WORK EXPERIENCE FOR [redacted]

9/00 – present

Title:	Environmental Engineer
Location:	National Institute of Standards and Technology, Building Environment Division, Gaithersburg, MD
Supervisor:	Dr. Andrew K. Persily, Indoor Air Quality Group Leader, (301) 975-6418
Duties:	Experimental and computational investigations of air and contaminant transport in buildings. Specific research areas include indoor product emissions testing, ultrafine particles, experimental validation of CONTAM (a multizone airflow and contaminant transport model), air cleaner technologies, and intervention strategies to improve environmental conditions in residential buildings.

8/98 - 9/00

Title:	Environmental Engineer
Location:	U.S. Environmental Protection Agency, National Exposure Research Laboratory, Reston, VA
Supervisor:	Dr. Lance A. Wallace, Environmental Scientist, (703) 648-4287
Duties:	Research involving experimental measurements and models to predict human exposure to hazardous pollutants. Specific research areas included characterizing indoor sources of particulate matter, assessment of particulate matter exposure for high-risk subpopulations, residential air change rates, and exposure to methyl tertiary butyl ether while bathing with contaminated water.

8/93 – 7/98

Title:	Research Assistant
Location:	The University of Texas at Austin, Austin, TX
Supervisor:	Dr. Richard L. Corsi, Associate Professor, (512) 471-3611, (512) 475-8617
Duties:	Indoor air quality project funded by the U.S. EPA to determine the rate of mass transfer of volatile contaminants from household tap water to the surrounding air. Project included experimental and computational investigations of chemical volatilization from kitchen sinks, showers, bathtubs, dishwashers, and washing machines. Two-phase mass balance models were used to predict mass transfer coefficients for a wide range of experimental chemicals. Results can be used to predict human exposure to drinking water contaminants.

5/93 - 8/93

Title:	Environmental Technician I
Location:	SCA Environmental, Inc., Berkeley, CA
Supervisor:	Glenn Cass, P.E.,C.I.H., I.N.C.E Vice President of Engineering, (510) 848-0390 Ext. 223
Duties:	Completed multiple surveys of municipal buildings diagnosed as "sick" and/or with high potential for spreading airborne diseases. Surveys included SF_6 monitoring of air exchange rates, using a Bruel &Kjaer Multi-Gas Monitor to sample for CO_2, CO, HCOH, and total organic compounds, collecting psychron relative humidity and temperature data, and examining building HVAC systems.

EXAMPLES OF RELEVANT PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS

- [redacted], C., Henzel, V., Nabinger, S., and Persily, A. (2008) "Development of a Field Test Method to Evaluate Gaseous Air Cleaner Performance in a Multizone Building," *Journal of the Air & Waste Management Association.*
- [redacted], Polidoro, B.J. (2006) "Database Tools for Modeling Emissions and Control of Air Pollutants from Consumer Products, Cooking, and Combustion," *NISTIR 7364,* National Institute of Standards and Technology.
- Emmerich, S.J., [redacted] C., Gupte, A.(2005) "Modeling the IAQ Impact of HHI Interventions in Inner-city Housing," *NISTIR 7212,* National Institute of Standards and Technology.
- Wallace, L.A., Emmerich, S.J., [redacted] (2004) "Source Strengths of Ultrafine and Fine Particles Due to Cooking with a Gas Stove," *Environmental Science & Technology,* **38**(8), 2304 - 2311.
- [redacted] Wallace, L., Emmerich, S.J. (2003). "Effect of ventilation systems and air filters on decay rates for indoor sources of particles measured in an occupied townhouse," *Atmospheric Environment,* **37**: 5295 – 5306.
- [redacted], Wallace, L., Emmerich, S.J. (2003). "Deposition rates of fine and coarse particles in residential buildings: Literature review and measurements in an occupied townhouse," *NISTIR 7068,* National Institute of Standards and Technology.
- Wallace, L.A., [redacted], Emmerich, S.J. (2002) "Continuous monitoring of particles in an occupied home for the year 2000," *Journal of the Air and Waste Management Association,* **52**: 828 – 844.
- Rea, A.W., Zufall, M.J., Williams, R.W., [redacted], and Sheldon, L. (2001). "The influence of human activity patterns on personal PM exposure: A comparative analysis of filter-based and continuous particle measurements," *Journal of the Air and Waste Management Association,* **51**, 1271 – 1279.
- [redacted] Rea, A., Zufall, M., Burke, J., Williams, R., Suggs, J., Walsh, D., Kwok, R., Sheldon, L. (2000). "Use of a continuous nephelometer to measure personal exposure to particles during the U.S. EPA Baltimore and Fresno panel studies," *Journal of the Air and Waste Management Association,* **50**, 1125 - 1132.

CONFERENCE PAPERS AND PRESENTATIONS

- [redacted] Little, J., Marand, E., Cox, S., Nabinger, S., and Persily, A. "Improving the Reliability of VOC Emissions Testing of Building Products," *ASHRAE IAQ 2007: Healthy and Sustainable Buildings Conference Proceedings,* October 2007.
- Wang, F., Wallace, L.A., and [redacted] "Measurement of Ultrafine Particles Generated by Indoor Combustion and Electric Appliances," *26th Annual American Association for Aerosol Research,* September 2007.
- [redacted], Emmerich, S.J. "Ranking Interventions to Improve Inner-city Housing Indoor Air Quality," *Annual Conference of the Air & Waste Management Association,* June 2005.
- [redacted] "Predicting Air Cleaner Performance in Real Environments," *United Technologies Research Center IEQ Workshop,* Hartford, CN, June 2004.
- [redacted], Wallace, L.A., and Emmerich, S.J. "Determination of particle deposition rates for cooking and other indoor sources," *19th Annual American Association for Aerosol Research,* St. Louis, MO, November 2000.
- [redacted], and Wallace, L.A. "Continuous Measurement of Particles (0.01 μm to 20 μm) in an Occupied Home," *18th Annual American Association for Aerosol Research,* Tacoma, Washington, October 1999.

[redacted]
[redacted] phon[redacted], fax [redacted]

PROFESSIONAL PROFILE

More than 25 years experience conducting research on indoor environments, specializing in building energy efficiency, building envelope performance, ventilation and HVAC system assessment, indoor air quality monitoring, and airflow and contaminant dispersal modeling.

International reputation as researcher and leader in the field of ventilation and indoor air quality based on publication record, standards writing experience, and other professional activities.

Ten years as leader of ventilation and indoor air quality research group involving program management, staff development, and raising research funds of roughly $1 million per year.

EXPERIENCE

Building and Fire Research Laboratory, National Institute of Standards and Technology
GROUP LEADER, Indoor Air Quality and Ventilation Group, 1990-present.

Supervise group conducting research on ventilation and indoor air quality in homes and large buildings involving field measurement of contaminant levels and ventilation performance, and development and application of computer models of building airflow and contaminant dispersal.

Pursue individual research interests including analyses of indoor carbon dioxide as an indicator of ventilation and indoor air quality, mechanical ventilation strategies for residential buildings, and tracer gas methods for evaluating building ventilation performance.

Obtain funding from within NIST, and from other federal agencies and outside organizations to support staff of six engineers, one technician and one secretary.

Assume various administrative roles within NIST, including serving on Institutional Review Board tasked with evaluation of research involving human subjects.

Center for Building Technology, National Institute of Standards and Technology
MECHANICAL ENGINEER, Indoor Air Quality and Ventilation Group, 1983-1990.

Conducted research on ventilation and air quality in homes and large buildings involving the development and maintenance of instrumentation, the design and performance of experiments, the analysis of experimental results, and the preparation of reports on research results.

Developed measurement methods for assessing building airtightness and ventilation performance, and for studying pollutant levels in large office buildings as a function of ventilation rate and system operation; applied multizone modeling methods to understand dynamics of airflow and pollutant transport in mechanically ventilated office buildings.

Fulfilled role of project leader by obtaining funding, interacting with outside funding agencies, and supervising staff.

Center for Building Technology, National Bureau of Standards
NATIONAL RESEARCH COUNCIL POSTDOCTORAL ASSOCIATE, 1982-1983.

Conducted independent research on airtightness measurement and analysis in buildings.

Participated in ongoing NBS research programs involving the development and demonstration of measurement techniques to assess thermal envelopes of office buildings.

Center for Energy and Environmental Studies, Princeton University
RESEARCH ASSISTANT, 1977-1982.

Conducted independent research project on air infiltration and associated heat loss in homes directed towards doctoral thesis.

Participated in larger research effort on energy conservation in existing buildings.

FACULY APPOINTMENT

Adjunct Faculty Member, Mechanical Engineering, Professional Masters Program
University of Maryland, College Park, Maryland, 1997-present.
Developed and taught class on Indoor Air Quality Engineering.

EDUCATION

Ph.D., Princeton University, 1982, Mechanical and Aerospace Engineering.
Dissertation Topic: Air Infiltration and Heat Loss in Buildings.

M.A., Princeton University, 1979, Mechanical and Aerospace Engineering.
Concentrations: Applied mathematics, Fluid mechanics, Combustion, Control theory.

B.A., Magna cum laude, 1976, Beloit College.
Majors: Physics, Mathematics, Elementary teaching certification.

PROFESSIONAL ACTIVITIES

Past Chair, ASHRAE SSPC62.1, Revision of ventilation standard for indoor air quality.

Chair, ASHRAE Conference IAQ and Energy 98; editor of conference proceedings.

Past Chair, ASHRAE Environmental Health Committee.

Past Chair, ASHRAE Technical Committee 4.3, Ventilation Requirements and Infiltration.

Past Chair, ASHRAE Technical Committee 4.3 Handbook Subcommittee, primary author of Chapter 22 of the 1989 ASHRAE Handbook of Fundamentals.

Past Chair, ASTM Subcommittee E6.41 Infiltration and Ventilation Performance.

Vice-chair, ASTM Subcommittee D22.05 Indoor Air Quality.

Co-chair, ASTM Symposium on Airflow Performance of Building Envelopes, Components, and Systems, co-editor of conference proceedings.

Member of AAAS, ASHRAE, ASTM and ISIAQ.

EXAMPLES OF RELEVANT PUBLICATIONS

Peer-reviewed Journals and Book Sections

[redacted] 2004. Building Ventilation and Pressurization as a Security Tool. ASHRAE Journal, 46 (9): 18-21.

[redacted] 1997. "Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide." ASHRAE Transactions 103.

[redacted], W.S. Dols, S.J. Nabinger. 1994. "Air Change Effectiveness Measurements in Two Modern Office Buildings." Indoor Air 4.

[redacted]. 1993. "Modeling Radon Transport in Multistory Residential Buildings." Modeling of Indoor Air Quality and Exposure, ASTM STP 1205. ed. Niren L. Nagda, American Society for Testing and Materials.

[redacted], J.W. Axley. 1990. "Measuring Airflow Rates with Pulse Tracer Techniques." Air Change Rate and Airtightness in Buildings, ASTM STP 1067. ed. M.H. Sherman, American Society for Testing and Materials.

Lagus, P., [redacted] 1985. "A Review of Tracer-Gas Techniques for Measuring Airflows in Buildings." ASHRAE Transactions 91.

[redacted]., G.T. Linteris. 1983. "A Comparison of Measured and Predicted Infiltration Rates." ASHRAE Transactions 89.

Reviewed Conference Proceedings, Publications and Reports

[redacted]., S.R. Martin. 2000. A Modeling Study of Ventilation in Manufactured Houses. National Institute of Standards and Technology, NISTIR 6455.

[redacted] 1998. A Modeling Study of Ventilation, IAQ and Energy Impacts of Residential Mechanical Ventilation. National Institute of Standards and Technology, NISTIR 6162.

[redacted] 1996. Carbon Monoxide Dispersion in Residential Buildings: Literature Review and Technical Analysis. National Institute of Standards and Technology, NISTIR 5906.

Emmerich, S.J., [redacted]. 1996. Multizone Modeling of Three Residential Indoor Air Quality Control Options. National Institute of Standards and Technology, NISTIR 5801.

Nabinger, S.J.,[redacted] K.S. Sharpless, S.A. Wise. 1995. Measurements of Indoor Pollutant Emissions from EPA Phase II Wood Stoves. National Institute of Standards and Technology, NISTIR 5575.

Fang, J.B., [redacted]. 1995. Computer Simulations of Airflow and Radon Transport in Four Large Buildings. National Institute of Standards and Technology, NISTIR 5611.

Emmerich, S.J., [redacted] 1995. Indoor Air Quality Impacts of Residential HVAC Systems Phase II.B Report: IAQ Control Retrofit Simulations and Analysis. National Institute of Standards and Technology, NISTIR 5712.

Fang, J.B., [redacted] 1994. CONTAM88 Building Input Files for Multi-Zone Airflow and Contaminant Dispersal Modeling. National Institute of Standards and Technology, NISTIR 5440.

[redacted]
[redacted] phone ([redacted]; fax [redacted]

PROFESSIONAL PROFILE

27 years experience at the U.S. Environmental Protection Agency conducting research on personal exposure. Conceived and implemented the EPA TEAM Studies of human exposure to VOCs, CO, pesticides, and inhalable particles. Received a number of awards from the EPA for these and other studies carried out during his career with the Agency. Spent two years as a Visiting Scholar at Harvard University, and has served as an advisor to a number of doctoral students at Harvard, Johns Hopkins, and the University of Washington. Published 80 articles in peer-reviewed journals, one book and 15 book chapters, and more than 100 research reports and presentations at conferences.

International reputation as researcher and manager of many multimillion-dollar research projects.

Charter member of two international organizations: International Society of Exposure Analysis (ISEA) and International Scientific Institute of Indoor Air Quality (ISIAQ).

EXPERIENCE

Project manager of multiple research projects at EPA on personal exposure to VOCs, CO, pesticides, and particles. These involved conceiving the approach, obtaining funding, selecting contractors, overseeing development of personal air quality monitors and breath sampling systems, assisting in study design, data analysis and writing the final journal articles.

Other projects on breath analysis (VOCs and CO). Developed mathematical 4-compartment model and tested it in chamber studies on 9 VOCs. Developed a separate model relating breath concentrations to dermal exposure; tested this model in a chamber study on subjects in baths while breathing pure air through masks to limit exposure to dermal only.

Studies on particles have included estimates of importance of resuspension and measurements of deposition rates, air change rates, filter efficiencies, and source strengths of various indoor sources of fine and ultrafine particles.

EDUCATION

Ph.D., City University of New York, 1974. Physics (Astrophysics).
Dissertation Topic: "Rolling Motions" in the spiral arms of the Milky Way Galaxy.

B.A., English Literature, University of Washington, 1959.

Physics studies, California Institute of Technology, 1956-58.

PROFESSIONAL ACTIVITIES

Founding Member of ISEA and ISIAQ. Member of AAAS, AAAR, A&WMA.

EXAMPLES OF RELEVANT PUBLICATIONS

Books

[redacted] *The TEAM Study: Summary and Analysis: Volume I.* U.S. EPA, Washington, DC. EPA 600/6-87/002a. NTIS PB 88-100060. 1987.

Ott, W.R., [redacted]., and Steinemann, A., eds. *Exposure Analysis*. CRC Press. Boca Raton, FL. 2006.

Book Chapters

[redacted]. Human Exposure to VOCs. Published in: Indoor Air Quality Handbook. Editors: John Spengler, Jon Samet, John McCarthy. Chapter 33, pp. 33.1-33.35. New York, New York. McGraw-Hill, 2001.

[redacted]. "Personal exposure to VOCs in the home: Sources, concentrations, and risks." Appendix III. In: Humfrey, C., Shuker, L., and Harrison, P. Indoor Air Quality in the Home. Institute for Environment and Health, Leicester, England. 1996.

[redacted]. "VOCs and the environment and public health--exposure." In: Bloemen, H.J.Th. and Burn, J. (eds), Chemistry and Analysis of Volatile Organic Compounds in the Environment, pp. 1-24. Blackie Academic and Professional, Glasgow, Scotland. 1993.

Wallace, L.A. and O'Neill, I.K. "Personal Air and Biological Monitoring of Individuals for Exposure to Environmental Tobacco Smoke." In: Environmental Carcinogenesis: Selected Methods of Analysis: Volume 9--Passive Smoking, Chapter 7, pp. 87-104. International Agency for Research on Cancer (IARC), Lyon, France, 1987.

Peer-Reviewed Journal Articles

[redacted] (2006). Indoor sources of ultrafine and accumulation mode particles: number concentrations and size distributions. *Aerosol Science & Technology* **40**(5):348-360.

[redacted], Williams, R., Rea, A., Croghan, C. (2006). Continuous weeklong measurements of personal exposures and indoor concentrations of fine particles for 37 health-impaired North Carolina residents for up to four seasons. *Atmos Environ.* **40**:399-414.

[redacted] (2005). Real-time Measurements of Black Carbon Indoors and Outdoors: A Comparison of the Photoelectric Aerosol Sensor and the Aethalometer. *Aerosol Science and Technology* 39:1015-1025.

[redacted] (2005). Ultrafine particles from a vented gas clothes dryer. Atmos Environ 39:5777-5786.

[redacted] and Williams, R. (2005). Validation of a method for estimating long-term exposures based on short-term measurements. *Risk Analysis* 25(3):687-694.

[redacted] Williams, R (2005). Use of personal-indoor-outdoor sulfur concentrations to estimate the infiltration factor, outdoor exposure factor, penetration coefficient, and deposition rate for individual homes. *Environ Sci Tech* 39:1707-1714.

Allen R., Larson, T., Sheppard, L., [redacted] and Liu, L-J S. (2004). Estimated hourly personal exposures to ambient and non-ambient particulate matter among sensitive populations in Seattle, Washington. *J Air Waste Manage. Assoc.* **54**: 1197-1211.

[redacted], Emmerich S.J., and Howard-Reed C. (2004a). Source strengths of ultrafine and fine particles due to cooking with a gas stove. *Environ Sci Tech* **38**(8):2304-2311.

[redacted] Emmerich S.J., and Howard-Reed C. (2004b). Effect of central fans and in-duct filters on deposition rates of ultrafine and fine particles in an occupied townhouse. *Atmos Environ.* **38**(4):405-413.

Howard-Reed C., [redacted], Emmerich S.J. (2003). Effect of ventilation systems and air filters on decay rates of particles produced by indoor sources in an occupied townhouse. *Atmos Environ* **37** (38):5295-5306.

Allen R., Larson, T., Sheppard, L., [redacted] and Liu, L-J S. (2003). Use of Real-time Light Scattering Data to Estimate the Contribution of Infiltrated and Indoor-Generated Particles to Indoor Air. *Environ Sci Tech* **37**:3484-3492.

Liu L-J S, Box M, Kalman D, Kaufman J, Koenig J, Larson T, Lumley T, Sheppard L, [redacted] Exposure Assessment of Particulate Matter for Susceptible Populations in Seattle. *Environ Health Perspect* **111**:909-918. 2003.

[redacted] Mitchell H, O'Connor GT, Liu L-J, Neas L, Lippmann M, Kattan M, Koenig J, Stout JW, Vaughn BJ, Wallace D, Walter M, Adams K. Particle Concentrations in Inner-City Homes of Children with Asthma: The Effect of Smoking, Cooking, and Outdoor Pollution. *Environmental Health Perspectives* **111**:1265B1272. 2003.

Gordon, S.M., [redacted], Brinkman, M.C., Callahan, P.J., and Kenny, D.V. Volatile organic compounds as breath biomarkers for active and passive smoking. *Environmental Health Perspectives*, **110** (7): 689-698, 2002.

Evaluation of resuspended particles from carpeted versus uncarpeted flooring for dust control and improved indoor air quality

Principal Investigator: [redacted], Clarkson University, Potsdam, NY

Subcontractor: [redacted], [redacted], [redacted]
National Institute of Standards and Technology, Gaithersburg, MD

Project Description

Overall purpose

Hard flooring is often recommended to improve indoor air quality in residences and to reduce asthma symptoms. However, there is currently insufficient scientific evidence to support this recommendation. An unbiased, definitive study is proposed to estimate the level of exposure reduction based on flooring choice and other important environmental factors. Clear communication of the study is also proposed to facilitate the necessary changes to improve indoor air quality and human health.

House dust can contain many toxins, carcinogens, and allergens, including pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), phthalates, molds, pet allergens, dust mites, lead and other heavy metals (Roberts and Dickey, 1995; Rudel et al., 2003). These pollutants and allergens deposit on indoor surfaces and can resuspend into the indoor air when agitated. Resuspended particulate matter makes up a substantial portion of the airborne particulate matter that humans breathe (Yakovleva et al., 1999). However, there are limited data regarding the resuspension of indoor particles. As a result, the fate of these particles indoors is not well understood and human exposure estimates to these pollutants are uncertain.

To fill this knowledge gap, we propose to assess resuspension rates and resulting human exposures of specific types of particles as a function of particle type (e.g., inorganic metals; allergens), particle size, relative humidity, flooring material, and human activity patterns. This knowledge would contribute to a better understanding of indoor particle exposures and a reduction in pollutant and allergen exposure through material selection, housekeeping activities, indoor environmental conditions and/or personal habits. The following objectives have been identified for this project:

1) Characterize resuspension of inhalable particles using a consistent test methodology for different flooring materials, different particle types (e.g., specific allergens of interest such as dust mite and cat allergens), and varying relative humidity and particle loading conditions.
2) Estimate residential exposures to resuspended inhalable particles using NIST's CONTAM model with a new resuspension module.
3) Provide results in formats that can be easily communicated to scientists, builders and developers, public housing directors, and the general public.

The project objectives will be reached in three sequential phases of the project.

Phase 1. Characterize resuspension of dust

The first phase of the project will characterize resuspension of inhalable particles for different flooring materials, different particle types, and varying relative humidity and particle loading conditions. A consistent test methodology will be used to resuspend the particles such that the various factors can be compared. The dust will be loaded onto at least four different types of flooring materials including two types of carpet and two types of hard flooring (vinyl and hardwood flooring) that are commonly used in residences. The different particle types will focus on indoor allergens of concern. Biological particles are likely to have significantly different resuspension rates than an inorganic material (e.g., Arizona road dust) due to different surface characteristics and thus require independent testing. A range of different relative humidity conditions will be tested to determine its effect on resuspension of the particles. Finally, the effect of the depth of the particle loading will be investigated by varying the number of particle application and agitation cycles. The spatial distribution of the particles in the flooring will be observed as well as the effect of this distribution on particle resuspension. A factorial design will be employed to optimize the number of experiments conducted under Phase 1 and allow the determination of important factors, a best setting for reducing resuspension rates, and a model to predict resuspension rates for different floorings and environmental conditions.

Experiments for Phase 1 will be conducted in a humidity and temperature controlled 25 m^3 indoor air chamber in the Clarkson University Center for Air Resources Engineering and Science (CARES) facilities. The Clarkson indoor air chamber is constructed using typical residential construction materials including a wooden stud frame and painted sheetrock walls. Working with Dr. Andrea Ferro, the project team at the National Institute of Standards and Technology (NIST) will verify the results through tests in the NIST 33 m^3 stainless steel, temperature and humidity controlled chamber. Test results are expected to show resuspension rates as a function of particle size under the range of conditions found in residences.

<u>Phase 1 Roles:</u>
Clarkson University:

- Design and conduct experiments in environmental chamber.
- Lead data management and analysis task.

National Institute of Standards and Technology:

- Assist in the development of the factorial experimental design.
- Verify resuspension rate test method using NIST's test facilities.
- Analyze resuspension rate data to statistically determine significant factors affecting resuspension and best setting for minimizing exposure to resuspended particles.
- Specify data format for application to resuspension model development.

Phase 2. Characterize human exposure to resuspended dust

During Phase 2, the team will translate resuspension rates determined in Phase 1 to predicted human exposures for a wide variety of residential environments and scenarios. This human exposure assessment is necessary to provide practical guidance to the housing industry and general public sectors. To accomplish this task, a resuspension module will be added into NIST's indoor air quality and ventilation model CONTAM. Statistical analysis of the resuspension data will allow the development of a semi-empirical model that is a function of several factors including floor type, particle composition, particle size, and relative humidity. Screening-level exposure scenarios will be developed to represent a range of important factors related to resuspension including particle characteristics (e.g., size, composition, etc.), typical floor coverings, building characteristics and airflows, particle filtration technologies, occupant loading and activities, and floor cleaning schedules. Sources of model input data will include NIST's databases of building characteristics and particle model inputs, in particular the characteristics from the collection of representative US homes that NIST developed for HUD, and external sources such as the National Human Activity Pattern Survey (Klepeis et al., 2001). Clarkson University will run the simulations and analyze the exposure data. NIST will provide technical support for CONTAM to Clarkson University.

Phase 2 Roles:
Clarkson University:

- Support resuspension module development by providing resuspension rate data from Phase 1 and current scientific literature.
- Develop exposure scenarios for CONTAM simulations.
- Complete CONTAM simulations.
- Analyze exposure scenario results.

National Institute of Standards and Technology:

- Develop a semi-empirical model to predict resuspension rates for a given set of conditions.
- Add resuspension module and help documentation to existing IAQ and ventilation software program CONTAM.
- Aid Clarkson University in the development of exposure scenarios.
- Provide Clarkson University technical support for CONTAM.

Phase 3. Disseminate practical guidance

The results of this study need to reach multiple segments of the population: the scientific community, related segments of industry, and the general public. For the scientific community, the results will be published in peer-reviewed literature and presented at professional meetings by the investigators. For industry, the study results will be formatted in clear language to be of practical use to home builders, nonprofit developers, public housing directors, architects and designers, pulmonologists, and allergists. The results will be submitted to trade journals and communicated directly to trade associations. To reach the general public, Clarkson will produce press releases for mainstream media. A clipping service, such as BurrellesLuce, will be used to track impact of press releases. We will also work through governmental and non-governmental organizations that provide unbiased, authoritative information to the general public, including HUD and the The Healthy House Institute™ (HHI; www.HealthyHouseInstitute.com; Boise, ID). HHI "strives to be the most comprehensive educational resource available for creating healthier homes." HHI's educational partners include Building Green, Green Seal, Home Ventilating Institute, LEED™ for Homes, Housekeeping Channel, and Home Energy. Dr. Ferro is on the scientific Advisory Board of HHI. Results for flooring and associated resuspension factors as well as for exposure scenarios will be publicly available in a database managed by the project team.

Phase 3 Roles:
Clarkson University:

- Provide results in clear, unambiguous language for widespread dissemination.
- Produce and track press releases.
- Manage database for exposure scenarios.
- Manage database for flooring and associated resuspension factors.

Clarkson University/NIST:

- Present and publish results of study in scientific publications and organizations.
- Work with trade associations, government agencies, and non-governmental organizations to disseminate study results.

Response to Rating Factors

Rating Factor 1: Capacity of the Applicant and Relevant Organizational Experience

A strong, multi-institution team has been assembled to perform this work. The team has successfully managed similar projects (described below) and has the necessary resources available to conduct this work. The PI, Dr. [redacted], is an assistant professor in the Department of Civil and Environmental Engineering at Clarkson University and a registered professional engineer with approximately 20 years of experience in field studies, engineering design, and project management in environmental health and engineering. Her primary research interests are indoor air quality and human exposure to particulate pollutants. Dr. [redacted] has worked with the National Exposure Research Laboratory of the U.S. Environmental Protection Agency (EPA), and, currently, with NIST on a number of research projects related to human exposure to particulate matter. Dr. [redacted] currently a guest researcher at NIST, is an internationally known expert on indoor air and exposure to pollutants with over 30 years experience at EPA. Dr. [redacted] has more than 25 years experience conducting research on indoor environments, specializing in building energy efficiency, building envelope performance, ventilation and HVAC system assessment, indoor air quality monitoring, and airflow and contaminant dispersal modeling. More detailed descriptions of the participants' qualifications and experience as well as the institutional resources are provided below.

[redacted]*, Clarkson University*

[redacted] is an assistant professor in the Department of Civil and Environmental Engineering at Clarkson University. She has been a registered professional engineer since 1997 and has approximately 20 years of experience in environmental health and engineering. Her technical expertise is focused on indoor air quality and human exposure to particulate pollutants.

[redacted] has successfully managed many projects in her current position as an academic researcher, as a project manager for Camp Dresser & McKee, Inc., and as a system administrator for General Electric Plastics Division. She has been the PI or co-PI for research projects at Clarkson University ranging from $100K to over $500K. For these projects, she is responsible for hiring and training student researchers, purchasing and maintaining research equipment and supplies, overseeing experiments and data analysis, communicating results, as well as meeting the budget and deliverables. More details on these projects are provided in her curriculum vitae. At Camp Dresser & McKee, Inc., a large, international environmental engineering consulting firm, she was the project engineer or project manager for many projects related to air and water quality. These projects ranged in size from $100K to $2M. At General Electric Plastics Division, she was the system administrator for a $2M employee health database system.

[redacted] co-developed and co-taught one of the world's first courses on human exposure analysis at Stanford University (2000-2002). She expanded and taught a similar course at Clarkson University in 2005 and again in 2007. This unique course focuses on scientific and engineering issues involved in quantifying human exposure to toxic chemicals in the environment. She contributed to the resulting course textbook Human Exposure Analysis, Ott, Steinemann, and Wallace, eds., 2007, Taylor & Francis Group LLC, Boca Raton, FL.

[redacted] is currently conducting a study in collaboration with Syracuse University, funded by the U.S. Environmental Protection Agency, which is complementary to the proposed work. The Syracuse study, which investigates how human activities and air distribution systems (mixing, displacement, and personal ventilation) affect the resuspension, will significantly leverage the resources of the proposed study. Continuous optical particle counters, similar to the instruments proposed for this study, are being used to provide the necessary temporal resolution to quantify resuspension. The Syracuse study involves measurement of humans walking on flooring that is seeded with particles and modeling of the personal cloud around a human using computational fluid dynamics (CFD) for airflow and advanced resuspension and transport/dispersion models for PM. [redacted] has many papers published or pending on this topic (Ferro et al., 1999, 2002, 2004a, 2004b; Ferro 2003; Kopperud et al., 2004; Qian and [redacted] 2006, 2008; Qian et al., 2008; Zhang et al., 2007, 2008).

[redacted] ***National Institute of Standards and Technology***

From 1998 through 2000, Dr. [redacted] served as a post-doc for the National Exposure Research Laboratory of the EPA. During this appointment, Dr. [redacted] was involved with several research projects related to human exposure to particulate matter. In particular, she conducted many studies in an occupied townhouse to better understand particle generation and transport in a real environment. Results from these studies have been published in the *Journal of the Air & Waste Management Association, Atmospheric Environment,* and *Environmental Science & Technology*. Particle resuspension experiments conducted in the house included particle resuspension from floors and upholstered furniture due to scripted activities, spatial variation of concentrations following resuspension activities, and resuspension rates as a function of cleanliness.

In 1999, Dr. [redacted] participated in a field study with Harvard University to monitor personal exposure to particles of high-risk subpopulations. She continued her involvement with panel personal exposure studies, by analyzing continuous monitoring data from an EPA panel study conducted in Baltimore, MD. Through this pilot study, Dr. [redacted] demonstrated the importance of continuous personal particle measurements, which resulted in the standard use of continuous monitors in future EPA panel studies. These past particle research projects involved several test procedures and monitoring equipment that could be applied toward the development of a resuspension rate test method as described in this proposal.

Since 2000, Dr. [redacted] has been at NIST where she has served as the PI or co-PI on several indoor air quality research projects. She continues to conduct experimental work using NIST's test houses and chamber facilities. Dr. [redacted] has also contributed to the enhancement and validation of NIST's indoor air quality and ventilation model CONTAM. She has used this model for a number of IAQ exposure projects including a HUD funded project to model the IAQ impact of Healthy Homes Initiative Interventions in inner-city housing. Results from this project have been well-received and presented at several conferences. Dr. [redacted] CONTAM knowledge and exposure modeling experience will be a good resource for the development of exposure scenarios described in this proposal.

[redacted]

Dr. [redacted] has concentrated throughout his career on developing methods such as personal air quality monitors to measure human exposure to air pollution. Dr. [redacted] whose Ph.D. is in physics, conceived and implemented the EPA TEAM Studies of human exposure. These very large-scale studies used personal monitors carried by more than 2000 persons (selected to represent more than two million residents of a number of U.S. cities) to measure their exposure to volatile organic compounds, pesticides, carbon monoxide, and respirable particles. Many new unexpected sources of these pollutants were found, leading to an increased emphasis on personal behavior, consumer products, and building materials as sources of exposure.

The Particle TEAM (PTEAM) Study showed the great importance of resuspension in contributing to daytime human exposure, which was 50% higher than the corresponding indoor air concentration as measured by a fixed monitor. A recent source apportionment analysis of these data found that about 30% of total personal exposure to PM10 of the 178 subjects was from resuspension of indoor dust (Yakovleva et al., 1999).

Dr. [redacted] received a number of awards from the EPA for these and other studies carried out during his 30-year career with the Agency. He spent two years as a Visiting Scholar at Harvard University, and has served as an advisor to a number of doctoral students at Harvard, Johns Hopkins, and the University of Washington. He has published 80 articles in peer-reviewed journals, one book and 15 book chapters, and more than 100 research reports and presentations at conferences. Recently he was one of three editors of the first textbook on human exposure (CRC Press, 2007). Dr. [redacted] received the Jerome J. Weselowski award for lifetime contributions to human exposure and the Constance Mehlman award for scientific contributions affecting environmental policy from the International Society for Exposure Analysis (ISEA).

[redacted]

Dr. [redacted] has more than 25 years experience conducting research on indoor environments, specializing in building energy efficiency, building envelope performance, ventilation and HVAC system assessment, indoor air quality monitoring, and airflow and contaminant dispersal modeling. He has developed an international reputation as a researcher and leader in the field of ventilation and indoor air quality based on his publication record, standards writing experience, and other professional activities. Dr. [redacted] is currently the vice-president of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), and is past chair of ASHRAE SSPC 62.1, responsible for the revision of the ASHRAE Ventilation Standard 62. He is past chair of ASTM Subcommittee E6.41 on Air Leakage and Ventilation Performance and vice-chair of subcommittee D22.05 on Indoor Air Quality.

Dr. [redacted] first two years at the National Bureau of Standards were as a National Research Council Postdoctoral Research Associate, working on air infiltration in homes and large buildings. He received the Department of Commerce Bronze Medal in December 1989, and was named Young Engineer of the Year by the D.C. Council of Engineering and Architectural Societies in 1990. He was honored as an ASTM Fellow in 2002 and an ASHRAE Fellow in 2004.

Dr. [redacted] has spent the previous fifteen years as leader of NIST's Ventilation and Indoor Air Quality research group involving program management, staff development, and raising research funds of roughly $2 million per year. Dr. [redacted] has served as the principal investigator on several HUD projects in the past through the Office of Healthy Homes and Lead Hazard Control. The results and products from these projects have always been very well-received and made significant contributions to the field of IAQ. Dr. [redacted] has widely disseminated project results through conference presentations, NIST reports and peer-reviewed journal articles.

Clarkson University

Clarkson University, with its Center for Air Resources Engineering and Science, is an internationally recognized center for airborne particle research. The university has exceptional resources to support this study, including particle instrumentation, analytical facilities, test facilities (e.g., indoor air chamber, aerosol wind tunnel), and advanced instruction for students.

Two Clarkson research graduate students will be dedicated to the project. These researchers will be recruited for the project and will have at minimum an accredited undergraduate degree in environmental, civil, or mechanical engineering. As graduate students at Clarkson, they will become experts in the subject matter related to this study. The following graduate courses are regularly offered at Clarkson University and, in conjunction with their research activities, will provide the students with a solid, fundamental background:

- ME 637 Particle Transport, Deposition and Removal
- ME 537 Fluid Mechanics of Aerosol Dispersion
- ME 538 Experimental Aerosol Mechanics and Instrumentation
- CM 552 Aerosol Chemistry
- ES 533 Human Exposure Analysis
- CE 577 Atmospheric Chemistry (includes Aerosol Physics)
- ES 506 Industrial Hygiene Control (includes Ventilation)
- ES 534 Air Pollution Control

Administrative support will be provided to the project team by clerical staff in the Clarkson University Department of Civil and Environmental Engineering, Center for the Environment, and Center for Air Resources Engineering and Science. This administrative support is paid for by indirect costs applied to the project.

NIST

NIST brings the experience of developing standard methods, test facilities for verification of such methods, statistical expertise, and a validated indoor air quality and ventilation model to conduct exposure simulations. Support staff available for NIST research projects include world-renowned statisticians, programmers, test facility technicians, and student engineers from local universities, described below. Administrative support for NIST is included in the budget. A letter of commitment from NIST is attached to the proposal.

Statistician: The statistician will assist in the experimental design for the work to be done at NIST and serve as a consultant to Clarkson's efforts in the same area. He/she will also assist in data analysis in support of the resuspension model development for inclusion in CONTAM. The statistician will have a Masters degree in statistics with expertise in statistical design, analysis of experimental data, and in analysis of variance.

Programmer: The programmer will support the implementation of the resuspension model in CONTAM, including the necessary modifications to the data structures used by CONTAM, the calculation algorithms and the graphical user interface. He/she will also develop the document of the resuspension model to facilitate its use by others. The programmer will have a Bachelor of Science degree in computer science with experience in C/C++, Visual Basic, Java and HTML/CSS, PHP programming and in developing multizone network airflow and indoor air contaminant transport software, including interfaces for data input and for displaying results.

Technician: The NIST technician will provide support for the experimental effort at NIST, including equipment setup, calibration and maintenance, conducting the experiments and archiving the measured data. The technician will have experience in electronics, air sampling instrumentation, data acquisition systems.

Student Engineers: Undergraduate engineering students working at NIST at the time of this research will assist in the experimental effort by providing support for the testing and data analysis as needed. Students will be enrolled in accredited Bachelor of Science programs in engineering.

Rating Factor 2: Need/Extent of the Problem

Although the recommendation to use hard flooring instead of carpets to improve indoor air quality is common (e.g., ALA 2002; HUD 2002), sufficient peer-reviewed literature to back up this recommendation is not available. The opposite recommendation has also been made. For example, the Carpet and Rug Institute has maintained the position that carpeting reduces particle resuspension, and thus particle exposure, by trapping more particles than hard flooring (www.carpet-rug.com). Despite these competing viewpoints, very little is known regarding the rates of particle resuspension as well as the importance of factors, such as flooring material type, particle characteristics, and environmental conditions, on resuspension.

Dust on indoor surfaces contains toxins, carcinogens, and allergens. These particulate pollutants enter indoor environments via mechanical ventilation, infiltration through openings in the building envelope, track-in on shoes, and indoor source emissions. They deposit on walls, furnishings, and flooring, which can then act as particle reservoirs. Subsequently, particles can be resuspended mechanically via air currents or human activities. Little is known regarding the resuspension rates of these pollutants and the resulting human exposures, although initial studies have indicated that resuspension is an important indoor source. Several studies have reported high indoor and personal airborne particle concentrations as a result of human activities indoors that resuspend house dust (Brauer et al., 1999; Ferro et al., 2004a,b; Long et al., 2000; Thatcher and Layton, 1995; Rosati et al., 2008). Kopperud et al. (2004) found that during periods of human activity, in the absence of cooking and smoking, resuspended house dust accounted for almost all of the coarse (2.5 μm > particle diameter < 10 μm) and fine (particle diameter <2.5 μm) indoor PM in a residence. Ferro et al. (1999) and Long et al. (2000) found that human activity results in short-term, high concentration PM events. Applying receptor modeling to the data collected for the PTEAM study, a large-scale study of 178 homes, Yakovleva et al. (1999) found that 30 % of personal PM10 exposure is due to resuspension.

Several recent studies have correlated disease symptoms with increased ambient short-term PM. Asthma symptoms have been associated with 1-h and 8-h maximum PM_{10} concentrations (Delfino et al., 1998), increased chronic obstructive pulmonary disease hospital admissions with 1-h fine particle concentrations (Morgan et al., 1998), and decreased heart rate variability in elderly subjects with 4-h mean $PM_{2.5}$ concentrations (Gold et al., 2000). In addition, studies have found that house dust can contain high concentrations of pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), phthalates, molds, pet allergens, dust mites, lead and other heavy metals (Roberts and Dickey, 1995; Rudel et al., 2003).

Despite the lack of data, there has been much debate recently regarding the role types of flooring materials and other factors play in the resuspension rate of particles and subsequent impact on human health, particularly children's asthma. Asthma prevalence has increased worldwide over the past 20 to 30 years (Holgate, 1999). Moorman et al. (2007) report that asthma prevalence increased in the United States from 1980 to 1996; however, asthma attacks have not increased since 1997 and asthma prevalence was not found to increase further for the study period from 2001 to 2004. Moorman et al. (2007) also report that for the period of 2001 to 2003, "current asthma prevalence was higher in children (8.5%) compared with adults (6.7%), ... blacks (9.2%) compared with whites (6.9%), ... those below the federal poverty level (10.3%) compared with those at or above the federal poverty level (6.4% to 7.9%)..." It is well documented that exposure to aeroallergens can exacerbate the symptoms of asthma in children (e.g., Alvarez-Puebla et al, 2001; Amr et al., 2003; Chan-Yeung et al., 1995; Peat et al., 1996). Residential exposures, including exposure to allergens in dust, account for 39 percent (533,000 total) excess asthma cases for children under 6 years of age in the United States (Lanphear et al., 2001). Elimination of residential risk factors could result in a substantial decline in doctor-diagnosed cases of asthma for this age group.

No studies have been conducted that systematically investigate resuspension from human activities for different floorings in a controlled environment. The proposed study fills this gap by quantifying the contributing factors to increased PM exposure from resuspension. The study will lead to practical guidance on selection of flooring to minimize health impacts by providing the results in a format that can be disseminated and clearly understood. Results for flooring and associated resuspension factors as well as for exposure scenarios will be publicly available in a database managed by the project team.

Advancement of Current Knowledge

The existing data on resuspension from human activity are from limited field and chamber observations and the resuspension effect has not been well characterized. These field studies have roughly estimated resuspension rates from human activity ranging from 10^{-2} to 10^{-7} h^{-1}, depending on particle size and type of activity (Thatcher and Layton, 1995; Hambraeus et al., 1978; Qian et al., 2008; Qian and Ferro, 2008). The concentration of resuspended particles has been found to be associated with type of activity, number of persons performing the activity, particle size, relative humidity, particle loading, and flooring material (Ferro et al., 2004b; Qian and Ferro, 2008; Rosati et al., 2008). Rosati et al. (2008) found that, without a fan to enhance mixing, the airborne particle concentration varies with height and particle diameter; however, with a fan, the concentration gradient was not observed.

Qian and Ferro (2008) investigated resuspension from human activity by seeding carpeted and hard flooring with test particles and recruiting subjects to walk on the flooring in an instrumented chamber. From the semi-continuous number concentration data (Figure 1), we estimated resuspension rates in size ranges of 0.4 to 0.8 μm, 0.8-1 μm, 1.0-2.0 μm, 2.0-5.0 μm, and 5.0-10 μm ranging from 10^{-4} to 10^{-2} hr^{-1}, with higher resuspension rates associated with larger particles (Figure 2). Resuspension rates for the carpeted floor were on the same order of magnitude but significantly higher than those for the hard floor. Also, we found high person-to-person variability for resuspension due to differences in walking styles. *Therefore, a consistent method of resuspension, such as that proposed by this project, is needed to effectively compare flooring types.*

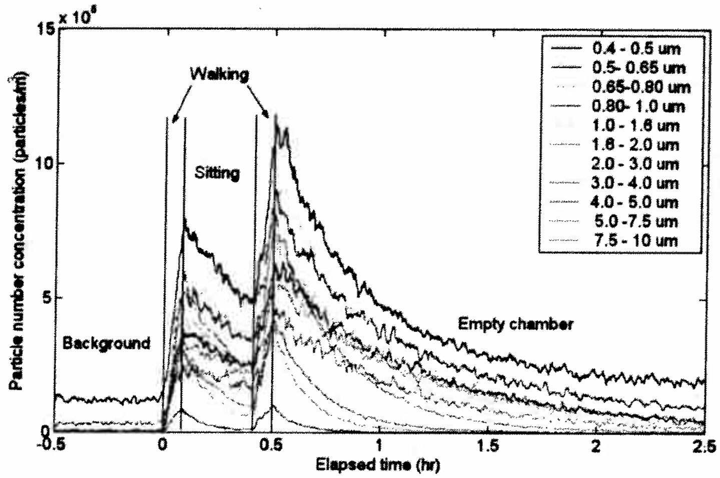

Figure 1 Number concentration (particles/m3) time profile for PM size ranges measured by the Grimm optical counter. The participant performed the prescribed activities on a seeded new carpet. The experimental conditions were: ACH = 0.4 h^{-1}, T = 25.4 ± 0.1 °C, and RH = 31.7 ± 0.2 %.

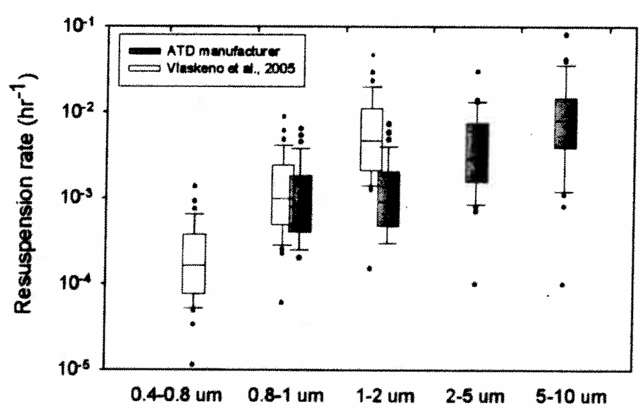

Figure 2 Resuspension rate for 34 participants for PM size ranges from 0.8-10 μm. The size distribution of the test dust (ATD) was provided by the manufacturer only for >0.8 μm. The 0.4-0.8 size range (and overlapping ranges) was provided by Vlaskeno et al. (2005) for a different batch of the ATD.

Results from the proposed study will identify significant factors affecting particle resuspension rates and determine factors to minimize exposure to resuspended particles. This information will address the question of flooring material for low-income housing as well as recommended cleaning practices and replacement criteria. Also, no models currently exist to predict resuspension rates of particles based on floor type, particle size and composition, particle loading, and relative humidity. This study will aid the development of a model to predict exposure due to resuspension, which will make future exposure estimates more reliable. For the first time, particle resuspension will be included in NIST's CONTAM model, which is publicly available (http://www.bfrl.nist.gov/IAQanalysis/). Because this model is not specific to any specific type of particle, it can be used to study a range of dust-related exposures, such as bacteria, fungi, mold spores, persistent organic pollutants (e.g., pesticides, phthalates), and specific chemical and biological agents.

Advancement of Current Methods

To date, there are only a handful of scientific and anecdotal studies to determine resuspension rates of particles from floor covering material resulting in incomplete knowledge of this potentially significant exposure mechanism and effective mitigation strategies. A resuspension test method will allow for consistent comparison of the particle resuspension potential for different flooring materials. A robust statistical study will provide recommendations for minimizing exposure to resuspended particles in terms of floor covering material, particle characteristics, particle loading, and relative humidity. The exposure scenarios developed for CONTAM can also be used as a tool to determine impact of floor covering choices and most effective control strategies.

Contribution towards Goals of Healthy Homes Technical Studies Program

This study meets HUD's specific objectives to control dust exposure and to better understand the relationship between residential exposure and childhood injury. In particular, this study will evaluate the importance of particle resuspension on exposure to pollutants and asthma triggers (i.e., allergens) through experiments and exposure analysis. The research will provide the needed scientific knowledge to make informed decisions on flooring choices and maintenance practices for low-income housing that will minimize human exposure to pollutants and related impacts on human health. Results will provide homeowners and developers guidance on choosing a floor covering material that will minimize the resuspended dust hazard. The proposed research will also identify important factors that affect particle resuspension rates, resulting in practical guidance for minimizing exposure to resuspended particles.

By addressing a major issue in indoor air quality, human exposure to resuspended pollutants and allergens, the proposed study supports the HUD Healthy Homes Technical Studies' overall purpose "to improve our knowledge of … housing-related health and safety hazards" as well as the program's stated interest in:

(1) Dust control measures; and
(2) Improving understanding of the potential effects of residential construction and rehab practices using "green principles" on indoor air quality and resident health.

This work also supports HUD's Strategic Goal to improve "the environmental health and safety of families living in public and privately owned housing." The end result of this work will be to recommend cost-effective methods for controlling this important housing-related hazard, a stated objective of the Healthy Homes Technical Studies Program.

Association with Housing Related Health Hazard

Because people in the United States spend most of their time indoors at home (Robinson et al., 1991), understanding exposures in homes is critical to estimating total human exposure to pollutants and allergens and related health outcomes. Resuspension of particles is a particular concern for children. Not only are children more active than adults, but their breathing zone is closer to the ground. Children are likely to stir up more particles and inhale them.

HUD's mission is to "provide decent, safe, and sanitary homes and suitable living environments" with a focus on rehabilitating low-income/affordable housing. Higher concentrations of pollutants have been found in low-income homes (Laquatra et al., 2002). In addition, children living below the poverty level are at increased risk of suffering from asthma and residential exposures account for a large percentage of excess asthma cases for children under 6 years of age (Moorman et al., 2007; Lanphear et al., 2001). This work will quantify exposure to resuspended particles, as well as provide practical guidance to reduce this housing related health hazard.

Rating Factor 3: Soundness of Approach

This research will examine particle loading on flooring materials, resuspension of those particles from human activities, and modeling human exposures associated with resuspended particles. In Phase 1, we will determine how flooring material, particle size, particle type, particle depth, and relative humidity affect resuspension rates. Results will be statistically analyzed to identify significant factors affecting the resuspension rates of particles. In Phase 2, we will develop and implement a module in CONTAM, predict human exposures due to particle resuspension for a variety of scenarios, assess the relative importance of various factors given these scenarios, and determine effective options for minimizing exposure to resuspended particles. In Phase 3, we will communicate the study results to the scientific community, the building and health care industries, and the general public. The three phases of the project are described on pages 2-4 of the project narrative. Additional details for the experimental methodology are provided below.

Hypotheses

The following hypotheses will be tested in this project:

H1. Hard flooring results in a lower resuspension rate via human activity than carpeted flooring.
H2. Particles that are embedded more deeply are less available for resuspension than particles on the surface of the carpet.
H3. Vertical distribution of particles embedded in carpet is dependent on particle type and size.
H4. Larger particles have higher resuspension rates than smaller particles.
H5. Particle composition has an impact on resuspension rates.
H6. Increased relative humidity reduces resuspension rates.
H7. Hard flooring results in a lower exposure to resuspended particles than carpeted flooring.
H8. Modeling can help identify strategies to reduce exposure.

Hypotheses 1 through 6 will be tested in Phase 1 by comparing the resuspension rates for each of the factors. For the factors that are statistically significant, the effects of these factors on resuspension rates will be quantified. Hypothesis 7 will be tested in Phase 2 by statistically comparing predicted human exposures from carpet and hard flooring. Although it will not be tested statistically, Hypothesis 6 will be addressed in Phase 3 by modeling exposure scenarios which represent a range of factors related to resuspension.

Particle Seeding (Phase 1)

The flooring will be seeded with test dust using a standard procedure modified from Lewis et al. (1999). Particle loading on flooring will be verified using surface sampling techniques using vacuum sampling (American Society for Testing and Materials (ASTM) International Standard D7144) and a gelatin foil technique (Schneider et al., 1996). The seeding method was developed and used successfully by Dr. [redacted]s research group (Qian and Ferro, 2008). A standard particle mixture will be used to seed the flooring. The most applicable existing standard particle mixture is ISO 12103-1, A1 Ultrafine Test Dust with a normal size of 0-10 μm and a known composition and particle size distribution. This standard particle mixture will allow for a repeatable standard to test methods in Phase 1 and a means for comparison to other particle types.

Because house dust has a higher organic fraction and different particle size distribution than the A1 Ultrafine Test Dust, house dust may have different resuspension behavior. Therefore, house dust will be tested separately in Phase 1. For Dr[redacted] related EPA project, house dust samples have been collected from a wide variety of homes using a vacuum collection method. The house dust samples have been combined, sieved through a 63 μm sieve, and characterized for organic carbon, elemental carbon, metals, and cat, dog, and dust mite allergens in the CARES laboratory at Clarkson. Additional dust samples will be collected and analyzed from at least 30 homes in different geographical locations for the proposed study to verify the representativeness of the "standard" dust that will be used for the particle seeding. The dust will also be compared with the NIST standard reference material (SRM) house dust (Poster et al., 2007). As an additional quality assurance step, at least 4 carpets will be placed in the living rooms of homes with occupants for 6 months to collect real dust. These carpets will be removed from the homes and tested along side the carpets that are seeded with dust in the laboratory to compare total particle loading, spatial distribution of particles, and size-resolved resuspension rates.

Resuspension Mechanism (Phase 1)

The resuspension mechanism to be used in Phase 1 is a prosthetic foot controlled by electric actuators which control the speed of the footstep and the pressure loading to effectively mimic a human footstep. This method was recently developed and tested by the Environmental Protection Agency for National Homeland Security applications (Rosati and Eisner, 2007). The foot does not move along the floor – the impact location is fixed. However, because resuspension only removes a very small fraction of the available particles on flooring, we do not expect this limitation to be a problem. We expect that the stationary device will provide results similar to that of a human, but with more consistency than is possible with a human participant. To confirm this assumption, we will directly compare results of the resuspension mechanism to those of a human walking under the same conditions. Use of a mechanical device allows flow field visualization of the particles using the Phase Doppler Particle Analyzer (PDPA) at Clarkson University. The PDPA requires a high-power laser that cannot be used with human participants.

Monitoring Protocol (Phase 1)

The experiments performed for this study will use continuous instruments, with averaging times ranging from seconds to minutes, in several locations to account for the temporal and spatial variability of the PM concentrations. These instruments include the Model 3321 Aerodynamic Particle Sizer® (APS, TSI, St. Paul, MN) spectrometer for real-time aerodynamic measurements of particles in 52 size channels from 0.5 to 20 μm and three types of optical particle monitors: Grimm Portable Dust Monitors (Ainring, Germany), Thermo Electron Personal DataRams (Franklin, MA), and Climet optical particle counters (Redlands, CA). Continuous instruments have been successfully used in several studies that have investigated increased indoor PM from human activities (Howard-Reed et al., 2000; Brauer et al., 1999; Ferro et al., 2004a,b; Long et al., 2000; Thatcher and Layton, 1995).

Integrated particle samplers will be collocated with low-volume, continuous particle counters to establish a relationship between the particle counts and particle mass over the duration of an experiment (approximately 4 hours). The integrated particle samplers will also be used to collect samples that will be analyzed for allergens. Integrated particle samplers that will be used for this study are the PM-2.5 Harvard Impactors (Harvard University, Boston, MA), which are comparable with the Federal Reference Method PM-2.5 (FRM) samplers (Yanosky, 2001).

The particle monitors will be set up in an array such that horizontal and vertical concentrations gradients from the source point can be determined. The mixing conditions and air change rate of the chamber will also be determined using the tracer gas decay technique with sulfur hexafluoride (SF_6) as the tracer (ASTM 2006). The SF_6 will be measured in 8 locations in the chamber using an Innova (Ballerup, Denmark) Model 2312 Photoacoustic Multi-gas Monitor along with a CBISS (Birkenhead, UK) Mark 3 Intelligent Sampling System. The well-mixed volume assumption, which is necessary for the mass balance model application, will be tested by comparing the concentration in multiple locations using both the particle and gas monitors.

Selection of Flooring Types (Phase 1)

Two carpet types and two hard flooring types have been selected for Phase 1 of the study. The carpets, one residential and one commercial, are manufactured by Shaw Industries, Inc. and are currently being used by HUD for cleaning trials. The Carpet and Rug Institute has identified these carpet types as commonly used and representative of the wider range of goods available. The descriptions for the carpet types are provided in Table 1.

Table 1. Carpet type descriptions.

Characteristic	Residential Cut	Commercial Loop
Pile Yarn Weight	25 Oz/Sq Yd ± 7%	26 Oz/Sq Yd ± 7%
Color	71107 Light Beige	10830 Multi-Color
Pile Height	0.56 Inch	0.143 Inch
Gauge	3/16	1/8
Stitches/Inch	6.5	8.0
Yarn	1500/2, Heatset, 3.0 tpi x3.0 tpi	2120/3, Air Entangled 3050, 2 ply
Face Fiber	Nylon 6 (Honeywell)	Nylon 6 Shaw Extruded Solution
Treatment	Soil Resist treated, (Scotchguard)	Dyed
Primary Backing	28 x 11 pick count woven polypropylene	Soil Resist treated (Shaw Generic)
Secondary Backing	16 x 5 pick count woven polypropylene	24 x 13 pick count woven polypro.
Style (Shaw Industries)	Style A3571	Style 50782

Two commonly used hard flooring types have been selected: vinyl flooring and hardwood flooring. The vinyl flooring, manufactured by Armstrong Inc., is a ToughGuard floor with a CleanSweep® PLUS no-wax wear surface in a 6-foot wide roll. The hardwood flooring is made of oak boards with a polyurethane finish.

Calculating Resuspension Rates using a Two-Compartment Model (Phase 1)

A two-compartment mass balance model will be used to estimate resuspension rates where the two compartments are the air compartment and the surface compartment. This model was used

[redacted]

to estimate resuspension rates in a residence and in a chamber by Dr. [redacted] group (Qian et al., 2008; Qian and [redacted] 2008). Inputs to the model are the measured air concentration and surface loading as well as the estimated deposition rate and air change rate. In this model, the mixing volume is assumed to be incompressible and instantaneously well-mixed and phase transfer, nucleation, coagulation and chemical reaction are assumed to be negligible. The model assumes a well-mixed air volume and even distribution of particles on the flooring surface. If a fan is use for mixing of the chamber air during the seeding and resuspension activities, these assumptions are reasonable (Rosati et al., 2008; Qian and Ferro, 2008).

The particle concentration will be modeled using a two-compartment materials balance model (eq 1 and eq 2).

$$V\frac{dC_i}{dt} = apVC_o + S + rA_rL - (a+k)VC_i \qquad (1)$$

$$A\frac{dL}{dt} = kVC_i - nA_vL - rA_rL \qquad (2)$$

Where A_r = Resuspension area (m^2); A = Surface area (m^2); A_v = Surface area for vacuum cleaning (m^2); V = Volume (m^3); a = Air exchange rate (hr^{-1}); p = Penetration factor; k = Deposition rate (hr^{-1}); r = Resuspension rate (hr^{-1}); n = Vacuuming rate (hr^{-1}); C_i = Concentration inside chamber (particles/m^3); C_o = Concentration outside chamber (particles/m^3); L = Floor loading (particles/m^2); and S = Indoor source emission rate (particles/hr).

For eq 1, term $apVC_o$, which represents particles infiltrated from the laboratory outside the chamber, can be removed since the supply air will be filtered by a HEPA filter. Term S can also be removed since there are no other indoor sources. For eq 2, term nA_vL(t) can be removed because no vacuuming events will occur during the experiments. The resuspension rate can then be derived from simplified eq 1 as:

$$r = \frac{V}{A_rL}\left(\frac{dC_i}{dt} + (a+k)C_i\right) \qquad (3)$$

Solving for r requires the input values of L and C_i. Combining eq 1 and eq 2 and rearranging terms, we get:

$$A\frac{dL}{dt} = -V\left(\frac{dC_i}{dt} - aC_i\right) \qquad (4)$$

By integrating both sides of eq 4 from time 0 to t, the continuous floor loading L(t) can be estimated by eq 5, given an initial $L(0)$.

$$L(t) = L(0) - \frac{V}{A}\left(C_i(t) - C_i(0) - a\int_0^t C_i(t_1)dt_1\right) \qquad (5)$$

Using L(t) and C_i(t), r(t) are solved using a numerical forward difference approximation (eq 6).

$$r(t+\Delta t)=\frac{V}{A_r L(t)}\left(\frac{C_i(t+\Delta t)-C_i(t)}{\Delta t}+(a+k)C_i(t)\right) \qquad (6)$$

Values for A_r and V will be measured in the chamber. Values for a and k will be determined for each experiment using a tracer gas and particle decay method (Qian and [redacted] 2008). Values for C_i will be measured using the TSI APS particle spectrometer.

Statistical Design (Phase 1)

A primary objective of this study is to determine if certain factors (e.g., flooring material, particle characteristics, etc.) significantly affect particle resuspension rates (Phase 1). A second objective is to develop a model to predict particle resuspension for use in exposure assessment (Phase 2). To meet these objectives, a robust statistical design must be implemented for completing the experiments under Phase 1, which will be used to develop the model in Phase 2. As such, a factorial experimental design will be used with the response variable being the change in concentration of airborne particles following a resuspension event. For testing the two carpet types, the testing factors and their levels as currently envisioned are listed as follows:

- Factor A: Carpet face weight, +1 for 22 oz/sqft, and -1 for 36 oz/sqft;
- Factor B: Relative humidity, +1 for 30%, and -1 for 50%;
- Factor C: Types of dust, +1 for Arizona Road Dust, -1 for House dust;
- Factor D: Conditions for depth of loading, +1 for unembedded deposition, -1 for embedded deposition.

For testing smooth surface flooring, the factors will be the same as above except factor A will be +1 for wood flooring and -1 for vinyl flooring and factor D will be open for an additional factor, if needed. Other factors that might affect the resuspension will be controlled within minimum variation, including the ventilation, variation in the resuspension mechanism, and the initial charge status of the flooring. As a first approach, a minimal aberration two-level fractional factorial design will be used to screen out the major factors (see Table 2). In this 2_{I}^{4-1}V design, the defining relation I is equal to ABCD. Thus, the main effect will be confounded with other three-factor interactions, which can typically be assumed to be negligible. The two-factor interactions will be confounded with other two-factor interactions. The confounding pattern of the factors is:

- main effect confounding A + BCD, B + ACD, C + ABD, D + ABC;
- 2-factor interactions confounding AB + CD , AC + BD, AD + BC.

All screening-level experiments, as described in Table 2, will be duplicated to provide a measurement of experimental error. Therefore, a total of 16 carpet and 16 smooth flooring (32 total) screening-level experiments will be conducted. Once the factors with the large main effect and important 2-factor interactions are discerned, an augmented design can be used to optimize further experiments. Although difficult to predict before conducting the screening level experiments, we expect to conduct approximately 50 additional experiments to quantify the effect of the factors on the resuspension rate. Statisticians at NIST will review the experimental design as well as provide guidance for the statistical analysis of the data.

Table 2: A 2_{IV}^{4-1} factorial design, I = ABCD

Condition No.	A	B	C	D=ABC
1	-1	-1	-1	-1
2	1	-1	-1	1
3	-1	1	-1	1
4	1	1	-1	-1
5	-1	-1	1	1
6	1	-1	1	-1
7	-1	1	1	-1
8	1	1	1	1

CONTAM Model (Phase2)

CONTAM is a multizone analysis computer program designed to predict airflow and pollutant transport in buildings and resulting occupant exposures. CONTAM has a graphical interface that allows users to draw a building's zones and add airflow paths, ventilation systems, contaminant sources and sinks, and building occupants. The program first calculates airflow rates between zones by solving for the pressure in each zone based on a mass balance of air. The resulting mass airflow rate values are then used with contaminant information to calculate concentrations in each zone. The user supplies data characterizing airflow paths, contaminant source emission rates, contaminant removal rates, chemical reaction coefficients, and occupant schedules. CONTAM currently has the capability to model the penetration and deposition of particles of multiple sizes. With the addition of a resuspension module, CONTAM is an ideal tool to simulate the impact of using different types of flooring materials in a residential or commercial building. CONTAM has been widely used around the world by approximately 7000 modelers from government, industry, consulting and academia. It has been referenced in over 200 publications, many of which include exposure scenarios. Detailed information regarding CONTAM may be found at the following website: http://www.bfrl.nist.gov/IAQanalysis/.

Decision Points

Due to the current lack of resuspension test methods and data, the researchers expect this study to involve several decision points. Decision points will follow the 32 screening-level experiments conducted under the fractional factorial design to design the remainder of the Phase 1 experiments. The experimental phase of the project will be completed when Hypotheses 1-6 can be proven to be true or untrue. Experiments will be repeated as necessary to give the most unambiguous statistical results as possible. The next decision points will take place in the modeling phase of the study to determine the set of scenarios which will be used for prediction of human exposure to resuspended particles. These scenarios will be selected to represent a range of human activity, from quiescent to highly active.

Data Management, Recordkeeping, and Document Control

This project will involve many experiments with the collection of a large number of data points. All experimental data will be initially recorded in dedicated log books and transferred to an electronic database. All experimental data will be stored in an Access© database on a single master server managed by Clarkson University. Data will be backed up on a portable hard disk at regular intervals and copies of the database will also be located at NIST. S-Plus© will be used to complete the statistical analysis of the data. All exposure simulation data will be exported to Excel© from CONTAM for further analysis.

FY2008 Policy Priorities

This study will address HUD's FY2008 policy priority to "improve the environmental health and safety of families living in public and privately owned housing by including activities that...reduce or eliminate health-related hazards in the home caused by toxic agents, such as molds and other allergens, carbon monoxide, and other hazardous agents and conditions." Specifically, the study will improve the health of families by providing guidance on how to reduce their exposure to resuspended particles. These particles potentially include hazardous pollutants and allergens that are harmful to human health, especially for those family members suffering from respiratory illness.

Quality Assurance

All experimental procedures will be carried out using strict quality control and assurance procedures, and all results will be reported with an associated expanded uncertainty. The team will use the Quality Assurance Plan for HUD Healthy Homes Initiative and Lead Technical Studies Grantees and Contractors template (VERSION 2.0, November 2003) as provided by HUD to develop the quality assurance plan. The research team has extensive experience with the equipment that will be used for the study as well as with the quality assurance procedures required to conduct scientific research. Several quality assurance issues are discussed below.

Collocation of Continuous Instruments

The continuous instruments will be calibrated and matched by the manufacturer prior to and periodically during the experimental period. The relative precision of collocated paired semi-continuous instruments will be determined by regression analysis, using a correlation model (Zar, 1999). It is assumed that both instruments vary together, and generate random data in the form of a bivariate normal distribution. The test of significance is based on the alternate hypothesis (Ha) that the correlation coefficient (r), as computed by a linear regression algorithm (Microsoft Excel® 2002), is not 0, and the level of significance is interpolated from a table of critical values for r. The relative precision of filter duplicates will be computed using Root Mean Squared Error (RMSE) of the pairs.

Data Quality Indicator Goals

The data quality indicator goals are established based upon our experience with the measurement systems and the need to quantify deposition rates and resuspension rates in the chamber. Data quality indicator goals for critical measurements are presented in Table 3. Data quality indicators for the critical measurements are calculated as follows:

<u>Calculation of Precision</u>: Precision is determined as the %RSD from the daily span check data. The average and standard deviation are determined for a minimum of 3 measurements at the span concentration.

$$\%RSD = \text{Std dev} / \text{Mean} * 100. \qquad (7)$$

Where: Std dev = standard deviation
Mean = average of 3 or more readings at daily span concentration.

<u>Calculation of Accuracy</u>: Accuracy is determined as % recovery of the average of the span check values compared to the standard value.

$$\%Recovery = \text{Response average} / \text{standard} * 100. \qquad (8)$$

Where: Response average = average of minimum of 3 readings.
Standard = calibration standard generated at 80% of full scale.

<u>Calculation of Relative Precision</u>: Relative precision is defined as root mean squared error (RMSE), which is the square root of the mean of the squared differences between measurements from the two collocated monitors, expressed as a percentage of the mean at the selected standard monitor.

$$\%RMSE = 100 * [((\text{mean}(A-B)^2)^{0.5})/\text{mean}(A)]. \qquad (9)$$

Where: A = selected standard monitor.
B = test monitor.

<u>Calculation of Completeness</u>: Completeness is defined as the % of data that is judged valid as compared to the amount of planned data.

$$\%Complete = 100 * V/n. \qquad 10)$$

Where: V = number of measurements judged valid.
n = number of measurements planned.

Detection Limit and Quantification Limits

Detection limit is defined as the concentration level at which an analyte can be reliably detected with a defined confidence (specified as 95 % in this study). It is determined as 3 times of the standard deviation of the instrument's response to a clean background air sample. Quantification limit is the concentration level at which an analyte can be reliably quantified with a defined (e.g. 95 %) confidence. In this study, it is defined as three times of the detection limit in this study.

Periodic Calibration Checks

Span checks will be required before each chamber test for the SF_6 measurement system. The span check is conducted by connecting the sampling line of the automatic sampling system to the high pressure cylinder containing the 500 ppb SF_6 calibration gas supply. A mixing bulb with open port vents excess SF_6 to atmosphere. A positive flow is verified from the port of the mixing bulb and 5 air changes of the mixing bulb volume are allowed before the SF_6 concentration of the standard gas is determine. The average response is calculated for 3 determinations of the SF_6 concentration to compute the span average:

$$\text{Span(avg)} = (x_1 + x_2 + x_3)/n,$$

where x = area counts for each determination. If the span average is within acceptance criteria, then the system is determined to be suitable for use. If the system fails to meet the zero or span check limits, the system will be troubleshot and the span check repeated. If the system does not meet span performance specification after corrective actions, it will be repaired and re-calibrated.

Table 3. Data Quality Indicator Goals for Critical Measurements.

Parameter	Measurement Device	Precision	Accuracy	Relative Precision	Complete -ness
Chamber SF_6 Concentration	Innova 1312 Photoacoustic Multi-gas Monitor	± 15 % RSD for 3 one min averages at 80% of full scale	±15 % of SF6 standard at 80% of full scale	±15 % of SF6 standard at 80% of full scale	90 %
Particle number size distribution (aerodynamic)	TSI APS 3321	±2% of reading	NA	±15% RMSE for collocated monitors	90 %
Particle number size distribution (optical)	Grimm 1.108 Portable Dust Monitor	±2% of reading	NA	±15% RMSE for collocated monitors	90 %
Continuous PM2.5/PM10 concentration (optical)	Thermo Electron pDR-1200/1000AN	±2% of reading or 0.0015mg/m3, whichever is larger	±5% of reading ± precision	±15% RMSE for collocated monitors	90 %
Particle number size distribution (optical)	Climet-500CI (6 size categories from 0.3 to >10 µm)	±10% of reading	NA	±50% RMSE for collocated monitors	90%

Sample Handling and Custody Requirements

The material samples to be tested will be obtained from manufacturers/suppliers directly, and stored in a designated storage room under controlled environmental conditions before testing. Sample custody procedures will be used to ensure the sample integrity and the process will be documented. A lab technician will be responsible for documenting the production dates, transportation/handling processes, and the length of time stored before testing. Samples will be taken and analyzed within three months. All samples will be tagged in indelible ink to indicate sample location, sample type, date and time. Every sample will be assigned a unique identification code, which follows the sample through analysis and logging of all data. Samples will be logged in the field on individual data sheets and in the field log book. All activities will be logged into a permanent, bound logbook for duration of the sampling. Data sheets will accompany the samples when shipped or hand carried from the chamber to the laboratory.

The project evidence will be under the custody of the PI and the sample custodian is the laboratory coordinator at the individual labs. The project evidence will contain all field data sheets, results of laboratory analyses and copies of the site log entries. All pertinent information from the data sheets will be transferred to electronic media via computerized spreadsheets. The computer files will be backed-up whenever new data is added and copies will be kept in secure areas at all times. Data generated by the analytical instrument will be stored in both electronic and hard copy formats. All samples will be stored for the duration of the project.

CONTAM simulations

The CONTAM program has been in existence for more than two decades and has been widely accepted for calculating building airflows and contaminant concentrations in building airflow systems. CONTAM employs established multizone mass balance analysis techniques that are used in all multizone airflow and IAQ programs and which have been examined in a number of validation studies (Emmerich, 2001; Emmerich et al., 2003). In addition, the analysis methods used in CONTAM have been compared to simple cases where close-form solutions exist (Walton and Dols, 2005). A conclusion of all these exercises is that the calculation procedures are sound and that the key determinants of the reliability of the simulation results are the input values used in the simulation and their correct entry into the software interface. An audit system to check data inputs to CONTAM simulation runs will be implemented.

Data Management

Routine procedures will be implemented to ensure that data generated in experiments conducted in the chamber lab and the CONTAM simulations are reviewed for completeness and accuracy, compiled, and archived so as to form a complete and secure record of an experiment. Three types of data will be generated in the course of each experiment or simulation: 1) data that describe the conduct of the test (e.g., set point conditions of the test chamber, sampling locations; model inputs); 2) data that describe the performance of the environmental control system during the test (e.g., relative humidity, air exchange rate); and 3) data that describe the emissions of the source (e.g., PM resuspended by human activity) determined at the sampling locations during the test. Data will be recorded in logical locations and forms during an experiment or simulation and will be brought together in a summary data spreadsheet that contains set points, summary environmental performance data, and concentration-time data for resuspension experiment. The summary data spreadsheet will become, in tabular form, an appendix to the written report that is the record of the experiment. Supporting electronic files and the summary data files will be periodically transferred to compact disc for archive.

Project Management Plan

This research team assembled for this project is uniquely qualified to perform this research. Dr. [redacted] will be responsible for the overall success of the project, insuring compliance with the QAPP, making sure there is adequate and meaningful communication and that the project remains on schedule. [redacted] will be responsible for leading the design and of the experimental work in Phase 1 as well as the modeling work in Phase 2. [redacted] will be responsible for managing the subcontract at NIST and interacting with the rest of the project team.

Work will be conducted concurrently at Clarkson and NIST, with several exceptions. The experimental work for Phase 1 will begin at Clarkson. Once all methods are in place, experiments at Clarkson and NIST will be conducted concurrently. Preliminary experimental data will be provided to the NIST statistician as soon as it becomes available so that he/she can set up the code for the statistical analysis. Each round of experimental data will be analyzed by the statistician to determine the significance of the results and to provide feedback for the next round of experiments. For Phase 2, NIST will program the resuspension module into CONTAM while Clarkson and NIST determine the exposure scenarios that will be tested. Then, Clarkson will run the scenarios and provide the results back to the project team for analysis. Both Clarkson and NIST will be involved in the communication of results in Phase 3.

Communication between investigators will include regularly scheduled conference calls (at least 1/month), frequent e-mails, and face-to-face visits. The investigators will meet at least once per year.

Table 4 provides an outline the overall project schedule.

Table 4. Project Schedule

Proposed Work Schedule - Tentative Start Date October 1, 2008

Task	**Months when work is performed on tasks**																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Develop QAPP	X	X																						
Phase 1		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Phase 2																					X	X	X	X
Phase 3																					X	X	X	X
Reporting			X			X			X			X			X			X			X			X

Task	**Months when work is performed**											
	25	26	27	28	29	30	31	32	33	34	35	36
Develop QAPP												
Phase 1												
Phase 2	X	X	X	X	X	X						
Phase 3	X	X	X	X	X	X	X	X	X	X	X	X
Reporting			X			X			X	X	X	X

Budget

See detailed budget form submitted separately.

Rating Factor 4: Leveraging Resources

Cost sharing by Clarkson University includes [redacted] for the tuition of two graduate student research assistant for three years. NIST has an internally funded project on aerosol model development that relates directly to the proposed effort and which will provide roughly [redacted] of cost sharing of both staff time and supplies. The NIST project that is related is an investigation of evaluation methodologies for air cleaning systems and involves chamber measurements of the performance of particle filtration devices. This project will provide experimental procedures and analysis methods that will be very helpful to conducting the proposed research. The leveraging includes the time for an engineer and a technician plus some expendable items for the laboratory work, including air sample tubing and sampling pumps; instrumentation calibration, laboratory expendables (e.g. compressed gas).

The following resources will be available for this study as in-kind contributions totaling over [redacted]: stainless-steel indoor chamber located at NIST ([redacted]); indoor air chamber located at Clarkson University ($[redacted]); aerodynamic particle counter: 1 TSI (St. Paul, MN) Model 3321 Aerodynamic Particle Sizer from Clarkson University ([redacted]); optical particle counters: 2 Grimm (Ainring, Germany) Model 1.106 Portable Dust Monitors from Clarkson University ([redacted]); 8 passive semi-continuous PM_{10} monitors: MIE Personal DataRam, Thermo Electron Corporation (Franklin, MA) Model pDR-1000AN from Clarkson University ($[redacted]; 8 active semi-continuous PM monitors: MIE Personal DataRam, Thermo Electron Corporation (Franklin, MA) Model pDR-1200 from Clarkson University (cost included above – pDR-1000AN models can be converted to pDR-1200 models); optical particle counters: 2 Climet (Redlands, CA) from NIST ([redacted]); integrated particle samplers: 20 Harvard Impactors (Boston, MA) PM-2.5 and associated pumps from Clarkson University ($[redacted]; SF_6 monitor: Innova (Ballerup, Denmark) Model 2312 Photoacoustic Multi-gas Monitor from Clarkson University ([redacted]; Multipoint sampler: CBISS (Birkenhead, UK) Mark 3 Intelligent Sampling System from Clarkson University ([redacted]; and solid aerosol generator: Topas GmbH ASHRAE SAG from Clarkson University ([redacted]).

Rating Factor 5: Achieving Results and Program Evaluation

Benefits and Outcomes of Project

The expected benefits of the proposed research will be the development of new scientific information related to exposure to particulate pollutants in homes. This project will improve our understanding of the relationship between pollutant and allergen concentrations in the house dust and human exposure. It will test the recommendation to remove carpets from homes to improve indoor air quality and reduce allergen loading. In addition, this study will calibrate and standardize the approach to assessing resuspension from human activity. This information will provide much needed data for use in exposure assessment and risk assessment studies of pollutants, biological agents, and allergens in the United States. This study will result in greater protection of public health by providing information that will inform the public about risks of exposure to pollutants found in house dust and how to decrease their exposure to these pollutants. For example, this study could provide scientifically-based guidance for homeowners and developers as to floor covering choices and associated maintenance to improve indoor air quality.

Performance Indicators and Documentation

Specific project performance indicators include publications and presentations at professional meetings by the investigators. The research progress will be summarized every quarter in a report to HUD. In addition, each phase of the research will be documented in individual reports followed by an all-inclusive final project report to HUD. Clarkson Ph.D. students will benefit from research training and the opportunity to develop their dissertations based on this work. Results from this study will also be published in several journals (e.g., *Atmospheric Environment, Journal of Exposure Analysis and Environmental Epidemiology,* and *Journal of the Air & Waste Management Association*). The study's particle resuspension rate test method has the potential to be published as an ASTM standard method or guide for use in future studies. The investigators will present results at multiple conferences including the *Annual American Association for Aerosol Research Conference*, the *Annual International Society of Exposure Analysis Conference*, and HUD-sponsored meetings. In addition to the scientific community, results will be formatted for dissemination to related segments of industry, specific at-risk population, and the general public.

Barriers and Contingencies

Success of the project is primarily dependent on the success of the test methodology, the usability of the flooring and exposure scenario databases, as well as the effectiveness of the public outreach program. Based on current work by the project team mentioned under Rating Factor 1, the team is confident that the test methodology is feasible. In case the mechanical device fails, the team can use a person walking with a defined cadence to resuspend the particles for different scenarios. To assure database usability, the databases will be tested by the project team and selected outside experts prior to the public launch date. The outreach program will be monitored by tracking website visitors to assess use of the databases and using a clipping service to track the impact press releases. The project team will conduct regular meetings to address and avoid other potential obstacles. Status of work will be reviewed quarterly by project team.

Logic Model Form

Several clarifications to the Logic Model Form, submitted separately, are provided below:

- "Samples" listed in the Logic Model Form should be interpreted as "experiments", for which a suite of monitors will be used. Each experiment lasts several hours and produces thousands of data points from the semi-continuous monitors that are used.
- For services "staff trained" and "samples collected", the outcome is the same as the services, that is, trained staff and samples collected. Therefore, an outcome is not listed.
- For the new service "develop exposure estimates for people living in residences with various types of flooring materials," "exposure scenarios" is listed as a measure. This is to indicate the number of screening-level exposure scenarios which will be used to represent a range of important factors related to resuspension, including particle characteristics, typical floor coverings, building characteristics and airflows, occupant loading and activities, and floor cleaning schedules.
- For the service of outreach and education, the number of "sessions" refers to the type of outreach beyond professional scientific publication and presentations (i.e., press releases, direct communication with industry, and articles in trade journals and newsletters).

We expect our guidance will result in reductions in housing related health hazards, including exposure to lead, mold, cockroach, dust mite, mice, cat, dog, and rat allergens, and other pollutants that are in house dust. Although we will not be able to directly quantify these reductions in actual homes for this study, we will be able to predict reductions given implementation of our recommendations. These predictions will be available via the exposure scenarios database.

Benchmarks and Milestones

Table 5. Benchmarks and Milestones

Phase	Task	Task Description	Start Date	End Date
1	1	Develop quality assurance plan	10/1/08	11/30/08
1	2	Test experimental methods at Clarkson	11/1/08	12/31/08
1	3	1st quarter progress report to HUD		12/31/08
1	4	Design and conduct first round of experiments	1/1/09	3/31/09
1	5	2nd quarter progress report to HUD		3/31/09
1	6	Analyze first round of experiments	3/1/09	4/30/09
1	7	Conduct experiments at Clarkson and NIST	3/31/09	6/30/09
1	8	3rd quarter progress report to HUD		6/30/09
1	9	Continue with Phase 1 experiments and analysis	6/30/09	9/30/09
1	10	Phase 1 report / 4th quarter progress report	8/1/09	9/30/09
1	11	Continue with Phase 1 experiments and analysis	9/30/09	12/31/09
1	12	1st quarter progress report to HUD		12/31/09
1	13	Continue with Phase 1 experiments and analysis	12/31/09	3/31/10
1	14	2nd quarter progress report to HUD		3/31/10
1	15	Compile data into database	3/1/10	4/30/10
1	16	Complete statistical analysis of data	3/1/10	6/30/10
1	17	3rd quarter progress report		6/30/10
2	1	Add resuspension rate module to CONTAM	6/30/10	9/30/10
2	2	Develop exposure scenarios	6/30/10	9/30/10
2	3	Phase 2 report / 4th quarter progress report		9/30/10
2	4	Enter exposures in CONTAM	10/1/10	10/31/10
2	5	Run CONTAM simulations	11/1/10	12/31/10
2	6	1st quarter progress report to HUD		12/31/10
2	7	Analyze exposure scenario results	1/1/11	3/31/11
2	8	2nd quarter progress report to HUD		3/31/11
3	1	Prepare publications for peer review	6/30/10	9/30/11
3	2	Prepare articles for trade journals and communications for trade associations	4/1/11	6/30/11
3	3	Prepare public guidance documents	4/1/11	6/30/11
3	4	Prepare press releases	4/1/11	6/1/11
3	5	3rd quarter progress report to HUD		6/30/11
3	6	Follow up and tracking on all levels of information dissemination	4/30/10	9/30/11
		Final Project Report	7/1/10	9/30/11

OMB Approval No. 2501-0017

Grant Application Detailed Budget Worksheet

(Exp. 01/31/2008)

Name and Address of Applicant:

Clarkson University
8 Clarkson Avenue, CU Box 5630
Potsdam, NY 13699-5630

Category — Detailed Description of Budget (for full grant period)

1. Personnel (Direct Labor)	Estimated Hours	Rate per Hour	Estimated Cost	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Position or Individual											
PI: [redacted]	1,040	$51.52	$53,576	$53,576	$0						
Graduate Student	3,900	$16.38	$63,889	$63,889	$0						
Graduate Student	3,900	$16.38	$63,889	$63,889	$0						
Total Direct Labor Cost			$181,354	$181,354							

2. Fringe Benefits	Rate (%)	Base	Estimated Cost	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Full fringe benefits	32.70%	$26,788	$8,759	$8,759							
Statutory fringe benefits	7.65%	$26,788	$2,049	$2,049							
Total Fringe Benefits Cost			$10,808	$10,808							

3. Travel

3a. Transportation - Local Private Vehicle	Mileage	Rate per Mile	Estimated Cost	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Trans - Local Private Vehicle											

Grant Application Detailed Budget Worksheet

Detailed Description of Budget

3b. Transportation - Airfare (show destination)	**Trips**	**Fare**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
PI Travel to Washington, DC annually	3	$1,000	$3,000	$3,000							
PI Travel to International meeting annually	3	$1,500	$4,500	$4,500							
				$0							
				$0							
				$0							
Subtotal - Transportation - Airfare			$7,500	$7,500							
3c. Transportation - Other	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Ground transportation to/from airports	12	$25	$300	$300							
				$0							
				$0							
				$0							
				$0							
				$0							
Subtotal - Transportation - Other			$300	$300							
3d. Per Diem or Subsistence (indicate location)	**Days**	**Rate per Day**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Washington, DC (annual)	15	$200	$3,000	$3,000							
International Meeting (annual)	21	$200	$4,200	$4,200							
			$0	$0							
				$0							
				$0							
Subtotal - Per Diem or Subsistence			$7,200	$7,200							
Total Travel Cost			$15,000	$15,000							
4. Equipment (Only items over $5,000 Depreciated value)	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Total Equipment Cost											

Grant Application Detailed Budget Worksheet

Detailed Description of Budget

5. Supplies and Materials (Items under $5,000 Depreciated Value)											
5a. Consumable Supplies	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Filters	600	$5.00	$3,000	$3,000							
Test dust (ISO ultrafine)	12	$150.00	$1,800	$1,800							
tracer particles (monodisperse PSL)	24	$150.00	$3,600	$3,600							
batteries (NiCad)	42	$5.00	$210	$210							
batteries (lithium)	12	$100.00	$1,200	$1,200							
			$0	$0							
			$0	$0							
Subtotal - Consumable Supplies			$9,810	$9,810							
5b. Non-Consumable Materials	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Tubing	350	$5.00	$1,750	$1,750							
Ducting	36	$40.00	$1,440	$1,440							
Staging	1	$1,000	$1,000	$1,000							
Other construction materials	1	$1,000	$1,000	$1,000							
			$0	$0							
			$0	$0							
Subtotal - Non-Consumable Materials			$5,190	$5,190							
Total Supplies and Materials Cost			$15,000	$15,000							
6. Consultants (Type)	**Days**	**Rate per Day**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Total Consultants Cost											
7. Contracts and Sub-Grantees (List individually)	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
NIST	1	$350,065	$350,065	$200,065						$ [redacted]	
Total Subcontracts Cost			$350,065	$200,065						$ [redacted]	

form HUD-424-CBW (2/2003)

Grant Application Detailed Budget Worksheet

Detailed Description of Budget

8. Construction Costs

8a. Administrative and legal expenses	Quantity	Unit Cost	Estimated Cost	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Administrative and legal expenses											
8b. Land, structures, rights-of way, appraisal, etc	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Land, structures, rights-of way, ...											
8c. Relocation expenses and payments	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Relocation expenses and payments											
8d. Architectural and engineering fees	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Architectural and engineering fees											
8e. Other architectural and engineering fees	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Other architectural and engineering fees											

Grant Application Detailed Budget Worksheet

8f. Project inspection fees	Quantity	Unit Cost	Estimated Cost	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Project inspection fees											
8g. Site work	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Site work											
8h. Demolition and removal	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Demolition and removal											
8i. Construction	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Construction											
8j. Equipment	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Equipment											
8k. Contingencies	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Contingencies											
8l. Miscellaneous	**Quantity**	**Unit Cost**	**Estimated Cost**	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Subtotal - Miscellaneous											
Total Construction Costs											

Grant Application Detailed Budget Worksheet

9. Other Direct Costs											
Item	Quantity	Unit Cost	Estimated Cost	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
Publication Costs			$2,000	$2,000							
Communications and postage			$1,500	$1,500							
CARES Analytical Services			$20,000	$20,000							
Graduate Student Tuition			$62,480		[redacted]						
Total Other Direct Costs			$85,980	$23,50[redacted]							
Subtotal of Direct Costs			$658,207	$445,727	[redacted]						

10. Indirect Costs												
	Type	Rate	Base	Estimated Cost	HUD Share	Applicant Match	Other HUD Funds	Other Federal Share	State Share	Local/Tribal Share	Other	Program Income
56% of MTDC	MTDC	56.00%	$250,662	$140,371	$140,371	$0						
Total Indirect Costs												
Total Estimated Costs				$798,578	$586,098	[redacted]						

Organizational Chart