Carpet in the Modern Indoor Environment
Summary of a Science-Based Assessment of Carpet

Michael A. Berry, Ph.D.[ab]
Chairman

2003 REVIEW OF CARPET

A panel of ten academic and industry researchers and technical specialists met at the University of North Carolina at Chapel Hill on July 29-30, 2003, to critically examine peer-reviewed or otherwise credible science with regard to the positive or negative attributes of carpet in the modern indoor environment. The review was organized to assess environmental benefits of carpet as well as negative perceptions and environmental concerns. The primary objective of the expert review was to examine key studies that address carpet as a major contributor to indoor environmental quality and as a possible source of adverse human response. Regarding the latter, the panel was asked to closely examine any relevant scientific data related to toxic substances and allergens commonly found, or alleged, to be in and over carpet and related non-carpet surfaces. The panel was also asked to evaluate maintenance and management practices related to long-term carpet performance and health protection.

A robust assessment of carpet is fundamental to any objective judgment related to carpet and human exposure indoors. A responsible decision with regard to carpet in sensitive environments, such as schools and health care facilities, should be based on factual, documented evidence. Therefore, it is intended that this body of information be considered in the process of establishing public and industry policies with regard to carpet, carpet buying decisions, and responsible communication with consumers, public administrators, and the technical community.

Hundreds of studies were examined in the course of this review. The review examined the scientific literature at large, but mainly focused on information found throughout the peer-reviewed technical literature, National Health Sciences Libraries, EPA's research information database, and previous reviews and conferences conducted by recognized experts.

In advance of the meeting, each expert prepared a review paper for his or her specialty area. These papers were the basis for presentations and discussion at the workshop. Each expert took and heard comments and critiques from other panel members. In the exchange, new sources of information were identified, points of view surfaced, and important issues were highlighted. The authors represented in Part I, along with the titles of papers they prepared and presented, are indicated below:

Dr. Alan Hedge: Professor, Cornell University. Director of Human Factors and Ergonomics Laboratory, Department of Design and Environmental Analysis. Research and teaching focus on issues of design and workplace ergonomics as they affect health, comfort and productivity of workers. ***Ergonomic Design Issues and Carpet: A Review.***

Dr. P. Barry Ryan: Professor, Department of Environmental and Occupational Health, Rollins School of Public Health at Emory University. Research interests focus on understanding the impact of environmental pollutants on human health through exposure assessment. ***The Impact of Carpeting on Indoor Air Quality and Health: An Annotated Bibliography.***

Dr. Mitchell W. Sauerhoff: Board certified toxicology consultant with faculty appointments at the University of Connecticut Medical School (Medical Toxicology) and School of Pharmacy (Toxicology Division). Assists in

[a] Review Panel Chairman, Research Professor at University of North Carolina at Chapel Hill.
[b] Prepared October 2003.

training emergency room physicians in principles of medical and industrial toxicology. ***Carpets, Rugs, and Health: A Current Perspective.***

Dr. Alan E. Luedtke: Product Steward, Invista/DuPont Nylon Flooring Systems. Research areas include impact of process variables on carpet emissions, VOCs from carpet and carpet installation materials, efficacy of carpet cleaning, and the release of easily suspendable particles from surfaces. ***Floorcoverings, Dusts, and Airborne Contaminants.***

Dr. Karen K. Leonas: Professor of Textile Science, University of Georgia. Research areas include fabrics as barriers to liquid and small particle transmission, biomedical textiles, Laser Scanning Confocal Microscopy evaluation of textiles, and antimicrobial treatments for carpets and other areas. ***Microorganisms in Carpet.***

Karin K. Foarde: Research Triangle Institute, Senior Microbiologist and Manager of Environmental and Industrial Sciences' microbiology laboratory. ***Measurements of Biocontaminants in Two Schools: The Impact of Carpet vs. Smooth Floor Covering.***

Dr. Roger D. Lewis: Associate Professor of Community Health in Environmental and Occupational Health at Saint Louis University School of Public Health. Teaches management and control of environmental occupational health hazards, risk communication, control of infectious disease, and occupational safety. Board certified industrial hygienist. ***Retention and Removal of House Dust Contaminants from Carpet: Integrating our Knowledge of Source Dusts, Carpet Properties, and Carpet Cleaning for a Healthier Indoor Environment.***

Jeff Bishop: Administrator of Clean Care Seminars, Inc., teaching over 50 courses annually in seven cleaning and restoration subjects. Chairman of the Institute of Inspection, Cleaning, and Restoration Certification's Certification Board and Director of the International Society of Cleaning Technicians. 1) ***The Science of Carpet Cleaning and 2) Cases of Effective Carpet Cleaning.***

Dr. Michael A. Berry: Research Professor, Carolina Environmental Program, University of North Carolina at Chapel Hill. Retired Deputy Director of USEPA National Center for Environmental Assessment at Research Triangle Park, NC. Research interests include environmental science education, environmental risk assessment, built environments, and environmental management systems. ***A Systems Modeling Approach to Assessing Carpet and Environmental Risk.***

Louise Dobbs served as the workshop coordinator. The staff of the University of North Carolina Health Science Library conducted initial literature searches and retrievals and the University of North Carolina Friday Center for Continuing Education provided IT support and a comfortable facility in which to conduct the workshop.

SUMMARY OF A SCIENCE BASED ASSESSMENT OF CARPET

Major Findings

- A comprehensive review of the literature supports the contention that carpet is a significant positive contributor to the quality of life indoors. The purpose of every indoor environment is to provide for security, comfort, social interaction and productivity. A healthy indoor environment is one that achieves these four purposes and radiates a "sense of well-being" to inhabitants. An elevated sense of "well-being" is the basis for the human condition we call "healthy." Reviewers, working independently, noted how carpet contributes to these "healthy design" factors: usable space that promotes social interaction and productivity; safety as in the prevention of slips and falls; aesthetics; physical comfort and ergonomics; lighting to include the management of glare or light reflectance; acoustics and the management of noise; climate control in keeping the surrounding space warm, cool, and dry; and cost effective maintenance with minimal environmental impact.

- Carpet is a product designed specifically to enhance the quality of life indoors. From an environmental science perspective, the desirable aspects of carpet are based on the fact that carpet is an energy absorber with a strong tendency to adsorb matter. Because of these properties, carpet is acknowledged in many health-related documents as having desirable attributes for sensitive environments. Carpet creates a sense of well-being in sensitive environments, particularly nursing homes, hospitals and schools.

- As with any high-volume-use indoor product, when carpet is reasonably maintained, it poses no adverse exposures or health effects. When installed and maintained as intended, carpet is not a risk to public health. When examined in proportion to its use, carpet is associated with minimal complaints, consumer dissatisfaction or concern. Research going back over 40 years consistently shows that carpet is a preferred and widely used floor covering associated with long-term consumer satisfaction. In the United States alone, there are approximately 150 billion square feet of carpet currently installed in over 100 million buildings. About 2 billion square yards of carpet are installed annually. A large proportion of the developed world's population is exposed to carpet, and so it is remarkable and significant that this review found no epidemiological or toxicological studies presenting clear or direct evidence that exposure to carpet in any environment causes an adverse human health response. Furthermore, where controlled studies have been conducted in relation to carpet chemical emissions and animal and human response, no adverse response was found to have occurred.

- Carpet does not emit concentrations of VOCs that present a real risk. Carpet entraps particulates and removes them from the indoor environment. When weighing the different factors in making a flooring selection, health effects, if considered at all with regard to carpet, should be considered in a positive rather than negative context.

- The most controversial aspect of the impact of carpeting on air quality is the perception of indoor air quality in buildings containing carpeting. Only recently – essentially within the timeframe for this review – have scientists attempted to quantify this effect of carpeting, despite the fact that odor perception studies have been undertaken, primarily in occupational settings, for over 30 years. In the current review of the literature the "perception" of the quality of air indoors may be the parameter most closely associated with non-quantified or non-quantifiable health effects including sick building syndrome and multiple chemical sensitivity.

- The review indicated that there are a vast number of studies that describe, measure, and address particles, dusts, allergens, and other contaminants of all types in carpet and other indoor surfaces. In these studies, no source and exposure relationships were established between contaminant accumulations in carpet and airborne concentrations of particles and dusts. This is consistent with the lack of finding a direct link between carpet and human health effects. This is a fundamental risk assessment finding that has significant non-exposure implications. Human response cannot occur unless there is exposure and sufficient dose delivered to the human receptor.

- Wet, dirty carpet will support microbial growth. However, less is known by way of the literature about human exposure and response to this microbial growth – other than symptoms tend to diminish with drying and cleaning of these spaces. Studies of damp or water-damaged environments tend not to consider or sort out the specific roles of the various building materials.

- Recommendations to remove carpet to reduce or prevent allergic responses have not been based on studies showing a relation of carpet to allergic reaction. This review failed to find any study or benefit analysis of carpet removal from sensitive environments. If carpet alone was removed from environments for the purpose of preventing or reducing allergic response, there is no evidence in the literature that allergic condition or response improved. Recent allergy conference held at the Royal Society of Edinburgh supports the above finding. *"In the past 10 years there has been a generalized trend for the removal of carpet in home and public places. This has been widely recommended and has occurred despite the absence of studies demonstrating beneficial effects of isolated removal. Indeed, in Sweden between 1973 and 1990 there has been a 3-fold increase in asthma and allergy despite an 80% decline in carpeting and substitution and laminate flooring."* (Devereux, 2003, pg 402)

- In sensitive environments like hospitals that have been studied for nearly 40 years in relation to carpet, there is no indication that carpets contribute to the spread of disease. A recent CDC expert workgroup concluded: *"Broad recommendations against the use of carpets in immuno-compromised patient care areas have been removed from this Guideline, since there is no epidemiological evidence to show that carpets influence the nosocomial rate in hospitals."*

- Little published research is available on the presence of microorganisms in carpet. Although some studies have compared the presence of microorganisms in rooms with carpet and those in rooms without carpet, much of the reported research provides information on air quality. Most carpet today that is used in commercial settings is produced from synthetic materials including nylon, polypropylene, polyester and SBR. Unlike materials used historically, such as wool, cotton and jute, these fibers do not support the growth of microorganisms. Their chemical composition does not inherently provide the nutrients required to support microorganism growth. In addition, these products have low moisture regain, and therefore, excess moisture is not present in the components of modern day soft floor coverings.

- Wool, cotton and jute all have relatively high moisture regain (approximately 15%, 10% and 10% respectively) and are susceptible to microorganism attack. Jute, although resistant to microorganism attack, will deteriorate rapidly when exposed to moisture. Insects and microorganism that may be present are looking for a food source. Carpet made with synthetic fibers will not sustain insect life. When insects are found on carpet, either the carpet is a pathway, or they are eating something spilled or tracked on the carpet. The best solution is to keep carpet and rugs clean to eliminate the insects' food source. There is little recently reported research that looks at the presence of microorganism in today's carpet.

- Published, peer-reviewed research suggests that carpet floor covering is not the major contributor to airborne levels of biocontaminants in non-problem schools. This review examined recently conducted and published school research. Two schools, as similar as possible with the exception of their floor coverings were selected, one predominantly tiled and one predominantly carpeted. Neither school was a 'problem' building. Multiple biocontaminants were measured. For flooring, there were statistically significant differences for all the tested parameters except fungi. As expected, the carpeted surfaces, being strong sinks, contained higher levels of measured contaminants except for fungi. However, airborne allergen levels were statistically significant higher over hard floors than carpeted floors. Significant differences were found for spores, fungi, and dust mass.

- The interaction of carpet types with vacuum cleaners and dust loading, suggests that a systems approach be used for addressing the removal of house dust contaminants from carpets. If carpet is to remain a staple of the indoor environment, then an understanding of the source of dust-borne contaminants - how they are retained, released, and removed - may inform the debate on how to maintain a healthy indoor environment.

- This review finds that that the body of science related to effective carpet cleaning is not broadly published and disseminated to the individuals who need the information. Proper maintenance and cleaning, employed proactively in a well-planned and managed built environment, can prevent or solve most problems related to IEQ issues. Much, if not most, of the current body of science related to carpet cleaning appears to concentrate on somewhat narrow, quantifiable issues, rather than the overall result of the cleaning process.

- There is a body of research based on well established environmental management principles that has evolved over the past 15 years that helps us better understand the impact of carpet and carpet clearing activities on the quality of indoor environments. These studies point to the fact that there are scientific principles behind effective carpet cleaning and that carpet cleaning is an integral part of the overall environmental strategy necessary to keep indoor environments (environments where people spend the vast majority of their time) inviting, comfortable, productive and safe. An effective cleaning program must emphasize (tested) technology directed at maximum extraction, minimum residue, safety, and ease of use; a cost effective cleaning strategy plan and schedule; training and recognition of cleaning technicians; and periodic inspection, assessment and management review of cleaning programs.

- Every high use building requires cleaning as intense and frequent as any high use office complex. With regards to the proper maintenance of floor surfaces, BOMA-published statistics show that cleaning cost is reduced in relation to carpet environments. BOMA estimated maintenance in carpet environments to cost $0.64 per square foot of flooring as compared to $1.24 per square foot for VCT. An independent cost analysis done as part of this assessment came to same general conclusion ($1.38 per square foot for VCT and $0.83 per square foot in a 12-month school year operation.) In addition, there are a number of hidden costs and environmental life cycle considerations including water use, chemical use, residue disposal, storage and labor stress, which are all considerably higher for hard floor maintenance than for carpet maintenance.

- The review established that clean carpet poses no risk to public health. The amount of matter in any environmental compartment, such as dust in carpet, is referred to as "loading." Field data suggests that carpet with a loading of less that 1 gm/ m^2 is for all practical purposes "sanitary." However, carpet with loading greater that 2 gm/m^2 is more likely to release matter to the surrounding environment, elevating exposure and risk. Kinetic modeling suggests that IAQ is most influenced by ventilation and cleaning practices. Models and first-order relationships suggest that carpet has the physical potential to negatively influence IAQ when carpet is heavily loaded with matter. Tracking, not air deposition, is the primary means of loading carpet. Heavily loaded carpet has the potential to influence IAQ more than other elevated surfaces indoors because of the large amount of matter carpet is capable of holding, a small portion of which is eventually transferred to air. Modeling suggest that so long as that matter deposited in carpet is not excessive or is managed, through walk off mats, vacuuming, and extraction carpet cleaning, IAQ is not adversely affected.

Ergonomic Design Issues and Carpet (Dr. Alan Hedge)

The science-based literature contains information on key ergonomic factors related to carpet: safety, slips and falls, comfort and acoustics. Professor Alan Hedge found it challenging to locate science-based information related to the ergonomic benefits of carpet primarily because there are obvious and automatically assumed benefits. Dr. Hedge found that the best documented attributes of carpet are found in literature related to slips and falls and, to some extent, comfort. Noise control is also an attribute of carpet, but is not clearly indicated in contemporary design literature.

Dr. Hedge makes a persuasive case in showing science-based attributes of carpet in relation to human physiology, especially with regard to the elderly, who are a growing segment of the population. From Dr. Hedge's review and presentation, one can conclude that carpet, which represents about 74% of floor covering, is a powerful contributor to a healthy, safe, and ergonomically sound indoor environment and to the quality of life indoors.

The gathered evidence suggests that carpet may offer several benefits for indoor environments, but organized confirmatory studies of these obvious benefits generally are lacking. Dr. Hedge's review indicates the need to get information on ergonomic and environmental benefits into the scientific literature. Future research on the effect of carpet on the ergonomic design of interiors should focus on addressing the following:

- How does carpet affect the risks of slips and falls?
- How does carpet affect standing comfort and fatigue?
- How does carpet affect the thermal insulation of the floor?
- How does carpet affect the acoustical design of a room?

The Impact of Carpeting on Indoor Air Quality and Health Effects Review of the Literature (Dr. P. Barry Ryan)

Dr. Barry Ryan conducted a detailed and critically thoughtful review of the scientific literature that included several hundred abstracts related to carpet and IAQ dating from the late 1980's. He observed that IAQ issues related to carpet have evolved through three phases:

- The first phase (1988-1994) centered around concerns and unknowns, such as public health "maybes," related to 4-PCH, various VOCs, and TVOC exposures. Most of these concerns disappeared from the scientific community discussion after investigation failed to show a toxicological-based cause/effect relationship.

- Phase 2 (1994-2000) centered on recognition of carpet as a strong "sink" and secondary source. During this phase, scientific discussions of mass balances and carpet as reservoirs or compartments for particles and allergens dominated. Many of these issues remain unresolved. Questions linger about chemical mixtures and secondary VOC compounds. Research is suggested by these concerns, e.g., trace formaldehyde as the result of ozone exposure.

- Phase 3 (2001-Present) was described by Dr. Ryan as the era of "perception." He reported a reduced level of productivity associated with perceptions derived from indirect exposure to dirty carpet. Dr. Ryan held a strong opinion that the paper was important because it indicated the need to address scientific methods to examine perceptions.

In spite of Dr. Ryan's review, there appears to be reoccurring clusters of 'public health correctness' or 'prudent avoidance' practices when it comes to removing carpet from sensitive environments. However, nowhere can a source of scientific data be found to support this recommendation. There are numerous papers and documents in the literature critical of carpet, such as with 4-PCH and VOC issues. As noted by Dr. Ryan, these cluster in well-defined time periods and, in the absence of scientific evidence, most are forgotten or deemed to be irrelevant. However, other documents, some containing errors and misinformation, remain in circulation and continue to serve as the basis for decision-making. For example, one of the often cited and misleading sources of information is the "The Healthy School Handbook" put out by the National Education Association in 1994. This document is widely used by school administrators and is often cited as the basis for removing carpet from schools.

Much of the challenge to carpet today - and where concerns exist no matter how limited - centers on the "perception" that carpet is the source of adverse human response. Dr. Ryan has made an important recommendation to the carpet industry and the scientific community that, if perceptions are to be understood and addressed, then credible scientific methods must be devised and applied by which to study them. Clearly, if we are to understand human response indoors, we need to better understand and study human perception.

Carpet, Rugs and Health - A Current Perspective (Dr. Mitchell Sauerhoff)

Dr. Mitchell Sauerhoff presented a review of the toxicology issues previously associated with carpet and an evaluation of previous studies and risk assessments. He concurred with previous assessments in the finding of no observable or likely human response to exposure of chemicals emitted because of remarkably low concentrations and toxic potentials.

Dr. Sauerhoff made reference to his periodic encounters with "sick building syndrome" claims which, in his professional opinion, are never related to carpet exposure. Dr. Hedge also commented that what is called "sick building syndrome" is a sensationalized description that has long been established as "tight building" condition. Dr. Berry concurred and recommended a return to using the correct term, "tight building," in the interest of good science.

Dr. Sauerhoff made mention of some indication in the literature of possible concerns over the secondary formation of formaldehyde as the result of ozone exposure. Chemical mixtures many also be a concern.

There was no disagreement from any member of the committee on Dr. Sauerhoff's assessment. The following questions were posed: "Is there any science, published or otherwise, that indicates adverse human response to chemicals emitted from carpet?" No member of the expert committee or observer at the meeting knew of any science. The following question was then asked: "If there are no known or likely health effects associated with carpet chemicals, why are consumers, taxpayers, government agencies, and the carpet industry spending millions of dollars looking at and measuring chemicals at levels not indicated by the science to be a problem?" There was no explanation, rational or political, given.

Dr. Sauerhoff concluded, "What I have learned and attempted to communicate today is that carpet is not a public health concern. Carpets do not emit concentrations of VOCs that present a real risk. Carpet entraps particulates and removes them from the indoor environment. The decision process for selecting different types of floor covering may be difficult with the choices available. However one weighs the different factors in making a flooring selection, health effects, if considered at all, should be considered in a positive, rather than negative, context."

Dr. Ryan's findings of perception and abnormally extreme physical sensitivity suggest we can continue to expect infrequent concerns related to low level exposures of odorous organic chemicals.

Carpet, Dusts, and Resuspension (Dr. Alan Luedtke)

Dr. Alan Luedtke presented data from an exhaustive review of the scientific literature showing the composition and quantity of carpet dusts. His presentation was highly insightful in showing the physical conditions necessary for certain substances to suspend in air, deposit onto flooring surfaces, and re-suspend into air. He identified the size range and composition of dusts most likely to re-suspend from carpet under various carpet loading and activity scenarios.

Dr. Luedtke has assembled a comprehensive, well-documented analysis of carpet dust. When published, the data will be very useful in the current effort to model the transfer of matter through various indoor compartments and to evaluate the potential efficiencies of cleaning systems and methods.

Human exposures associated with indoor contaminants are very complex. There are a myriad of contaminants, a wide range of physical characteristics of contaminants, the influence of building systems, the impact of building occupants, the effects of occupant activities, the role of moisture, the effects of building care and the influence of outdoor conditions.

The majority of contaminants that accumulate on smooth floors, in carpet, and on other surfaces are outdoor sourced. Dusts and soils on flooring areas result mostly from foot traffic. Assessment of the sources for dusts on elevated surfaces is more difficult to determine. However, settled dust from ambient air, particles from indoor activities, and resuspension of dusts from floors and upholstery appear to explain much of these accumulations.

The composition of soils and dusts can be broken into two generic categories: bulk dust, which represents most of the total mass, and the trace contaminants. The bulk components of dust appear to be relatively similar worldwide – mixtures of inorganic particles, cellulose fibers, animal dander, and high molecular weight organics (oils, resins, gums). The trace contaminants consist of potential allergens, low volatility organic compounds (pesticides, PCB's, etc.) and heavy metals. From a human health standpoint, the trace substances carry the most interest.

As expected, carpet almost always carries a higher burden of soils, dusts, and trace contaminants per unit area than smooth surfaces. For a large number of contaminants, the levels are similar on a-per-gram-of-dust basis. However, carpet dusts on average trend higher and, in a few instances, are statistically higher. One rationale offered was that organic substances and spores deep in the carpet pile were somewhat protected from the destructive properties of light. In a majority of the studies reviewed, the actual differences are not large and rarely exceeded a factor of two; in most cases the differences are a few percent.

The primary route of human exposure for most contaminants of concern is inhalation. Despite the fact that carpet typically carries higher burdens of contaminants than smooth surfaces, it is extremely rare to find a study which reports a statistically significant contribution for carpet of contaminants to the air. In most of the science reviewed, indoor concentrations of contaminants are most frequently driven by outdoor conditions or by building occupant activities. There is no correlation between dust mite allergen loads in carpet and airborne concentrations. Cat allergen is the only allergen which seems to show a relationship between dust loadings of any surface and air concentrations.

Several studies estimated that only about 1% of bulk carpet dust was available for dermal contact. It would not be unreasonable to expect that the contaminants re-suspended from a carpet would come from this fraction, and hence, a relatively low level source of airborne particles.

There is a substantial amount of data which indicates small particles (<5 microns) are not easily re-suspended. This is a positive from the standpoint of exposure to lead (Pb), pesticides, PAH's, and PCBs, which were associated predominantly with submicron particles. Larger particles (>25 microns) are not frequently observed in air because they tend to be removed more efficiently via deposition, do not become airborne easily, and settle quickly. Even though particle size fractions in the range where many allergens reside (10 to 25 microns) are more easily re-suspended than other size fractions, there are indications that the percentage of available particles is quite small. Overall, it appears the ratio of airborne concentration of a contaminant to surface source loading ranged from 10^{-3} to 10^{-6}.

There are areas where additional work would be helpful in order to better understand and define the role of carpet and other floor coverings with respect to indoor exposures. The first is to develop a more comprehensive understanding of the relationship between the physical properties of a surface and the propensity to release 10-25 micron particles with a disturbance. This would also include an assessment of carpet construction variables as well. Another need is to develop a better understanding of the contaminant loading capacity of various carpets because carpet functions as a significant sink for several key contaminants. It would be beneficial to know when carpet begins to function as a significant source. A more comprehensive assessment of the kinetics associated with the movement of contaminants onto carpet, within carpet, and out of carpet would be anticipated to provide models which could reliably predict human airborne exposures.

Microorganisms in Carpet (Dr. Karen Leonas)

Dr. Karen Leonas correctly indicates that the carpet industry and its suppliers have noted a loss of market share in commercial settings such as schools and hospitals over the past several years. This has occurred most notably in the southeastern United States where humidity is high and environmental conditions support the growth of mold and mildew. It was estimated that in 1999 the carpet industry was losing approximately $2 million annually due to the perceived relationship between soft floor coverings and an increase in the presence of mold, mildew and illnesses.

The paper presented a review of the current literature on microorganisms in the indoor environment and the impact of carpet on their presence. Much of the research completed in this area has focused on allergens of dust mites, cockroaches and pet dander. However, there is limited information on microorganisms cultured from indoor air samples, which is the focus of this review. The information is presented in three sections: 1) a discussion of allergens and pathogens that are linked with allergies, illness and infections; 2) a general overview of microorganisms and antimicrobial chemicals, specifically the finishing of textiles, and; 3) carpet-related testing to reduce the presence of microorganisms in carpets.

Dr. Leonas made a comprehensive and informative review on antimicrobials applied to fabrics specifically for the control of bacteria and fungi. She presented information regarding the variation of organism response to different classes of antimicrobials. This information is useful in the developing cleaning science as well as to understanding the efficacy of antimicrobials specifically designed for carpet.

Dr. Leonas described research results from a study in which antimicrobals were applied to carpet installed in a very active school environment. Antimicrobials were applied to just the face pile of the carpet and to both the face pile and backing of the carpet. The treatment was found to be most effective when both the face pile and carpet backing were treated. Dr. Leonas indicated that the potency of the antimicrobials was diminished after 18 months.

Dr. Leonas surfaced as one of the very few addressing antimicrobial applications. Considering today’s microbial anxiety, a hard look at antimicrobial treatments applied to carpet is warranted. There must be a balanced, science-based discussion surrounding consumer anxieties over antimicrobials, as well as limited, but useful and safe applications in special, high-microbial risk environments like hospitals and nursing homes where extensive dermal contact is not involved. This review suggests a need to better study the effective use of antimicrobials in some special situations, hospitals and nursing homes, and possibly the need for developing communication strategies for discussing antimicrobials with consumers.

Carpet and Biological Measurements (Karin Foarde)

Karin Foarde presented results of a carefully designed study on the biocontaminant levels associated with carpeted floors and smooth surface flooring in two schools located in rural North Carolina. The objective of this study was to determine if there was a quantifiable difference in biocontaminant levels between a school with predominantly carpeted floors and a school with predominantly vinyl composite tile (VCT) smooth surface flooring.

Floor covering is just one of many factors that can vary between schools. To effectively assess the biological contributions of carpet versus smooth flooring to the school environment and within the cost constraints of the study, it was important to minimize the impact of the other variables.

Two primary criteria were used to select the site: the school management had to be willing to participate and to be supportive of the research effort and the schools had to meet our school profile. The school profile focused on the engineering aspects of the school buildings and identifying schools with similar ventilation systems in the zones being sampled, similar student loads, building age, etc. The two schools selected for the study were comparable in age, design and student load, with the major difference between them being the type of floor covering. Both schools were non-complaint, non-problem buildings. The tiled school was a middle school and the carpeted school an elementary school.

The two schools were paired as closely as possible. Both were from the same school district and situated in rural locations in North Carolina and were first occupied in 1996. The HVAC systems were as similar as possible and appeared well maintained. Four basic efficiency fiberglass panel air filters were used in each air handling unit. The school system had a standard operating procedure for the cleaning and maintenance of all of the schools in the system. As best as could be determined, the procedure was followed in the two schools participating in this study.

The smooth surface school had tile floors in all areas with the exception of the administration and media center areas. In the carpeted school, the classroom floor area was two-thirds carpet and one-third tile. The halls, kitchen, cafeteria and art room were tiled; the music room, general purpose room, administrative areas and media center were carpeted. In total, approximately 70 to 75 percent of the floor was carpet. This percentage is typical of a school in North Carolina.

Each school was sampled five times throughout the school year. Sampling at each school took one full day; therefore, the two schools were sampled on sequential days to minimize any short-term climatic or weather differences. One primary goal was to collect a sufficient number of samples to perform statistical analyses on each parameter to help elucidate flooring differences and non-flooring differences, such as time of year. Therefore, between three and five replicate samples (depending upon the contaminant) were collected and analyzed each sampling trip.

Both air and floor dust samples were collected from the two schools. The air samples were analyzed for culturable fungi, total airborne spores, airborne PM2.5 dust mass (particulate matter with aerodynamic diameters less than 2.5 µm), allergens (dust mite, cockroach, and cat), endotoxins, and ß-1, 3 glucans. The dust mite, cockroach, cat allergen, endotoxins and ß-1, 3 glucans were quantified in the airborne PM2.5 dust sample. The floor dust samples were analyzed for culturable fungi, allergens (dust mite, cockroach, and cat), endotoxins, and ß-1,3 glucans.

A comparison of the floor contaminant loading, calculated per area of floor, showed that the carpet flooring had 25 times the concentration of biocontaminants as an equal area of tiled flooring, except for the culturable fungi. There were statistically significant differences in flooring contaminant loading between the two schools. This is not a surprising result because the floor dust samples were collected with a specialized research vacuum cleaner, and carpet is known to serve as a sink. One of the properties of carpet is that it holds and prevents tracking of dirt. Regular maintenance of carpet is desirable to prevent excessive loading of contaminants before tracking can occur.

Further comparison of the concentration of each contaminant, calculated per gram of floor dust, showed little difference in the concentration of the contaminants in the floor dust between the two schools.

The airborne sample analyses found no statistically significant difference in the airborne levels between the two schools for the three allergens, but significant differences between the two schools for airborne levels of spores, fungi, ß-1, 3 glucan, dust mass, and endotoxins. In all cases, the airborne levels in the tiled school were higher than the carpet school. The full implication of this finding is not clear. All of the parameters that were significantly different have outdoor sources in this study. Although the schools were paired as much as realistically possible, there may have been more outdoor air infiltration in the tiled school than the carpet school. Subtle differences can influence airborne concentrations. While there may be reasonable explanations for these differences involving the HVAC systems and outdoor concentrations, the results suggest that floor covering is not the major contributor to airborne levels of biocontaminants in non-problem schools. One possibility that should be investigated is that smooth surface floors permit a greater quantity of particle reintrainment than soft surfaces such as carpet. However, additional data are needed to support this idea.

Karin Foarde indicates that an excellent start has been made on collecting baseline data for carpet and smooth surface floored schools. However, care should be taken when extrapolating these data because only two schools were studied. Additional studies including other paired schools are needed. For example, a study of carpet loads that begin to significantly influence IAQ would be useful in motivating effective cleaning programs. Such a study would simultaneously focus on the measurement of carpet load, IAQ and outdoor air.

This work, although contrary to the personal opinions of some in the indoor environmental community, has been peer reviewed multiple times and is gradually making its way into the scientific literature. The findings suggest that adequately maintained carpet is not an IAQ detractor in schools. The data are consistent with much of the data collected by Dr. Luedtke and previous studies, e.g., Frank Porter Graham Study 1992, Charles Young School Study, 1998-2001.

Retention and Removal of House Dust Contaminants in Carpet (Dr. Roger Lewis)

Dr. Roger Lewis' review addressed the state of the science surrounding retention and removal of house dust contaminants in carpet. He presented studies that address contaminants, health issues, sources, mechanics of soiling and cleaning. He indicates that contemporary public health concerns about carpet dusts tend to focus on lead, dust mite, cat allergen, and their effective management indoors.

Dr. Lewis reviewed the results of a study he conducted for the Department of Housing and Urban Development in 1998 that produced very useful data on fluorocarbon coatings, surface area, wear and retention, and the removal of lead. In this well designed experiment, Dr. Lewis examined both dry vacuum and wet extraction of carpet dust containing lead using methods judged to be typical of those available to the average consumer. From the technology available in 1998, he found many vacuum cleaners cleaned with only marginal results. His main conclusion for the systems he examined was that dry vacuuming appeared to be superior or equivalent to wet extraction in lead removal. He noted that the interaction of carpet types with vacuum cleaners and dust loadings suggest that a systems approach be used for the removal of dust contaminants from carpet.

The research presented by Dr. Lewis is important because it shows the typical, marginally effective extraction results in common cleaning efforts. Although both Dr. Berry and Jeff Bishop commented that training and effective equipment will likely produce much greater lead dust extractions than those observed by Dr. Lewis in his experiment, Dr. Lewis' work points to a great need for cleaning equipment testing, training in cleaning methods and cleaning standards.

In his capacity as a public health educator, Dr. Lewis makes an extremely important observation for the carpet industry, health officials, and consumers alike: "If carpet is to remain a staple of the indoor environment, then a understanding of the source of dust borne contaminants, how they are retained, released, and removed may inform the debate on how to maintain a healthy indoor environment."

Logical follow-up research to this review would be a comparison of Green Label vacuums and effective carpet cleaning such as that used in Anderson Creek School to the result Dr. Lewis obtained in his 1998 lead extraction study.

The Science of Carpet Cleaning (Jeff Bishop)

Jeff Bishop presented a comprehensive overview of the science of effective carpet cleaning from the eyes of a national technical expert and educator in the professional cleaning and restoration industry. He noted that cleaning, as a process, is well defined in professional standards, as are the scientific principles and steps involved for effective carpet cleaning.

Summary of Carpet Cleaning Principles

1. Dry soil removal through vacuuming in three areas: overall with a commercial upright vacuum; in entries to remove abrasive particle soils; along edges to remove dust buildup.

2. Soil suspension through:

- chemical action to dissolve, suspend and emulsify soils
- elevated temperature (heat) to excite chemicals for optimum performance
- agitation for uniform chemical distribution to achieve maximum contact with soils, and
- dwell time to allow chemicals to suspend embedded or oxidized soils

3. Extraction of suspended soils through absorption, wet vacuuming, rinsing to flush suspended soils from fibers, and/or dry vacuuming following cleaning and drying to remove detergent and soil residues.

4. Finishing (grooming) of carpet pile to maximize appearance for customer; distribute additives, such as fabric protectors; promote drying by untangling tufts; and eliminate appearance of matting and crushing that causes complaints.

5. Drying to minimize customer inconvenience and promote safety and health using structure equipment (fans, HVAC system); procedural considerations (dry stroking, equipment maintenance); auxiliary drying equipment (carpet dryers, dehumidifiers).

Indoor environmental quality problems (IEQ) related to maintenance and cleaning must be viewed holistically. Currently, diverse cleaning applications appear unconnected. Building maintenance issues are disconnected, and daily housekeeping, periodic maintenance and restorative cleaning programs are seldom coordinated. Proper maintenance and cleaning, employed proactively in a well-planned and managed built environment, can prevent or solve most problems related to IEQ issues.

Most of the current body of science related to carpet cleaning appears to concentrate on narrow, quantifiable issues, rather than the overall result of the cleaning process. While there are several excellent studies on the types and quantities of soil in carpet, soiling methods are deficient in that they fail to reproduce the conditions that cleaners encounter normally in the field. The body of science related to cleaning is not broadly published and disseminated to the individuals who need the information. Many of the studies reviewed lack the perspective of a professional cleaner and fail to achieve credibility in the industry. Carpet cleaning frequencies, both residential and commercial, recommended by specifiers, architects, carpet retailers and manufacturers are unrealistic.

Jeff Bishop stresses that, if we are to be able to convince consumers that carpet has long-term value, we must be able to prove in the consumer's mind that it can be maintained routinely and restored to a highly acceptable condition with cleaning. Otherwise, consumers will opt for other types of floor coverings in the future.

Jeff Bishop was in agreement with Dr. Lewis that a body of science must be developed for the cleaning industry and the public at large. The Institute for Inspection, Cleaning and Restoration Certification's (IICRC) Carpet Cleaning Standard S100 is a step in the right direction, but more is needed. The carpet industry, along with the environmental health community, must be able provide end-users with referrals to effective systems and qualified cleaners, or we must be able to train in-house maintenance personnel in both the procedures and the "art" of carpet maintenance and cleaning. Additional studies should focus on simplifying procedures for more effective cleaning.

Jeff Bishop's review indicates an immediate high priority need to provide carpet cleaning techniques and guidance for the non-professional audience (in-house maintenance staff, homeowners).

A Review of Carpet Cleaning Research (Dr. Michael Berry, Jeff Bishop, Karin Foarde)

Jeff Bishop introduced a number of studies and research projects reviewed and provided by Dr. Berry which, if studied, can begin to address a widespread misperception that carpet cannot be kept clean (sanitary) and that because of its inability to be kept clean, carpet contributes significantly to a deteriorated indoor environmental quality, especially unhealthy indoor air quality. This unnecessary misperception often leads to misguided policy decisions for removing carpet from many environments such as schools, health care facilities and public agencies.

Overall, the health science literature indicates that carpet poses no risk to public health when it is clean. In addition, we have a body of science from over the past 15 years that helps us better understand the impact of carpet and carpet cleaning activities on the quality of indoor environments. These studies point to the fact that there are scientific principles behind effective carpet cleaning and that carpet cleaning is an integral part of the overall environmental strategy necessary to keep indoor environments (environments where people spend the vast majority of their time) inviting, comfortable, productive, and safe.

The Denver Study (1991)

The Denver Study strongly suggests that professional carpet cleaning with the wet extraction method is the most effective process in reducing contaminant levels of biopollutants and particles. The "before" and "during" cleaning measurements of air pollutants show that the highest concentrations of airborne pollutants were associated with environments that that were moderately to heavily soiled, cleaned infrequently, or were cleaned with methods that had excessive chemical or particle residue. This central finding in the Denver research suggests that an effective cleaning program is critical to improving or maintaining indoor air quality, even though the focus on the study was limited to carpet cleaning.

Frank Porter Graham Child Development Center Study (1993-1994)

The Frank Porter Graham (FPG) data demonstrates that both indoor and ambient environment pollution are significantly controlled through an effectively managed indoor cleaning program. In the FPG study, the building was approximately 70% carpet. The study reinforces a key finding of the 1991 Denver Study that carpet environments that are frequently vacuumed and cleaned applying the "maximum extraction and minimum residue" principle are not expected to be associated with indoor air problems.

Charles Young School Study (2001)

Maintenance of a high activity level, center-city school emphasized effective vacuuming and scheduled extraction cleaning of all parts of the building including carpet. This cleaning program was found by way of environmental measures to be highly effective in keeping the school building healthy. An investigation revealed the following: no unsanitary conditions or health complaints related to the building in any way; no indications of indoor air quality problems; and no student or teacher health response to allergens. Data collected in the most health-sensitive portions of the building found that indoor pollution levels tended to be higher over hard surfaces than over carpet.

The Anderson Creek School Study (2001-2002)

The results of the Anderson Creek School Study showed there were significant improvements in the form of decreases in the pre- and post-cleaning levels of airborne of endotoxins (56%), β-1, 3 glucan (48%), and cockroach antigen (66%). There was no difference in the airborne levels for the PM2.5 dust mass, dust mite and cat allergens, and culturable fungi, most probably indicating the holding strength of carpet. The extraction cleaning program resulted in reductions in the surface loading for all of the contaminants. Key to a successful cleaning program is effective extraction equipment, a system and schedule for cleaning, and the positive and proactive attitude of the custodial staff and leadership of the school and the school system.

The Air Quality Sciences Study of Carpet Cleaning (1999)

In this study, poorly maintained carpet from a high humidity/high temperature environment was cleaned and placed into a normal environment with humidity less than 65%. No mold regrowth was noted. After cleaning, test results from the previously contaminated carpet were comparable to those of a clean control carpet in terms of biocontaminants in the carpet and airborne particles.

Hydro Labs Mold Study (2001)

The main conclusion of the Hydro Lab research with respect to effective carpet cleaning is that the hot water extraction method of cleaning is highly effective in reducing the likelihood of mold growth and that clean carpet does not support mold growth even at prolonged and elevated temperature and humidity levels. It was clearly demonstrated that vacuuming carpet surfaces is highly effective in reducing and managing the levels of culturable mold spore. It is a conclusion for this project that for any organic material the following applies: organic matter plus water equals mold growth. The obvious management solution for mold indoors is to keep all carpet materials dry or at least clean.

The research conducted in recent years shows that carpet is most effectively cleaned when the following exist:

- A definition of cleaning as the process of locating, identifying, containing, removing and properly disposing of unwanted material. This means removing unwanted substances from an environment or environmental compartment. When exposure is reduced, the probability of an adverse effect is also reduced.
- Constant attention to and application of principles of maximum extraction and minimum residue especially as they apply to safety, the proper and effective use of chemicals, carpet extraction machines, and vacuum cleaners.
- A recognition that carpet cleaning must be conducted in relation to the management of sources of unwanted substances that can get into the carpet, activity levels, design of carpet and the environment in which carpet is installed, and ventilation.
- A consistent management program that emphasizes effective (tested) technology directed at maximum extraction, minimum residue, safety, and ease of use; cost-effective cleaning strategy, plan, schedule; training and recognition; measurement and management review.

The research projects discussed in this review indicate that environmentally sound, public-health-oriented guidance on carpet cleaning is currently represented by the IICRC's wet extraction guidelines. These guidelines were found to be highly effective in cleaning carpet in the most sensitive of environments and contributing to enhanced levels of environmental quality. The other methods described by IICRC do not achieve effectiveness objectives and are not indicated by the existing research as effective and efficient in pollutant removal as wet extraction carpet cleaning.

Already government agencies, such as the State of Pennsylvania, are pointing to effective wet extraction for the upkeep of carpet. This kind of guidance from government agencies can be expected to grow rapidly in the months and years to come.

A Systems Modeling Approach to Assessing Carpet and Environmental Risk (Dr. Michael Berry)

Dr. Michael Berry presented a paper that examined carpet in a broad, systematic manner in order to conduct a benefit-risk analysis for carpet. The main thrust of his assessment was directed at determining, applying, and explaining transfer rates of various substances to and from carpet, other flooring, and major indoor compartments and to assess the various effects of indoor environmental quality by way of mass balance modeling. This paper suggests the feasibility of using STELLA models to develop a portfolio of scenarios that can be used to explain noise, pesticide residue and fungal spore transfer between indoor compartments.

Dr. Berry presented modeling results of common indoor environment scenarios. His conclusions were as follows:

- The environmental benefits of carpet should be balanced with real hazards and their effective management. The healthy indoor environmental attributes of carpet include useful and flexible space, thermal and physical comfort, safety, aesthetics, glare reduction and noise control. These benefits are often overlooked or ignored in the face of nonexistent or trivial, anxiety-driven risk issues sensationally brought to attention of consumers from time to time.

- The principles of environmental science apply to the study of carpet indoors as much as they do to any other compartment in a particular environmental system. Therefore, kinetic modeling is useful in understanding the influence various indoor compartments such as carpet on other indoor compartments in the transfer of matter.

- Kinetic (mass balance) modeling suggests that IAQ is most influenced by ventilation and cleaning practices. Heavily loaded carpet has the potential to influence IAQ more than other elevated surfaces indoors because of the large amount of matter carpet is capable of holding. Carpet with loading greater that 3 gm/m^2 is indicative of heavy loading and is likely to release matter to the surrounding environment.

- The vast majority of matter found in carpet poses minimal-to-low risk to humans. Certain size particles (5-15 um) pose the most potential to re-suspend and are within the size range in which many allergens fall.

- The science clearly indicates that modern carpet is manufactured to be environmentally safe and that clean carpet poses no risk to public health. Routine, cost-effective cleaning technologies can easily keep source strength (particles mass loading) of carpet and other surfaces at levels where IAQ will not be adversely affected.

REFERENCES

1. Devereux, Graham, et al. “The increase in allergic disease: environment and susceptibility. Proceedings of a Symposium held at the Royal Society of Edinburg, 4th June 2002”, Clinical Experimental Allergy 2003: 394-406, 2002.

2. Ayliffe GAJ, et. al. Cleaning and Disinfection of Hospital Floors, Brit Med Journal, 2:442-445, 1996.

3. Greene VW. Microbiological Contamination Control in Hospitals, Hospitals JAHA, 43:78-88, 1969.

4. Lee R., The Advantages of Carpets In Mental Hospitals, Ment Hospital, 16:324-325, 1965.

5. Maki DG, Alvarado CJ, Hassemer CA, Zilz MA, Relation of The Inanimate Hospital Environment to Endemic Nosocomial Infection, N England J Medican, #07:1562-1566, 1982.

6. Spaulding EH, Role of Chemical Disinfection in the Prevention of Nosocomial Infections. In: Proceedings of the International Conference of Nosocomial Infections, 1970.

7. Brachman PS, Eickoff TC, eds, Chicago, IL, American Hospital Association; p. 247-254, 1971.

8. Simmons D, et. al., Considering Carpets in Hospital Use, Dimensions, June: 18-21, 1982.

9. Shaffer J, Key I, The Microbiological Effects of Carpeting On the Hospital Environment, Hospitals JAHA, 30:293-300, 1966.

10. Skoutelis AT, et. al, Hospital Carpeting and Epidemiology of Clostridium difficile, American Journal Infection Control; 22:212-217, 1993.

11. Wille B: Microbiological Hygienic Aspects of Wall-to-Wall Carpeting in Hospitals, I: Disinfection of wall-to-wall carpets, pp.2-37, Symposium, Copenhagen, 1974