GRANT NUMBER 5 RO1 OH03328

Final Performance Report

NIOSH Grant 5RO1 OH03328

PERSONAL AEROSOL SAMPLER FOR OCCUPATIONAL ENVIRONMENTS

Institution:
Center for Health-Related Aerosol Studies
Department of Environmental Health
University of Cincinnati, POB 670056
3223 Eden Ave., Cincinnati, OH 45267-0056

Principal Investigator:
Sergey A. Grinshpun, Ph.D.

Co-Investigators:
Klaus Willeke, Ph.D.
Tiina Reponen, Ph.D.

Project period:
February 1, 1998 – January 31, 2002
(3 funded years and 1-year no-cost extension)

Cincinnati, Ohio
April 25, 2002

Abstract

A new concept for personal aerosol sampling was developed by Drs. Grinshpun and Willeke during the period of 1995-97. They designed a prototype sampler with a curved, porous inlet and a 25-mm collection filter directly behind the inlet. The design allowed avoiding transmission losses in the sampler and made its aspiration efficiency less sensitive to the ambient wind speed. The preliminary study demonstrated several advantageous features of the new device: the physical sampling efficiency of the device was confirmed to have low sensitivity to ambient air conditions, such as wind speed and direction; and the filter samples showed high uniformity of the particle deposits. The sampler prototype was further modified by SKC Inc. that made it commercially available in 1997 (marketed as the "Button Aerosol Sampler").

This grant was funded by NIOSH in 1998 to evaluate the performance of the new Button Aerosol Sampler in the laboratory and in the field. The primary goal was to determine whether the new concept and device can be successfully utilized for the assessment of worker exposure in occupational environments contaminated with airborne dust and microorganisms. The device was tested under various environmental conditions (including wind speed and direction) and different sampling modes. A considerable database was established for airborne particles of different concentration levels and sizes ranging from respirable particles to "very large" particles (beyond the upper limit of the inhalability convention, i.e., >100 μm). In addition to non-biological particles, the sampler was tested with viable microorganisms, including seven species of bacteria and fungi. The performance of the new sampler was compared with four other commercially available aerosol samplers designed for personal and stationary sampling.

The laboratory evaluation of the Button Personal Aerosol Sampler was conducted in three wind tunnels featuring different designs, test zone dimensions, and aerosol generation systems. One of these was a small wind tunnel built in the Aerospace Laboratory of the University of Cincinnati College of Engineering. The second was a large walk-in wind tunnel facility made available through our collaboration with the Alice Hamilton Laboratory, NIOSH-Cincinnati. The third one was a newly-designed open-area wind tunnel built in our laboratory in the Department of Environmental Health at the University of Cincinnati. The sampler was first tested while freely-suspended. Then experiments were conducted while the sampler was mounted on either a full-size manikin, a simplified torso, or a small plate. As an important outcome of this effort, a new simplified protocol was developed for testing personal aerosol samplers in small wind tunnels at relatively low operational cost. The new testing facility was built in the Department of Environmental Health at the University of Cincinnati and is now available for testing other personal aerosol samplers.

The laboratory evaluation of the Button Sampler performance and its comparison with the IOM sampler and the 37-mm closed-face cassette as well as with two bioaerosol samplers, such as the Burkard personal volumetric air sampler and the Air-O-Cell, showed that the Button Sampler is suitable and can be advantageous for measuring airborne particles and microorganisms in various environments, including workplaces.

The sampler was tested with spores of actinomycetes and other bacterial and fungal spores, as well as with vegetative cells, which are common in industrial, agricultural, and health-care environments.

The field evaluation of the Button Personal Aerosol Sampler was performed in occupational environments with different sources of airborne particles that in turn had different particle characteristics, such as the size distribution, concentration, and chemical composition. For example, the sampler was used to assess the metal exposure among abrasive blasting workers at four U.S. Air Force Bases and among workers performing active lead abatement and post-abatement cleaning in indoor environments. In environments with extremely high concentrations of very large, projected particles (beyond the inhalability convention range), the new sampler was used with an external protective screen. Overall, the field studies have shown that the Button Sampler can be successfully used in occupational environments for assessing the worker exposures.

All the work initially proposed in the grant application (Specific Aims A through G, see below) has been accomplished. None of the specific aims indicated in the grant application has been modified.

Significant Findings and Their Usefulness

This study responds to several major NIOSH needs and research priorities outlined in NORA, in particular, the development of monitoring methods and techniques for aerosol exposure assessment in occupational environments. The new personal sampling concept has been evaluated. The Button Personal Aerosol Sampler was shown to be suitable and advantageous for assessing the worker exposures in occupational environments contaminated with airborne dust as well as with particles of biological origin, such as bacteria and fungi. The ACGIH criteria for representative sampling of airborne dust particles and microorganisms and the NIOSH recommendations on current priorities in aerosol characterization have been applied. The major findings addressing each specific aim are described below.

SPECIFIC AIM A
Development of Prototypes of the New Personal Aerosol Sampler and Modification of the Dust Sampler Evaluation Facility for their Physical Evaluation (Years 1 and 2).

The experimental facility for the physical evaluation of the Button Aerosol Sampler with particles ranging from 5 to 100 µm was completed in Year 1. The prototype of the inhalable sampler, which was made available to us through SKC Inc. (Eighty Four, PA), has the following characteristics: subtended angle of 160^0, 21% porosity, and 381-µm orifice diameter. The sampler utilizes a 25-mm filter as the collector. The total screen area of the inlet is 19.6 cm^2. The existing experimental facility was modified to accommodate the sampler evaluation when it was freely-suspended as well as mounted on a full-size or simplified manikin. Special attention was given to the sampling of large particles from low-velocity flows, for which a new wind tunnel facility with several unique features was designed and built (Year 2). The method and testing facility development effort of this specific aim is summarized in the following peer-reviewed papers (copy attached, see also Publication List below):

Conventional wind tunnel: **Aizenberg, V., Grinshpun, S.A., Willeke, K., Smith, J., and Baron, P.A. (2000). Performance characteristics of the button personal inhalable aerosol sampler. *American Industrial Hygiene Association Journal*, 61: 398-404.**

Simplified torso: **Aizenberg, V., Grinshpun, S.A., Willeke, K., Smith, J., and Baron, P.A. (2000). Measurement of the sampling efficiency of personal inhalable aerosol samplers using a simplified protocol, *Journal of Aerosol Science*, 31(2):169-179.**

New wind tunnel for large particles and low-velocity airflows: **Aizenberg, V., Choe, K., Grinshpun, S.A., Willeke, K., and Baron, P.A. (2001). Evaluation of personal aerosol samplers challenged with large particles, *Journal of Aerosol Science*, 32(6):779-793.**

SPECIFIC AIM B
Modification and Improvement of Methods, Techniques and Test Facilities for Microbial Analysis of Personal Bioaerosol Samplers (Years 1 and 2).

The aerosol generation and measurement systems of the Bioaerosol Sampler Evaluation Facility were modified as was initially proposed.

To study the performance of the Button Aerosol Sampler and other samplers with respect to the total microbial enumeration, our existing experimental facility was modified accordingly (Fig. 1 in [4], see Publication List). As part of the testing for the physical performance characteristics of the samplers, the samplers were challenged with 0.44–5.10 µm PSL particles and five microorganisms of 0.84–3.07 µm diameter: *Streptomyces albus*, *Bacillus subtilis*, *Cladosporium cladosporioides*, *Penicillium brevicompactum*, and *Penicillium melinii*. A Grimm optical particle counter measured the particle concentrations upstream and downstream of each sampler and, thus, determined the physical collection efficiency of the three samplers. Acridine orange (with epifluorescent microscopy) and lactophenol cotton blue (with bright light microscopy) staining techniques were used for the microscopic enumeration of the collected spores. The experiments were conducted with the Button Sampler along with that of two commonly used impactor devices, the Burkard Personal Volumetric Air Sampler (Burkard Manufacturing, Ltd, Hertfordshire, U.K.) and the Air-O-Cell sampler (Zefon Analytical Instruments, Inc., St. Petersburg, FL).

The performance of the Button Aerosol Sampler with respect to the viable microbial enumeration was compared to that of a 37-mm cassette at a relative humidity of 30 and 85%. *Penicillium melinii* fungal spores, *Bacillus subtilis* endospores, and *Pseudomonas fluorescens* and *Serratia marcescens* vegetative cells were used. The sampling periods ranged from 2 minutes to 8 hours. A modified CAMNEA method, involving vortexing and ultrasonic filter agitation (resulting in 96-98% efficient suspension extraction), inoculation, staining, and epifluorescent microscopic counting, was developed to analyze the viable counts. The experiments were conducted in a modified bioaerosol testing facility (Fig. 1 in [5], see Publication List).

Also, the effect of saturated backup pads on the microbial stress was discussed as an option to maintain microbial viability when collecting sensitive bacteria on the filter. As a result, gelatin filters were proposed to be used with the Button Sampler for bioaerosol collection.

In summary, the work accomplished to satisfy this specific aim is presented in methodological sections of the following peer-reviewed papers (copy attached, see also Publication List below):

Methods, techniques, and experimental facility to evaluate samplers for total enumeration of spores: **Aizenberg, V., Reponen, T., Grinshpun, S.A., and Willeke, K. (2000). Performance of Air-O-Cell, Burkard, and Button Samplers for total enumeration of airborne spores, *American Industrial Hygiene Association Journal*, 61: 855-864.**

Methods, techniques, and experimental facility to evaluate samplers with viable microorganisms: **Wang Z., Reponen, T., Grinshpun, S.A., Gorny, R., and Willeke, K. (2001). Effect of sampling time and air humidity on bioefficiency of filter samplers for bioaerosol collection, *Journal of Aerosol Science*, 32: 661-674.**

SPECIFIC AIM C

Laboratory Evaluation of Physical Sampling and Collection Characteristics of the New Sampler in the Dust Evaluation Facility (Years 1 through 3).

The sampler evaluation with non-biological particles of the inhalable particle size range was mostly completed in Year 1 (see also previous progress report on the wind tunnel tests with d_p = 7, 29, and 70 µm). In Year 2, the sampler's physical collection efficiency was evaluated with smaller particles that represent respirable and thoracic size fractions. The tests were performed with PSL particles ranging from 0.3 to 5 µm as well as with airborne bacteria and fungi of the same particle size range. The physical performance characteristics of the Button Sampler, such as the collection efficiency, the uniformity of deposit, and inter-sampling variation were compared with those of the IOM sampler, the 37-mm closed-face cassette, the Air-O-Cell cassette and the Burkard personal volumetric air sampler.

The findings are summarized in the following peer-reviewed papers (copy attached, see also Publication List below):

Non-bioaerosol particles: **Aizenberg, V., Grinshpun, S.A., Willeke, K., Smith, J., and Baron, P.A. (2000). Performance characteristics of the button personal inhalable aerosol sampler. *American Industrial Hygiene Association Journal*, 61: 398-404.**

Bioaerosol particles: **Aizenberg, V., Reponen, T., Grinshpun, S.A., and Willeke, K. (2000). Performance of Air-O-Cell, Burkard, and Button Samplers for total enumeration of airborne spores, *American Industrial Hygiene Association Journal*, 61: 855-864.**

SPECIFIC AIM D
Preliminary Field Studies of the New Sampler in Environments Contaminated with Airborne Particulates (Years 1 through 3).

The preliminary field evaluation of the Button Sampler was conducted in four buildings in Cincinnati during environmental cleaning following the procedures described in our earlier paper: Hauck, B.C., Grinshpun, S.A., Reponen, A., Reponen, T., Willeke, K. and Bornschein R.L. (1997). Field Testing of New Aerosol Sampling Method with a Porous Curved Surface as Inlet, *American Industrial Hygiene Association Journal*: 58(10): 713-719.

Also, collaboration was established with the Occupational and Environmental Health Directorate of Brooks Air Force Base in Texas (see letter by E.L. Stephens of the Human System Center in our 1999 progress report) to perform a field study on the performance of the Button Personal Aerosol Sampler in occupational environments involving high-pressure abrasive blasting operations.

Several preliminary tests were conducted with the Button Sampler for air exposure measurements during abrasive blasting operations conducted in confined environments in shipyards. The tests were performed in collaboration with NIOSH and Bath Iron Works Corporation, Bath, Maine (coordinated by D.C. Sylvain and M. Keifer of NIOSH and R. Knowles of Bath Iron Works). The results were discussed at the MACOSH meeting in Baltimore, December 5-6, 2000. It was concluded that the current NIOSH/OSHA sampling methodologies do not accurately represent worker exposure to lead and other elements during abrasive blasting, while the Button Sampler may be a suitable alternative solution.

The preliminary field studies built the foundation for the full-scale evaluation of the new sampler in different occupational environments, see Specific Aim F below.

SPECIFIC AIM E
Utilization of the New Personal Sampler for Bioaerosol Sampling. Laboratory Evaluation of its Filter Collection Uniformity and Study of Bioefficiency in the Bioaerosol Sampler Evaluation Facility (Years 2 and 3).

The uniformity of microorganism collection on the Button Sampler filter was evaluated using light microscopy. The relative particle surface density (defined as a ratio of the particle surface density in a specific field to the average one on the filter of the Button Sampler) was found to range between 89 and 137%. Its variability was substantially lower than that of the Air-O-Cell and Burkard impactors. The coefficients of variation of the microscopic counts obtained at specific locations on the sampling surfaces of the three samplers were 9.5, 19, and 31 % for the Button, Air-O-Cell, and Burkard samplers, respectively (Table II in [4], see Publication List).

Thus, the Button Aerosol Sampler was found to provide a substantially higher uniformity of deposition on its collection surface (a filter) than the two impaction devices. We attribute this to the curved shape of the Button Sampler's inlet screen, which gives it relative wind insensitivity and higher collection uniformity on the filter.

The bioefficiency of the Button Sampler was studied in the Bioaerosol Sampler Evaluation Facility described in [5] (see Publication List). When sampled with the Button Sampler, *P. melinii* demonstrated consistent culturability after sampling for 30 min to 8 hours, while less than 20% of *B. subtilis* spores formed colonies after four hours of sampling. *P. fluorescence* vegetative cells collected on the Button Sampler's filter were unable to form colonies at RH=30%, but were able to recover at RH=85% if sampled for 2 to 10 min. This suggests that the sampling time and relative humidity are critical factors influencing the bioefficiency of the Button Sampler. Additional tests conducted with *S. marcescens* (another microorganism sensitive to desiccation stress) have confirmed this conclusion.

In summary, the data on the filter uniformity evaluation and the bioefficiency of the Button Sampler are presented in the following peer-reviewed papers (copy attached, see also Publication List below):

Non-viable microorganisms: **Aizenberg, V., Reponen, T., Grinshpun, S.A., and Willeke, K. (2000). Performance of Air-O-Cell, Burkard, and Button Samplers for total enumeration of airborne spores, *American Industrial Hygiene Association Journal*, 61: 855-864.**

Viable microorganisms: **Wang Z., Reponen, T., Grinshpun, S.A., Gorny, R., and Willeke, K. (2001). Effect of sampling time and air humidity on bioefficiency of filter samplers for bioaerosol collection, *Journal of Aerosol Science*, 32: 661-674.**

SPECIFIC AIM F
Field Evaluation of the New Sampler (Year 3).

The Button Personal Aerosol Sampler was tested in occupational environments featuring different sources of hazardous aerosols and different environmental conditions.

First, the sampler was used to monitor the personal exposure of workers performing abrasive blasting tasks at four US Air Force facilities. The sampler was expected to be suitable for this work environment because of its ability to successfully withstand mechanical stress, prevent very large particles from collection, and to protect the filter from overloading and shredding by rebound particles. In addition, it was shown in previous laboratory studies to adequately follow the inhalability curve. Inhalable aerosols containing cadmium, lead, chromium, and 23 other metals were investigated. Inductively coupled plasma (ICP) was used to analyze the collected samples for all 25 metals. In addition, visual absorption spectrophotometry (VAS) was used to analyze for hexavalent chromium because of the presence of strontium chromate. Samples collected by the Button Sampler yielded 8-hr TWA concentrations that were up to 250, 6, and 5 times higher than the PEL's for cadmium, lead, and hexavalent chromium, respectively. Also, the chromium results measured by ICP and VAS exceeded the strontium chromate TLV by up to 640 and 950 times, respectively. The variability of the heavy metal concentrations measured by the Button Sampler was found to be similar to that reported in other studies that used the 37-mm cassettes.

The Air Force collaborators concluded that the Button Sampler is especially suitable for monitoring various blasting operations that can lead to metal exposures (see correspondence with Maj. Ellen England and Lt. Col. Gary N. Carlton of Brooks AFB). The paper describing this field study was prepared jointly with our Air Force collaborators and published in a peer-reviewed journal ([3], see Publication List).

The sampler was also used for assessing the exposures of workers performing active lead abatement and post-abatement cleaning in indoor environments. Personal monitoring of the workers' lead exposure was performed during lead-based paint (LBP) abatement of wooden surfaces in a room-size environmental chamber. Short-term task-specific lead exposures were determined for dry scraping, dry non-HEPA machine sanding, and wet scraping. Lead exposures were also monitored for different work practices during the final cleaning work task immediately after the required 1-hour waiting period following active LBP removal. The personal monitoring of workers was performed with the Button Sampler operated at 4 Lpm and the standard closed-face 37-mm cassette at 2 Lpm. It was found that the 90% upper confidence levels of short-term worker lead exposures (measured with the Button Sampler) for all of the investigated active LBP removal methods exceeded the half-facepiece air purifying respirator protection level of 500 $\mu g/m^3$ at least by a factor of 5. The two samplers were compared by correlation analysis, which indicated up to 50% higher lead concentrations when measured using the Button Sampler as compared with that measured using the 37-mm cassette. The regression coefficients ranged from 1.08 for final wet cleaning to 1.50 for dry scraping. Microscopic analyses of the samples for all the above-mentioned work tasks showed that the sampler regression coefficients were higher for work tasks with higher percentages of large (> 20 μm) inhalable particles. Since large airborne particles may penetrate through a respirator's faceseal leak less readily than submicron particles, we concluded that the half-facepiece respirator's work protection factor is likely to be sufficient for worker's protection during majority of LBP abatement work tasks. It was also concluded that additional studies on the lead concentrations inside face masks should be performed to clarify the situation. Based on this study, we have recently prepared a manuscript (Trunov, M., Grinshpun, S.A., Willeke, K., Choe, K.T., and Friedman, W. Personal workers' lead exposure during indoor lead-based paint abatement) that is being reviewed at the US Department of Housing and Urban Development (co-sponsored study) and will soon be submitted to the *American Industrial Hygiene Association Journal.*

Human subject approval for this study has been in place throughout the entire duration of the project. All the reports submitted by the PI to the Institutional Review Board were approved. The population (gender and minority) issues of the field studies have been specified in our grant applications. No modifications occurred.

Initially, we intended to field-test the Button Sampler with aerosols typical for industrial, agricultural, and health-care environments. Most of the field evaluation work was done in industrial environments (with non-biological particles). Since NIOSH had developed special interest in testing the new sampler in abrasive blasting environments, we devoted much more time to the evaluation of the sampler in industrial environments than was initially anticipated. Since our extensive laboratory studies with biological particles typically occurring in health-care and agricultural environments allowed us to collect all the necessary information about its physical and biological efficiencies, no additional field studies were conducted in these two environments.

In summary, the field evaluation data are presented in the following peer-reviewed papers (copy attached, see also Publication List below):

Abrasive blasting workers at air force bases: **Aizenberg, V., England, E., Grinshpun, S.A., Willeke, K., and Carlton, G. (2000). Metal exposure among abrasive blasting workers at four Air Force facilities, *Applied Occupational and Environmental Hygiene*, 15(10): 766-772.**

Lead abatement workers: **Trunov, M., Grinshpun, S.A., Willeke, K., Choe, K.T., and Friedman, W. (2002). Personal workers' lead exposure during indoor lead-based paint abatement, *American Industrial Hygiene Association Journal*, currently being reviewed at US HUD.**

SPECIFIC AIM G
Modification and Improvement of the New Sampler (Year 3).

The laboratory and field studies showed that the current version of the sampler could satisfy the need of accurate and precise personal sampling in different environments. However, its operational procedure was reviewed and modified based on the data obtained in the field. This included the use of an inlet protecting screen in environments with especially high concentrations of large metal particles and chemically aggressive substances. The data also suggest that the personal sampling pump should provide higher pressure drop in those environments preventing the pump from stopping. The bioefficiency evaluation data suggest that while the total enumeration of airborne microorganisms with the Button Sampler is accurate, its application for viable microbial enumeration is limited to hardy (stress-resistant) microorganisms, such as bacterial and fungal spores, and to short sampling times. If the sampler is used for collecting viable microorganisms, water-soluble gelatin filters are preferable.

Note: Since the public attention to highly infectious airborne biological agents has increased drastically after recent bioterrorist attacks in the United States, the Button Sampler's performance was evaluated with *Bacillus subtilis* spores (often called BG spores), which have been extensively used in the DoD and other facilities as simulants of *Bacillus anthracis*. Based on our laboratory evaluation data obtained with BG spores, we believe that the Button Sampler can be successfully used for testing buildings for *anthracis* spores and other stress-resistant bacteria. The above application may be further explored and special modifications of the sampling procedure can be developed in our laboratories if NIOSH expresses an interest in funding these activities is the future.

Publication List

The following seven peer-reviewed publications have resulted from this grant:

1. **Aizenberg, V., Grinshpun, S.A., Willeke, K., Smith, J., and Baron, P.A. (2000). Performance characteristics of the button personal inhalable aerosol sampler. *American Industrial Hygiene Association Journal*, 61: 398-404.**

2. **Aizenberg, V., Grinshpun, S.A., Willeke, K., Smith, J., and Baron, P.A. (2000). Measurement of the sampling efficiency of personal inhalable aerosol samplers using a simplified protocol, *Journal of Aerosol Science*, 31(2):169-179.**

3. **Aizenberg, V., England, E., Grinshpun, S.A., Willeke, K., and Carlton, G. (2000). Metal exposure among abrasive blasting workers at four Air Force facilities, *Applied Occupational and Environmental Hygiene*, 15(10): 766-772.**

4. **Aizenberg, V., Reponen, T., Grinshpun, S.A., and Willeke, K. (2000). Performance of Air-O-Cell, Burkard, and Button Samplers for total enumeration of airborne spores, *American Industrial Hygiene Association Journal*, 61: 855-864.**

5. **Wang Z., Reponen, T., Grinshpun, S.A., Gorny, R., and Willeke, K. (2001). Effect of sampling time and air humidity on bioefficiency of filter samplers for bioaerosol collection, *Journal of Aerosol Science*, 32: 661-674.**

6. **Aizenberg, V., Choe, K., Grinshpun, S.A., Willeke, K., and Baron, P.A. (2001). Evaluation of personal aerosol samplers challenged with large particles, *Journal of Aerosol Science*, 32(6):779-793.**

7. **Trunov, M., Grinshpun, S.A., Willeke, K., Choe, K.T., and Friedman, W. (2002). Personal workers' lead exposure during indoor lead-based paint abatement, *American Industrial Hygiene Association Journal*, manuscript is currently being reviewed at US HUD.**

All seven papers acknowledge the support of NIOSH through this grant. Three co-authors, Drs. Grinshpun, Willeke, and Reponen, are the faculty investigators of this grant listed in the enclosed budget. The first authors of the above papers, Dr. Aizenberg, Ms. Wang, and Mr. Trunov, are graduate assistants, partially supported by this grant. Dr. Gorny joined our research team in May 1999 as Postdoctoral Fellow (at no cost for NIOSH, supported by another source). Dr. Friedman is a co-author from the US Department of HUD; Dr. Baron is a co-author from NIOSH-Cincinnati; Drs. England and Carlton are co-authors from the US Department of Defense (US Air Force).

In addition, our results have been presented at national and international conferences (with minimal or no support from NIOSH funds):

Grinshpun, S.A., Willeke, K., Reponen, T., Mainelis, G., Trunov, M., Trakumas, S., Aizenberg, V., and Wang, Z. (1999). Sampling of biological aerosols: particle collection efficiency and survival of viable microorganisms, *Proceedings of the First Asia Aerosol Conference* (Nagoya, Japan, July 27-29, 1999): 23-24.

Grinshpun, S.A., Reponen, T., Willeke, K., Aizenberg, V., Wang, Z., Trakumas, S., Trunov, M., and Mainelis, G. (1999). Stationary and personal monitoring of bioaerosols, *Abstracts of the Annual Meeting of the American Association for Aerosol Research* (Tacoma, Washington, U.S.A., October 11-15, 1999): 1.

Aizenberg, V., Grinshpun, S.A., Reponen, T., Willeke, K., Wang, Z. (1999). Laboratory comparison of personal samplers for enumeration of airborne spores. *American Industrial Hygiene Association Conference and Exhibition* (Toronto, Canada, June 5-11, 1999), Session 305. Note: This paper was awarded the Best Poster Award (see the Certificate attached).

Reponen, T., Grinshpun, S.A., Aizenberg, V., Wang, Z., Gorny, R., and Willeke, K., (2000) Evaluation of new personal sampler for enumerating airborne spores, IN: *Proceedings of Healthy Buildings 2000* (Ed: O. Seppänen, and J. Säteri), International Society of Indoor Air Quality and Climate, Espoo, Finland, 1: 379-380.

Grinshpun, S.A., Aizenberg, V.A., Górny, R., Mainelis, G., Trunov, M., Trakumas, S., Wang, Z., Reponen, T., and Willeke, K. (2000) Performance of samplers for particles and microorganisms in indoor environments, *Abstracts of the International Symposium on Engineering Solutions to Indoor Air Quality Problems* (Raleigh, North Carolina, U.S.A., July 17-19, 2000): 5-6.

Grinshpun, S.A., Aizenberg, V.A., Reponen, T., Wang, Z., Górny, R., and Willeke, K. (2000) Performance of the Button Aerosol Sampler for total and viable enumeration of airborne microorganisms, *Abstracts of the American Industrial Hygiene Conference and Exposition* (Orlando, Florida, U.S.A., May 19-26, 2000), #197: 41.

Grinshpun, S.A., Górny, R., Trunov, M., Trakumas, S., and Willeke, K. (2000) Sampling and analysis of airborne dust and microorganisms in occupational environments, *Abstracts of the 26th International Congress on Occupational Health* (Singapore, August 27 - September 1, 2000): 213.

Grinshpun, S.A., Reponen, T., Aizenberg, V., Wang, Z., Górny, R., and Willeke, K. (2000) Characteristics of personal aerosol samplers for airborne spores, *Abstracts of the Annual Meeting of the American Association for Aerosol Research* (St. Louis, Missouri, U.S.A., November 6-10, 2000), 268.

Reponen, T., Grinshpun, S.A., G6rny, R.L., Aizenberg, V.A., Wang, Z., and Willeke, K. (2001) Characteristics of new personal sampler for collection of airborne spores, IN: *Exposure Assessment in Epidemiology and Practice,* (Eds.: M. Hagberg, B. Knave, L. Lillienberg, and Håkan Westberg), Vetenskaplig Skriftserie, Göteborg, Sweden: 269-271.

Conclusions

Overall, we believe that all the objectives of this grant were met. All the funds budgeted for this research project have been spent accordingly. It is understood that the final invention statement and the final financial report have been sent separately by the Sponsored Program Office of the University of Cincinnati.

We enjoyed performing this study and are happy that it has resulted in so many peer-reviewed publications and conference presentations. We will seek new opportunities to further extend the scope of this research.