ULTRAFINE PARTICLE REFERENCES

APPLICATION NOTE ITI-065

1. K T Whitby 1978 "The Physical Characteristics of Sulfur Aerosols." *Atmospheric Environment* **12**(1978):135-159.

   A review of the physical characteristics of sulfur-containing aerosols, with respect to size distribution of the physical distribution, sulfur distributions, distribution modal characteristics, nuclei formation rates, aerosol growth characteristics, and in situ measurement, has been made. Physical size distributions can be characterized well by a trimodal model consisting of three additive log-normal distributions.

2. M D Keywood, G.P. Ayers, J.L. Gras, R.W. Gillett, D.D. Cohen "Relationships between size segregated mass concentration data and ultrafine particle number concentrations in urban area." *Atmospheric Environment* **33** (1999): 2907-2913.

   Mass concentration data derived from samples collected with a micro-orifice uniform deposit impactor (MOUDI) in six Australian urban centers during periods of significant particle loading have been used to investigate the relationships between TSP, PM_{10}, $PM_{2.5}$, PM_1 and ultrafine particles. While PM_{10} and $PM_{2.5}$ display a clear relationship, the lack of correlation between PM_{10} and the coarse fraction of PM_{10} (PM_{10}-$PM_{2.5}$) suggests that variation in PM_{10} is dominated by variance in $PM_{2.5}$. Given that particles of less than 2.5 um are suspected to have adverse health effects, increasing the extent of $PM_{2.5}$ monitoring may improve detection of relationships between air pollution and human health. A lack of correlation between both PM_{10} and $PM_{2.5}$ with ultrafine mass concentrations indicates that PM_{10} and $PM_{2.5}$ cannot be used as a surrogate for ultrafine mass concentration. Similarly, ultrafine number concentrations cannot be inferred from mass concentration information determined by the MOUDI.

3. Sverre Vedal "Ambient Particles and Health: Lines that Divide." *Journal of Air & Waste Management Association* **47**(1997):551-581.

   Increases in ambient particle concentrations are associated with an array of adverse health outcomes. These outcome range from the least adverse, such as increases in symptoms of respiratory irritation and small decreases in level of lung function, to the most adverse, mortality. Because the vast majority of the data supporting the association is generated by observational studies, there has been legitimate concern that the association may not reflect a causal association. Arguments against the association being causal have been based on some of the following: use of inappropriate statistical methodology, inability to account for other factors (e.g., meteorology, co-pollutants, or other time-varying factors) that may result in the observation of spurious associations, and lack of biological plausibility. Arguably the most significant criticism, lack of biological plausibility, was shored up by observations that the associations between particle concentration and ill health

were present at concentrations measurable in almost any urban area, and that there was little evidence that a lower threshold concentration existed below which no association was observable.

4. Gunter Oberdorster, Robert M. Gelein, Juraj Ferin, Bernard Weiss "Association of Particulate Air Pollution and Acute Morbidity: Involvement of Ultrafine Particles?" *Inhalation Toxicology* (1995) **7**:111-124.

   Recent epidemiological studies show an association between particulate air pollution and acute mortality and morbidity down to ambient particle concentrations below 10 ug/m^3. Whether this association also implies a causality between acute health effects and particle exposure at these low levels is unclear at this time; no mechanism is known that would explain such dramatic effects of low ambient particle concentrations. Based on results of our past and most recent inhalation studies with ultrafine particles in rats, we propose that such particles, that is, particles below ~50nm in diameter, may contribute to the observed increased mortality and morbidity. In the past we demonstrated that inhalation of highly insoluble particles of low intrinsic toxicity, such as Ti02, results in significantly increased pulmonary inflammatory responses when their size is in the ultrafine particle range, ~20 nm in diameter. However, these effects were not of an acute nature and occurred only after prolonged inhalation exposure of the aggregated ultrafine particles at concentrations in the milligrams per cubic meter range. In contrast, in the course of our most recent studies with thermodegradation products of polytetrafluoroethylene (PTFE) we found that freshly generated PTFE fumes containing single ultrafine particles (median diameter 26 nm) were highly toxic to rats at inhaled concentrations of 0.7-1.0 $\times$ 10^6 particles/cm^3, resulting in acute hemorrhagic pulmonary inflammation and death after 10-30 min of exposure. We also found that work performance of the rats in a running wheel was severely affected by PTFE fume exposure. These results confirm reports from other laboratories of the highly toxic nature of PTFE fumes, which cannot be attributed to gas-phase components of these fumes such as HF, carbonylfluoride, or perfluoroisobutylene, or to reactive radicals. The calculated mass concentration of the inhaled ultrafine PTFE particles in our studies was less than 60 ug/m^3, a very low value to cause mortality in healthy rats. Aging of the fumes with concomitant aggregation of the ultrafine particles significantly decreases their toxicity. Since ultrafine particles are always present in the urban atmosphere, we suggest that they play a role in causing acute lung injury in sensitive parts of the population.

5. C M Castellani "Characterization of the atmospheric aerosol in an urban area and the vicinity of a main highway. In ENEA Environment Department meetings and seminars held in Bologna and Rome." INTO **7**(1993): 35-55.

6. Annette Peters, Thomas Tuch, Peter Brand, Joachim Heyder, H.-Erich Wichmann "Size distribution of ambient particles and its relevance to human health." *Proceedings of the Second Colloquium on Particulate Air Pollution and Human Health*. 1-3 May, 1996. Ed. Jeffrey Lee and Robert Phalent, Park City, Utah. Pages 406-412.

   On 145 days during the winter season 1991/92, mean size distributions of ambient particles in the range 0.01–2.5 um were determined with a differential mobility analyzer and an optical particle counter in Erfurt, a town in East Germany. During this period 79% of the particles were smaller than 0.1 um in diameter. The corresponding mean mass concentrations were calculated assuming an average particle density of 1.5 g cm^3. 82% of the mass concentration were associated with particles in the size range 0.1–0.5 um. Since the variation of particle number concentration was not highly correlated with the variation of particle mass concentration (r=0.51), these values were compared with daily mean expiratory peak flow rates of 27 non-smoking asthmatic residents of Erfurt. Elevated particle number concentration were closer associated with decreases in expiratory peak flow rate than elevated particle mass concentration. Thus, the ultra-fine particles may indeed play a role in air pollution-induced alterations of respiratory lung function.

7. M Jamriska and L Morawska "The effect of ventilation and filtration on Reduction of Indoor Air Exposure to Submicron Pollutant Particles - Case Study" *Proceedings of the 7th International Conference on Indoor Air and Climate*. 21-26 May, 1996. Nagoya, Japan. Pages 753-758.

   The issues of exposure to airborne pollutants and the health hazard associated with air quality are well recognised. Increasing attention is given to fine particulate contaminants in the submicron size range. Exposure to indoor pollutants could thus be significant as people spend up to 90% of their time indoors. There is so far no clear understanding of the indoor-outdoor air relationship in terms of airborne particulates, sources of pollutant particles and their significance as related to the exposure and health risk. This paper presents results of a case study in an office building focusing on the

relationship between outdoor-indoor air and investigating the effect of filtration and ventilation on indoor airborne particle characteristics.

8. Gunter Oberdorster "Effects of Ultrafine Particles in the lung and Potential Relevance to Environmental Particles." Aerosol Inhalation: Recent Research Frontiers. *Proceedings of the International Workshop on Aerosol Inhalation, Lung Transport, Deposition and the Relation to the Environment: recent research frontiers*. September 14-16, 1995. Warsaw, Poland. Pages 165-173.

   A number of epidemiological studies has been published over the past five years which reported an association between low ambient particle concentration (<100 ug/m^3) and acute morbidity and even mortality in the elderly. Since larger particles above ~ 0.3 um cannot explain such dramatic effects we hypothesize that ultrafine particles (<50 nm) present in the urban atmosphere at high number concentrations may be causally involved. We have evaluated this hypothesis by using model ultrafine particles of Teflon fume with diameters of 10–26 nm. These particles when inhaled by rats proved to be extremely toxic, leading to severe hemorrhagic pulmonary edema and even death at short-exposure durations (10–30 minutes) and particle number concentration of $1^{-5} \times 10^5$ particles/cm^3. The respective calculated mass concentrations are in the range of 30-60 ug/m^3. We conclude that certain ultrafine particles when inhaled as single particles can be highly toxic and that there is a need to study more closely environmentally occurring ultrafine particles.

9. Richard Fogarty "Solving IAQ Problems Through Real-Time tracking of Ultra-Fines." *Presentation at the annual ASHRAE Conference*. January, 1998. San Francisco, California.

10. Agarwal, J.K. and Sem, G.J., 1980, Continuous Flow, Single_Particle Counting Condensation Nucleus Counter, *Journal of Aerosol Science*, vol. **20**: p. 343.

11. Aitken, J., 1888, "On the Number of Dust Particles in the Atmosphere" *Proceedings Royal Society Edinburgh*, vol. **18**, p. 135.

12. Nelson, Peter A., 1999, "Ultrafine Particles: A New IAQ Metric?" *Invironment Professional*, Vol.**5**:8, p. 4

13. Stone, Vicki; Donaldson, Ken, 1998, " Small particles - Big problem" *The Aerosol Society Newsletter* No. **33**, September 1998

14. Nelson, P., Keady, P. and Halvorsen, T. "A New Method for Tracking Indoor Air Pollution Sources" *Proceedings of the 1999 Asia-Pacific Conference on the Built Environment*. November 29-December 2, 1999. Taipei, Taiwan. pp. F1-1 to F1-6.

    A new method and instrument for identifying indoor air pollutants is described. The method is an iterative process of identifying and remediating the sources of ultrafine particles. The instrument is an ultrafine particle counter. An ultrafine particle (UFP) is defined as having diameter less than 0.1 micrometer. Recent aerosol research has suggested a causal link exists between ultrafine particles and health effects but the physiology is not yet fully understood. Even though the science surrounding this technique is evolving, some indoor air quality (IAQ) practitioners are using this method to eliminate IAQ problems.

15. Nelson, Peter A. "Ultrafine Particles: a New IAQ Consideration" *Proceedings of the 1999 Fall Topical Conference sponsored by the American Filtration & Separations Society*. October 20-21, 1999. Minneapolis, MN. pp. 221-227.

    Ultrafine particles have been a known component of outdoor air pollution for many years. In recent years, these ultrafine particles have been receiving increased attention by researchers. Ultrafine particles are defined as having a diameter less than 0.1 micrometer. These very small particles represent very low mass concentration but very high number concentration. New research suggests that these minute particles may be highly potent and a causal link to adverse health effects is probable. Some IAQ consultants have found that the sources of ultrafine particles can be indoors or outdoors. Eliminating the source and/or filtering ultrafine particles from indoor air has been shown to significantly improve IAQ perceptions and eliminate IAQ complaints.

16. Hanley, J.T., Ensor, D.S., Dmith, D.D., Sparks, L.E. "Fractional Aerosol Filtration Efficiency of In-Duct Ventilation Air Cleaners", *Indoor Air 1994*, **4**: pp. 169-178.

The filtration efficiency of ventilation air cleaners is highly particle-size dependent over the 0.01 to 3 micrometer diameter size range. Current standardized test methods, which determine only overall efficiencies for ambient aerosol or other test aerosols, provide data of limited utility. Because particles in this range are respirable and can remain airborne for prolonged time periods, measurement of air cleaner fractional efficiency is required for application to indoor air quality issues. The objectives of this work have been to 1) develop a test apparatus and procedure to quantify the fractional filtration efficiency of air cleaners over the 0.01 to 3 micrometer diameter size range and 2) quantify the fractional efficiency of several in-duct air cleaners typical of those used in residential and office ventilation systems.

Results show that efficiency is highly dependent on particle size, flow rate, and dust load present on the air cleaner. A minimum in efficiency was often observed in the 0.1 to 0.5 micrometer diameter size range. The presence of a dust load frequently increased an air cleaner's efficiency; however, some air cleaners showed little change or a decrease in efficiency with dust loading. The common furnace filter had fractional efficiency values of less than 10% over much of the measurement size range.

17. Brown, S.K. "Assessment of Pollutant Emissions from Dry-Process Photocopiers", *Indoor Air 1999*, **9**: pp. 259-267.

Processes involved in pollutant emissions from a dry-process photocopier have been investigated in a controlled room dynamic environmental chamber. Volatile organic compound (VOC) emissions occurred at a constant rate dependent on copy speed. However, VOC emission rates per copy were increased by increases in chamber temperature (e.g., a 20% increase resulted from increasing temperature from 23°C to 32°C) or changing from single- to double-sided operation (40% increase). Respirable particle emissions occurred under copier-idle mode (probably from residues in the machine) as well as with copying. No significant chamber sink effects were observed for VOCs or respirable particles. Small emissions of nitrogen dioxide, ozone and formaldehyde were observed but were difficult to interpret. A procedure for assessing pollutant emissions from photocopiers is recommended.

18. Jamriska, M., Morawska, L. and Clark, B.A. "Effect of Ventilation and Filtration on Submicrometer Particles in an Indoor Environment", Indoor Air 2000, 10: pp. 19-26.

The effect of filtration and ventilation on reduction of submicrometer particle concentration indoors was investigated in an office building. The air-handling system consisting of dry media filters and an air-conditioning unit, reduced particle concentration levels by 34%. The characteristics of indoor airborne particles were dominated by, and followed the pattern of, outdoor air, with vehicle combustion aerosols as the main pollutant. The ratio indoor/outdoor particle concentration varied between 14 and 26% for different subzones. The presence of significant source of particles indoors was not observed. A simple mathematical model predicting evolution of particles indoors is presented. The model, based on a particle number balance equation, was validated with experimental data and showed very good agreement between predicted and measured parameters.

19. EPA Research Abstracts, “Health Effects and Exposure to Particulate Matter and Associated Air Pollutants”

