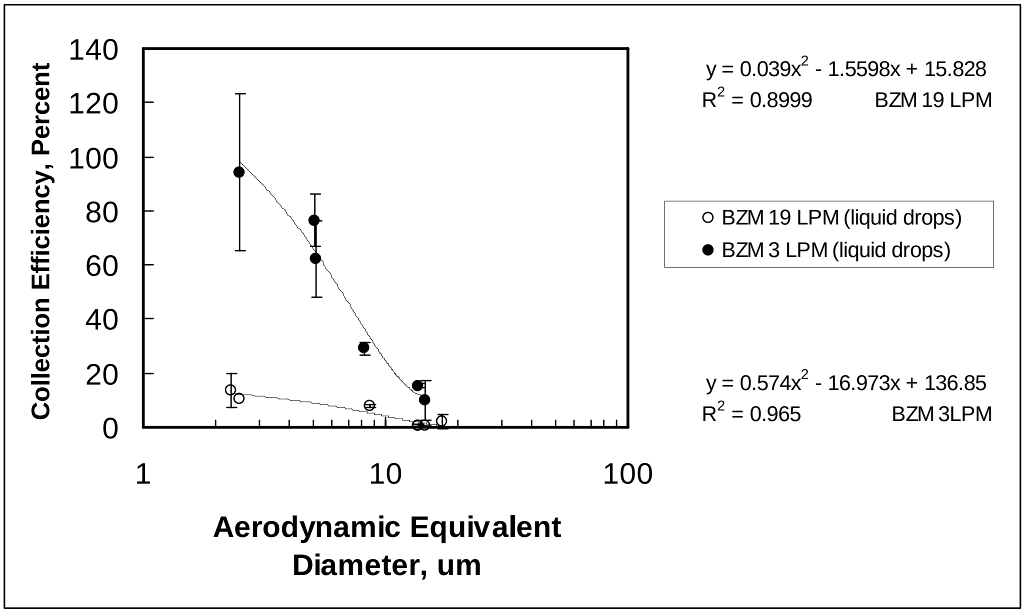


Figure 10. Results of testing the Bladewerx BZM at 3 LPM and 19 LPM (actual flowrate).

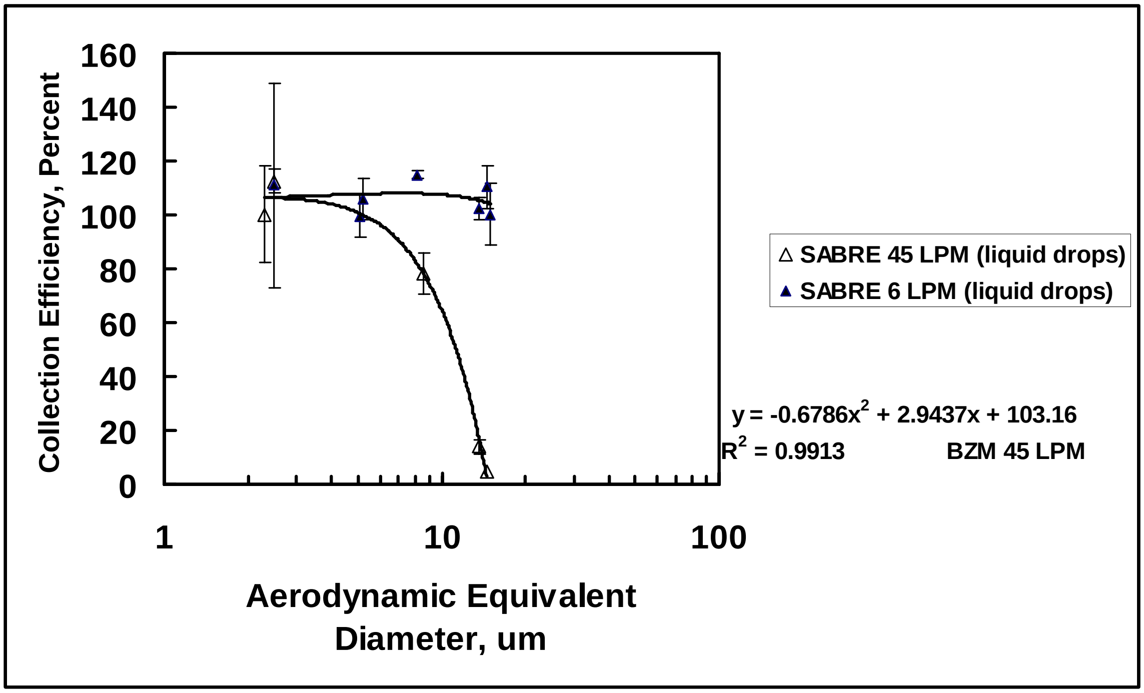


Figure 11. Results of testing the SabreAlert at 6 LPM and 45 LPM (actual flowrate).

At 6 LPM air flowrate, the SabreAlert sampler exhibits excellent particle collection efficiencies from about 2 microns up to 14.5 microns, and the measured aerosol collection efficiency ranged from about 100 to 110%. At the 45 LPM flowrate, the SabreAlert showed a characteristic air sampler response curve with an aerodynamic cutpoint diameter of about 11.3 µm, based upon a quadratic solution of the curve fit coefficients shown in Figure 11.

DISCUSSION AND CONCLUSIONS

A study of artificial radioactive aerosols in the environment (Dorrian 1997) concluded that Chernobyl fallout aerosols and radioactive particles resuspended from the ground were bimodally represented by two individual log-normal distributions of 0.6 and 6 µm AMAD (activity median aerodynamic diameter), respectively. The AMAD is the median aerodynamic diameter of a population of aerosol, such that 50% of the radioactive contribution is from sizes less than (or larger than) that median size. Based on this knowledge, the SabreAlert sampler would be suitable for sampling artificial radioactive aerosols at both of the flowrates tested in this study (6 and 45 LPM), since even for the 45 LPM case, the sampler is 50% efficient in collecting particles up to 11.3 µm AED. The Bladewerx BZM sampler at 3 LPM would be marginal in monitoring for artificial radioactive aerosols, since it would be less than 50% effective in collecting aerosol particles larger than 6.7 µm AED. At 19 LPM, it is not recommended to use the Bladewerx BZM in any situation, since it exhibited low particle collection efficiencies at all tested particle sizes.

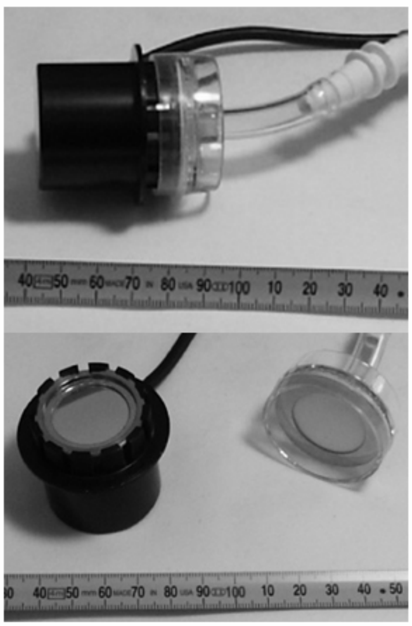


Figure 12. The Bladewerx BZM sampling head portrayed in both closed and open configurations. A flat stainless steel washer is covering a portion of the 37 mm filter. The indicated measure is in millimeters.

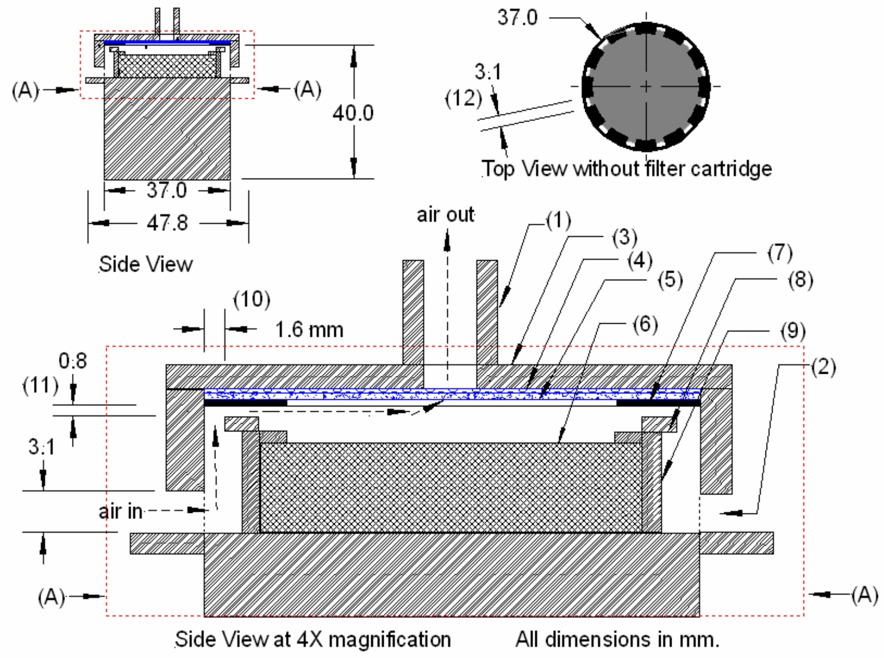


Figure 13. The Bladewerx BZM sampling head has a convoluted flow path into the filter.

Table 3: Bladewerx BZM sampling head for 37 mm filter cartridge

(1) Outlet tube for sample vacuum
(2) Air inlet into the sampling head
(3) 37 mm filter cartridge press fit onto sampling head
(4) 1.0 mm thick steel mesh screen
(5) 37 mm diameter filter media
(6) Silicon surface barrier detector (alpha)
(7) Stainless steel washer
(8) Stainless steel retainer ring
(9) Detector housing
(10) Air flow channel width (1.6 mm)
(11) Air flow channel height (0.8 mm)
(12) Air flow channel length (3.1 mm)

As seen from Figures 12 and 13 and from the information in Table 3, the Bladewerx BZM head has a complicated flow path from the ambient air into the collection filter. As seen in the photograph in Figure 12, a series of twelve raised protrusions perform several functions: (1) They provide a calibrated spacing to position the collection filter above the detector. (2) The spacings between the protrusions are the twelve channels through which the inlet air flows. (3) When the BZM head is disassembled for changing the filter, the protrusions provide a press fit surface for the 37 mm filter cartridge.

The SabreAlert exhibits a higher aerosol transmission (to the collection filter) performance than the BZM for all particle sizes tested. Since both of these samplers are manufactured and marketed by the same company, it might be possible to modify the BZM sampling head to a design more closely resembling that of the SabreAlert. This might improve the collection efficiency of the BZM sampler.

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