Evaluation of a Personal Nephelometer for Human Exposure Monitoring

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ABSTRACT

Current particulate matter (PM) exposure studies are using continuous personal nephelometers (*p*DR-1000, MIE, Inc.) to measure human exposure to PM. The personal nephelometer is a passive sampler which uses light scattering technology to measure particles ranging in size from 0.1-10 µm using a light scattering technique, however, it is more responsive to particles in the fine particle size range (0.3 – 2 µm). While the data from the nephelometer remain semi-quantitative, the instrument is very useful for identifying activities and microenvironments that may significantly enhance human exposure to PM. Based on the use of this instrument in the field, we recognize that it is important to identify activities or environments that may have an adverse effect on the instrument's response and subsequent data quality. We have tested the nephelometers response to sample vest fabric (cotton/polyester or nylon), sampler location on an individual (shoulder vs. waist), and relative humidity. Repeated scripted activities while wearing a 50-50 cotton/polyester or a nylon vest indicated that significantly more particles ($p < 0.01$) were introduced by the cotton/polyester vest than the nylon vest. The location of the monitor was weakly significantly different ($p < 0.1$) for many common activities, and significantly higher particle readings were observed at the waist ($p < 0.02$) while sweeping. After being exposed to relative humidity levels ranging from 40% to 90% at 21° C and from 40% to 60% relative humidity at 32° C, monitors equilibrated with stationary monitors within 2 to 3 minutes. Recovery took 5 to 15 minutes at relative humidity ranging from 80% to 85% at 32° C. Some monitors had problems recovering after being exposed to 90% relative humidity (32° C). Although some activities appeared to affect the response of the nephelometer, they were easily identified and the overall data quality was not likely to be compromised.

INTRODUCTION

Several EPA sponsored panel studies have recently been conducted assessing human exposure to particulate matter (PM).[1-5] Although significant difficulties have been encountered, some studies have tried to assess PM exposure in various microenvironments and activities with single 12- to 24-hr mass measurements and time activity diary data.[5-7] There is a growing scientific need for small time resolution or continuous PM data collection to adequately assess human exposure and identify important activities and microenvironments. Nephelometers have been shown to agree quite well with fine particle mass data.[5,8,9] Recently a passive personal nephelometer (pDR-1000, MIE Inc, Bedford, MA) has been developed that responds to PM (0.1 – 10 μm) and records data over intervals as small as 1 min averaging times. This monitor is lightweight and quiet, and has been used on a test basis in the 1998 Baltimore PM Exposure study and in the 1999 Fresno PM Exposure study.[4,5] It is also being used in the field as a personal monitor in the EPA sponsored 2000-2001 NERL RTP PM Exposure study.

Previous studies have shown that, while nephelometers generally agree with fine particle mass data[5,9], they are also subject to certain limitations and their response may be affected by relative humidity and liquid or semi-volatile aerosols.[8,10] A recent study of asthmatic children in California[9], found that the response of the passive pDR-1000 in the field was affected when relative humidity exceeded 85%. Hygroscopic growth of particles in humid conditions has been shown to interfere with the nephelometer response in field and laboratory studies.[11,12] Other interferences with the response of the nephelometer involve the characteristics of the particles being sampled; optimal particles are those < 2.5 μm with mass median diameters between 0.2 to 1.0 μm.[8,10] In practice, people are exposed to particles in humid environments as well as particles of varying sizes, shapes, diameters, and composition.

In order to assess the utility of the pDR-1000 passive nephelometer as a personal monitor, we have evaluated these monitors under normal atmospheric conditions and a range of particle concentrations. The focus of these experiments was to assess their utility and use in ongoing field studies. Specifically, we have examined the precision of the monitor at varying PM levels (ranging from 10 to ~ 600 μg m^{-3}), and the monitor's response to (1) sampling location on the individual (waist vs. shoulder), (2) sampling vest fabric (cotton blend vs. nylon), and (3) temperature and relative humidity. This monitor appears suitable for use as a personal monitor, but is subject to some limitations and the data should be interpreted on a semi-quantitative basis. In addition, it should be noted that, unless the nephelometer data are compared to a filter based sample, the data recovered from the nephelometers should be interpreted semi-quantitatively.

EXPERIMENTAL METHODS

The instrument evaluated was the *personal*DataRam (pDR-1000, MIE, Inc., Bedford, MA). This nephelometer is a passive, lightweight (~0.5 kg), quiet device that is generally worn at waist level in PM exposure studies.[4,5,9] Particles are detected in a sensing chamber within the instrument after illumination with near-infrared light and detection by a silicon light detector. The instrument is reported to respond to particles ranging from 0.1 μm to 10 μm in diameter, but is believed to be most sensitive to particles in the 0.3 μm to 2 μm range.[10] The mass concentration reported by the nephelometer is based on the manufacturer's calibration with SAE Fine test dust (2.5 g cm^{-3}; 2-3 μm mass median diameter; refractive index: 1.54-0*i*). According to the manufacturer, the pDR-1000's measure particle concentrations from 1 to 400,000 μg m^{-3} with a precision of ± 0.5 μg m^{-3} (or ± 0.2%) based on a one-minute averaging time.

In human exposure field studies, we have found it necessary to run these instruments for 24-hr intervals. However, as received from the manufacturer, these instruments have run times of ~19 hours using standard 9V alkaline batteries. We have modified the nephelometers to hold an additional 9V alkaline battery so that the operation time has been extended to >30 hours. All of the monitors used in these experiments and in the current NERL RTP PM Exposure study have been matched in side-by-side tests and are not statistically different ($p < 0.01$). Prior to each experiment, the nephelometers were zeroed using a particle free air generator attached to the MIE, Inc. zero air bag. This enables a constant flow of particle free air and is much easier than hand pumping the bag to zero the instruments per the manufacturer's guidelines. Scripted activities were performed that were anticipated to be similar to activities participants may do in the field. These activities included walking both inside and outside, sitting in a cafeteria, photocopying, and activities involving movement such as climbing steps, deskwork, sweeping, reaching for and lifting items, and putting on and removing the vest and leaving it nearby. We did not do activities such as cooking, as this has been examined elsewhere.[7,13,14]

RESULTS AND DISCUSSION

Instrument Precision

We have tested the precision of these instruments using collocated samples collected at varying PM concentrations. At PM concentrations ranging from ~10 to 30 μg m^{-3}, the instruments generally produced similar results (Figure 1a). At these concentrations, a difference of 2 to 6 μg m^{-3} results in a significant relative difference between the two monitors ($p < 0.01$). At higher PM concentrations (~80 to 600 μg m^{-3}), the precision was much better (Figure 1b) and similar to the manufacturer's specifications. These data indicate that the monitors respond very similarly at high PM concentrations. However, at lower PM concentrations, the monitor's response is variable and comparisons between instruments at low PM levels should be interpreted in a semi-quantitative manner.

Figure 1a. Side-by-side testing of the nephelometers at low PM concentrations. The * indicates that the monitors are significantly different at p< 0.01. Each pair of bars represents the mean ± standard deviation from a separate experiment.

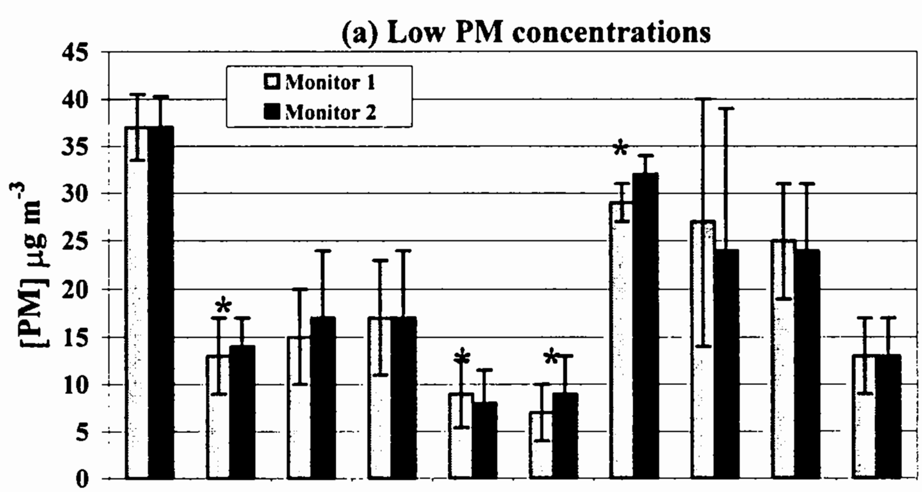
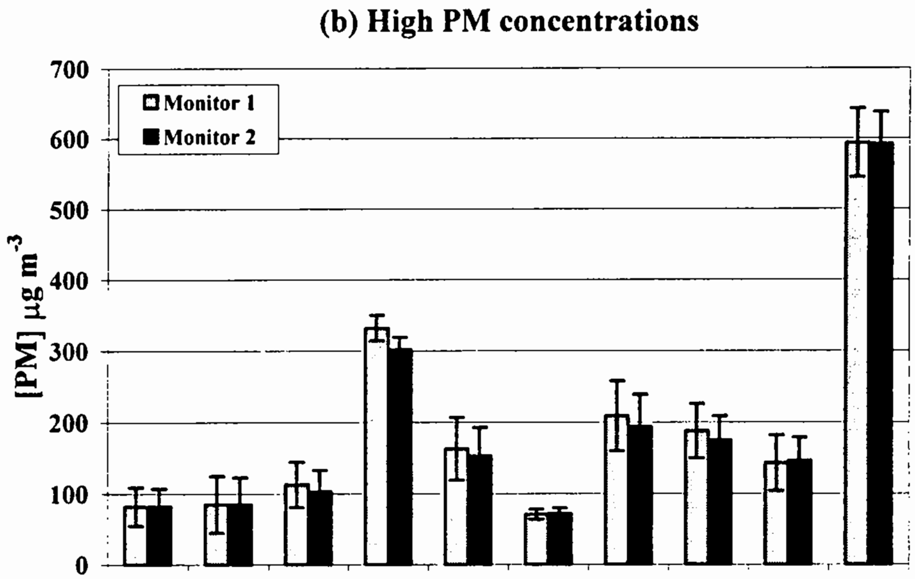


Figure 1b. Side-by-side testing of the nephelometers at high PM concentrations. (See Figure 1a).

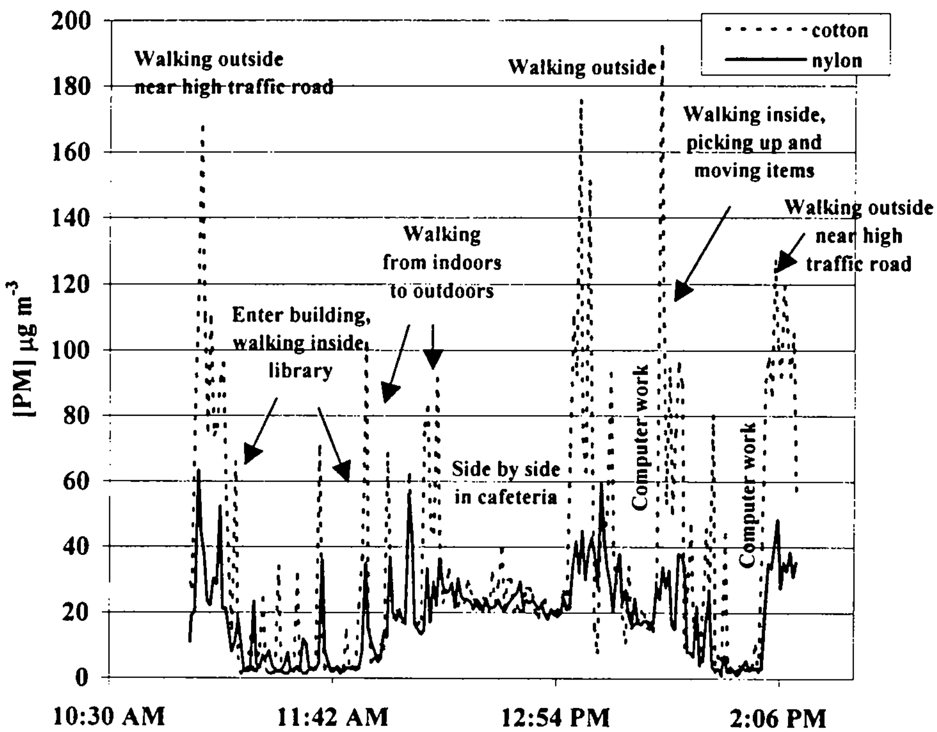


Cotton vs. Nylon Sampling Vest

Participants in human exposure studies wear a sampling vest that is designed to hold monitoring equipment. In the 1998 Baltimore PM Exposure Panel Study and the 1999 Fresno PM Exposure Panel Study, participants wore sampling vests made of a 50-50 cotton/polyester blend.[1-5] In a current EPA-funded study in the Research Triangle Park, NC area, participants are wearing vests made from nylon material. Previous studies have noted that the 'personal cloud' may be influenced by fibers being released by the clothing and sampling vest worn by a participant.[14-16] Although we have not tried to assess the personal cloud in these studies, the contribution of fibers from sampling vest material may be important.

The difference between the cotton and nylon sampling vests was examined in experiments where one person wore a cotton vest and another person wore a nylon vest. Both individuals performed the same activities simultaneously. The activities ranged from walking inside an office building, walking outside along a high traffic road, going to a library and photocopying, sitting in a cafeteria, and working on a computer or general office work. The data in Figure 2 show that during periods of movement, the monitor in the cotton vest responded significantly higher ($p < 0.01$) than the monitor in the nylon vest. Periods of low activity such as office work show little difference between either type of vest. The mean (± std. dev.) nephelometer response while wearing the cotton vest was 36 ± 41 μg m^{-3}, while the response from the nylon vest was 19 ± 15 μg m^{-3} (Figure 2). The mean percent difference between the two monitors was 58 ± 52% and was as high as 200% (153 μg m^{-3}). Repeating this experiment yielded similar results (data not shown) with differences between the two vests of 59 ± 51% (cotton: 68 ± 75 μg m^{-3}; nylon 31 ± 20 μg m^{-3}).

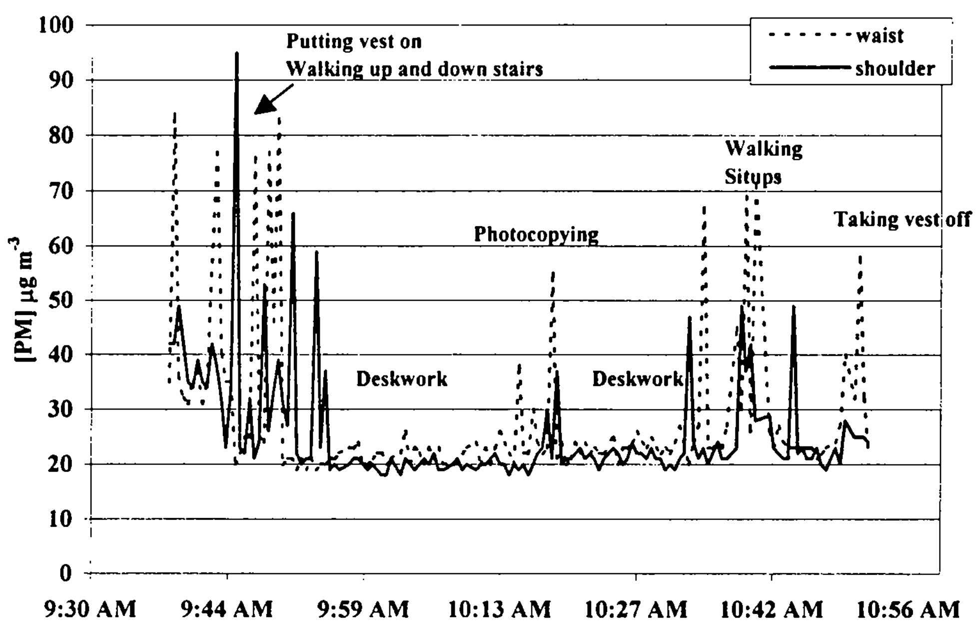
Figure 2. Nephelometer response from two individuals doing similar activities, while one wore a cotton vest and another wore a nylon vest to hold the monitor.



Location of the Monitor

The importance of the location of the monitor on the individual was examined by wearing the monitor at both the waist and shoulder level. In field studies, these monitors are generally worn at the waist due to their size, while 24-hr integrated filter-based samples (e.g., Personal Environmental Monitors; PEM®; MSP, Minneapolis, MN) are worn at shoulder height. In this experiment, two matched monitors were worn, one at shoulder level and one at waist level. The nylon sampling vests were worn and the shoulder monitor was clipped in the location that the PEM is usually placed. Two people wore the monitors this way and simultaneously went through the same activities, which included walking, stair climbing, office work, and doing sit-ups. As shown in Figure 3, the monitors indicate some variability throughout the duration of the experiment. The response for the waist monitor was 29 ± 14 μg m^{-3} and 26 ± 12 μg m^{-3} for the shoulder monitor (mean ± standard deviation). These data indicate that location of the monitor resulted in a weakly significant difference in the monitor's response ($p < 0.1$). The second individual wearing the monitor had similar results (data not shown). For the second individual, the mean ± standard deviation for the waist monitor was 30 ± 18 μg m^{-3} and 41 ± 25 μg m^{-3} for the shoulder monitor. The data from this individual showed no significant differences between monitors ($p < 0.5$).

Figure 3. Results from wearing one nephelometer at waist level and another at shoulder level while doing scripted activities.



A separate experiment was performed comparing the location of the monitor while sweeping. It was hypothesized that sweeping would generate particles that may be observed by a waist level monitor but not a shoulder level monitor. The location of the monitors was found to be significantly different ($p < 0.02$) while standing and sweeping using a large handled broom. Mean concentrations were 84 ± 10 μg m^{-3} at the waist and 63 ± 6 μg m^{-3} at the shoulder. The differences between monitors are likely due to proximity to the source. Using a dustpan and broom while crouching with the monitors at similar heights and proximity to the source resulted in no significant difference between a shoulder and waist level monitor ($p < 0.9$). The mean shoulder level concentration was 72 ± 34 μg m^{-3} and the mean waist level concentration was 68 ± 19 μg m^{-3} when the monitors were at similar heights (while crouching).

These experiments indicate that wearing the monitor at shoulder level or waist level will generally not be affected by normal activities. There will, of course, be certain activities that will result in higher exposures for a monitor worn at the waist rather than the shoulder. Activities that may impact the monitor's response include sweeping or other types of cleaning, as well as sitting down or getting up off of cushions that may have entrained dust.

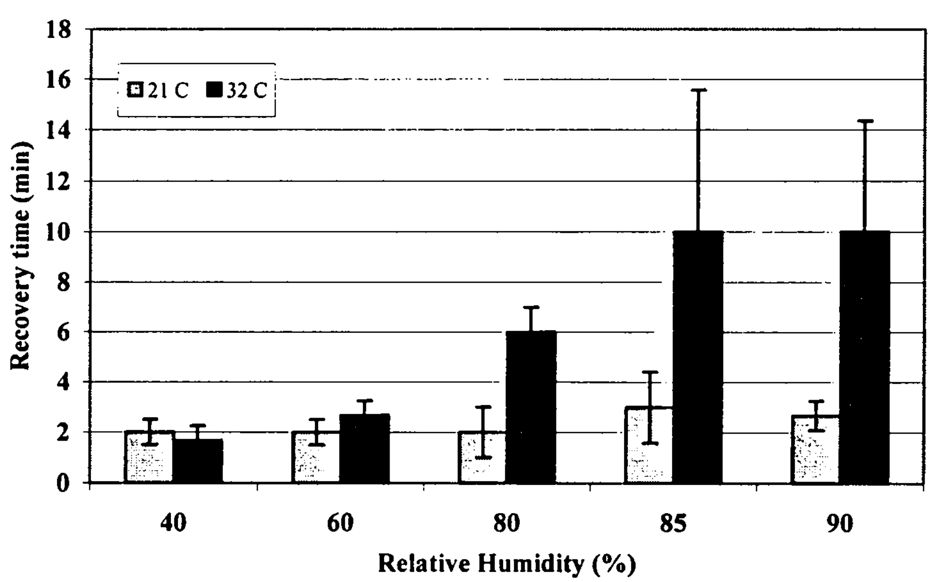
Response to Relative Humidity

The response of the nephelometer to humidity may be an important PM measurement parameter. A recent study found that when using these monitors in the field, the instrument's response is skewed high when the relative humidity was greater than 85%.[9] The effect of relative humidity on the response of the pDR-1000 may have important implications for field studies, especially when monitoring occurs in humid locations (bathroom) and/or seasons (summer).

We have tested the ability of the nephelometer to recover after being in a humid environment. In this experiment, we operated 5 matched nephelometers side-by-side in the laboratory and then placed three of the five nephelometers inside a relative humidity and temperature-controlled chamber. A polydisperse aerosol was introduced using an aerosol generator through a Collison nebulizer. The particle concentrations inside the chamber were not held constant, but fluctuated between 100 and 300 μg m^{-3}. The air inside the chamber was well mixed by circulation fans in the walls and ceiling of the chamber. Temperature was held constant at either 21° C (69.8° F) or 32° C (89.6° F) while the relative humidity was varied (40%, 60%, 80%, 85%, 90%). After running the instruments inside the chamber for 30 to 60 min, the instruments were removed and placed on a counter with the two stationary nephelometers. Recovery was determined by how quickly the monitors in the chamber returned to the levels recorded by the stationary monitors. Recovery rates from these experiments are shown in Figure 4.

At 21° C, the instruments recovered fairly quickly, usually within 2 to 3 minutes under all humidity levels. Even at the 85% and 90% humidity levels, the instruments took ~3 min to recover and did not show any signs of being impacted by the high humidity levels when the temperature was 21° C.

Figure 4. Mean (± std. dev.) recovery rates from 3 nephelometers after being removed from a chamber under high particle concentrations (100-300 μg m^{-3}) and controlled temperature and humidity levels.



At 32° C, the instruments were not affected up to 60% humidity and recovery rates were between 2 and 3 mins. However, the instrument recovery rate increased to 5 min at 80%

humidity (32° C). The instruments did not show any effects other than a longer recovery rate under these conditions. When the relative humidity was increased to 85% (32° C), the instrument recovery rate was much longer (ranging between 7 and 15 minutes) as shown in Figure 4. Most likely, the longer recovery time was due to a temperature differential in the air inside and outside the chamber. Moving the instruments from 32° C to ~25° C will slow down the evaporation of moisture condensing inside the instrument.

The instruments did not fully recover after being exposed to 90% relative humidity. While the instruments in the chamber came within the range of the stationary monitors within 10 to 15 minutes, they continued to decrease and two instruments read zero after one hour. The other chamber instrument fluctuated and was consistently 10 – 15 $\mu g\ m^{-3}$ higher than the stationary monitors. Since the instruments did not recover and were no longer comparable to their matched stationary monitors, the memory on these three monitors was reset according to the manufacturer which resets the monitor's internal calibration (MIE pDR Instruction Manual). After the resetting procedure, the instruments appeared to recover and compared well with monitors that were not inside the chamber (± 3%).

CONCLUSIONS

We evaluated the utility of a passive nephelometer for personal or stationary monitoring. We also examined the precision of the instrument at low (~10 to 30 $\mu g\ m^{-3}$) and high (~100 to 600 $\mu g\ m^{-3}$) PM levels. In addition, we determined the effects of (1) the location of the monitor on the individual (waist vs. shoulder); (2) cotton vs. nylon sampling vests; and (3) the recovery of the instruments to varying relative humidity levels. Based on our results, the MIE pDR-1000 nephelometer is a useful instrument to assess human exposure to PM, if only on a semi-quantitative level. For many daily activities, there was no difference between wearing the monitor at the waist rather than at shoulder level. Wearing the monitor at shoulder height may be cumbersome and problematic to potentially PM-susceptible populations such as the elderly. Tests have also shown that higher PM levels were encountered while wearing the cotton/polyester sampling vest than while wearing a nylon sampling vest. The additional PM from the cotton/polyester material may contribute to the personal cloud. We found that these instruments generally recovered rapidly after being exposed to less than 90% relative humidity and temperatures of 21° and 32° C.

These monitors exhibited some limitations and caution should be used when interpreting data at low PM levels and at high relative humidity (> 90%) and temperatures. The variability associated with the monitor's response to low levels of PM (< 10 μg m^{-3}) indicates that these data remain semi-quantitative. The instruments also appear to be affected by relative humidity levels >90% and high temperatures (32° C), however, the response was not impaired at relative humidity up to 90% and lower temperatures (21° C). In field studies, portable relative humidity and temperature sensors (e.g. HOBO data loggers; Onset Computer Corporation, Bourne, MA) can be attached to the nephelometer. After sampling the nephelometer data can be screened for periods when the temperature and relative humidity are elevated. Overall, these monitors appear to be quite useful for collected continuous PM data and, in unison with time activity data, can indicate microenvironments and conditions in which people are subject to elevated PM.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

REFERENCES

1. Williams, R.; Suggs, J.; Zweidinger, R.; Evans, G.; Creason, J.; Kwok, R.; Rodes, C.; Lawless, P.; Sheldon, L. 2000a. The 1998 Baltimore Particulate Matter Epidemiology-Exposure Study: Part 1-Comparison of Ambient, Residential Outdoor, Indoor, and Apartment Particulate Matter Monitoring. *J. Expos. Anal. Environ. Epidem.* In press.
2. Williams, R.; Suggs, J.; Creason, J.; Rodes, C.; Lawless, P.; Kwok, R.; Zweidinger, R.; Sheldon, L. 2000b. The 1998 Baltimore particulate matter epidemiology-exposure study: Part 2-personal exposure assessment associated with an elderly study population. *J. Expos. Anal. Eviron. Epidem.* In press.
3. Evans, G.F.; Highsmith, V.R.; Sheldon, L.S.; Suggs, J.C.; Williams, R.W.; Zweidinger, R.B.; Creason, J.P.; Walsh, D. Rodes, C.E.; Lawless, P.A. *JAWMA* In press.

4. Howard-Reed, C.; Rea, A.W.; Zufall, M.J.; Burke, J.M.; Williams, R.W.; Suggs, J.C.; Sheldon, L.S.; Walsh, D.; Kwok R. *JAWMA* 50:1125-1132.
5. Rea, A.W.; Zufall, M.J.; Williams, R.W.; Howard-Reed, C.; Sheldon, L.S. submitted
6. Sexton, K.; Spengler, J.D.; Treitman, R.D. *Atmos. Environ.* 1984, 18, 1385-1398.
7. Morandi, M.A.; Stock, T.H.; Contant, C.F. *Environ. Mon. Assess.* 1988, 10, 105-122.
8. Waggoner, A.P. and Weiss, R.E. *Atmos. Environ.* 1980, 14, 623-626.
9. Quintana, P.J.E.; Saminimi, B.S.; Kleinman, M.T.; Liu L-J.S.; Soto, K.; Warner, G.Y.; Bufalino, C.; Valencia, J.; Francis, D.; Hovell, M.H.; Delfino, R.J. *J. Expos. Anal. Environ. Epidem.* In press.
10. Lillienfeld, P. "Nephelometry, an Ideal PM2.5/10 Method?" in Particulate Matter: Health and Regulatory Issues, Proceedings of an International Specialty Conference of the A&WMA, Pittsburgh, PA, April 4-6, pp. 211-225, 1995.
11. Thomas, A. and Gebhart, J. *Atmos. Environ.* 1994, 28, 935-938.
12. Bergin, M.H.; Ogren, J.A.; Schwartz, S.E.; and McInnes, L.M. *Environ. Sci. Technol.* 1997, 31, 2878-2883.
13. Wallace, L. Indoor Particles: A Review. *JAWMA* 1996, 46, 98-126.
14. Özkaynak, H.; Xue, J.; Spengler, J.; Wallace, L.; Pellizzari, E.; Jenkins, P. *J. Expos. Anal. Environ. Epidem.* 1996, 6, 57-78.
15. Rodes, C.E.; Kamens, R.M.; and Weiner, R.W. *Indoor Air* 1991, 2, 123-145.
16. Clayton, C.A.; Perritt, R.L.; Pellizzari, E.D.; Thomas, K.W.; Whitmore, R.W. *J. Expos. Anal. Environ. Epidem.* 1993, 3, 227-250.

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16. Abstract

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