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Does exposure science support the concern over indoor air quality?

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GRADUATE THESIS

DOES EXPOSURE SCIENCE SUPPORT THE CONCERN OVER INDOOR AIR QUALITY?

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ABSTRACT

The purpose of this thesis is to examine the growing concern over indoor air quality (IAQ) and determine if such concern is warranted. The first questions that steer this effort include: *Does scientific research substantiate a causal link between IAQ contaminants and human health? In addition, which indoor air contaminants appear to present the greatest health risks?* These questions were answered primarily by reviewing exposure science based criteria that have been developed by federal and state agencies and then comparing these criteria to nominal concentrations that have been measured in the workplace.

The second purpose of this thesis was to answer this secondary question: *Collectively, through the development of suggested response protocols, and individually, through actual response methods, are IAQ professionals focusing on conditions that present the greatest health risks?* This question was answered by reviewing the recommended protocols established by standard-setting organizations. In addition, IAQ professionals were questioned about their specific practices.

The study concluded that there is a valid concern over IAQ for some substances. The highest levels of risk are generally associated with exposures to volatile organic compounds including formaldehyde and 1,4-dichlorobenzene. The research indicated a lack of exposure science for broad mixtures of indoor air contaminants, which are typical in the workplace. The risk associated with typical mixtures is unknown but may be additive and possibly synergistic. High levels of risk are also associated with radon exposure; however, this radioactive material is rarely the focus of IAQ sampling or improvement by IAQ professionals because of its latent, non-acute effects. The research indicated that much of the effort promoted by standard-setting

organizations and implemented by IAQ professionals does result in overall risk reduction but often does not specifically target the highest risk elements of indoor air.

1.0 INTRODUCTION

This section provides an overview of the effort that was undertaken as part of this thesis effort. It provides the topic of the thesis, the significance and the interest in the topic, and the research objectives. This section also defines terms and acronyms that are used in this document.

1.1 Topic

On average, we spend about 90% of our time indoors where the concentrations of many hazardous air pollutants are one to five times the median outdoor concentrations EPA "Healthy" 8). It is no wonder then that the EPA places indoor air quality (IAQ) within the top five environmental threats to human health ("Healthy" 2). For the Environmental, Health and Safety (EHS) professional, indoor air quality is often viewed as a "soft" science. When IAQ potentially becomes a problem, it may be difficult to know where to begin an assessment. Oftentimes, workers originate concerns about IAQ because their physiological symptoms coincide with their physical presence inside of a specific building. These symptoms, however, may or may not have any relationship to building air quality. This thesis will examine current research on the health effects of common indoor air contaminants to determine if recent concerns over IAQ are well-grounded in legitimate exposure science. Furthermore, the author will attempt to determine if IAQ professionals are focusing their efforts on contaminants and conditions that have a valid correlation to human health effects.

1.2 Significance of and Interest in Topic

A World Health Organization (WHO) has noted that the occupants of up to 30% of new and remodeled buildings have logged excessive complaints about indoor air quality

(EPA “Indoor No.4” par. 2). The same organization estimates that about 3% of the global disease burden is due to indoor air pollution (WHO “Indoor” par. 3). A nationwide study of U.S. office workers by the American Lung Association found that 24% perceive air quality problems at work and 20% of those believed that their work ability was diminished as a result (“Indoor” 17). Poor IAQ may be at least partially responsible for the 75% increase in asthma occurrence from 1980 to 1994 (Greife). The National Academy of Sciences reports that there is a strong link between common indoor air substances and the development of or worsening of asthma symptoms (Greife 102). Although the full ramifications of poor indoor air is difficult to gauge accurately, it is estimated to cause thousands of cancer deaths and hundreds of thousands of cases of respiratory distress every year (EPA “Healthy” Intro.).

1.2.1 Financial Impacts of IAQ

According to Business Communications Company, Inc., recent attention to IAQ for issues such as “toxic mold” has driven the market to $5.6 billion in 2003 and is expected to reach $9.4 billion in 2008. (Rajan par. 2). Most of these resources are spent on equipment used to improve or monitor air quality.

Potential liability for poor IAQ has become a very important issue. Litigation for mold and mildew is increasing at an “alarming rate” (Coad 40). Mold damage claims cost America over $12 billion in 2003 (Harriman 23). Although the award was later reduced, a Texas woman was awarded more than $32 million in a battle against her insurance company for mold-related illnesses experienced by her and her family. Executive director of the Indoor Air Quality Association, Glenn Fellman, notes that in the cases that don’t make the newspapers, IAQ plaintiffs often walk away with $50,000 to $100,000 (Kirch

par. 4). The total cost of poor IAQ has been estimated at $100 billion annually (Spengler 33.24).

1.2.2 Interest in Topic

Many workers who occupy buildings are genuinely concerned about air quality. As an EHS professional, the author has heard and responded to concerns over IAQ and believes the topic of this thesis will be helpful in providing a scientific-based perspective on the subject. This will allow for better decision-making for those tasked with resolving IAQ issues.

1.3 Research Objectives

This research effort primarily focused on identifying and understanding the link between exposures to IAQ contaminants and related health effects: *Question #1 (2 parts) - Does scientific research substantiate a causal link between IAQ contaminants and human health? Which indoor air contaminants appear to present the greatest health risks?*

Exposure-risk information was evaluated for many common IAQ contaminants. This information was coupled with available data on nominal indoor air concentrations for these IAQ contaminants. The combined information on exposure risk and typical concentrations allowed a semi-quantitative assessment of the risks presented by typical indoor air contaminants. This led to the identification of IAQ contaminants that generally appeared to present the greatest level of health risk.

After this primary question was answered, the author then focused on how professionals, who respond to IAQ complaints, are evaluating and addressing hazards. This effort answered the second question. *Question #2 – Collectively, through the development*

of suggested response protocols, and individually, through actual response methods, are IAQ professionals focusing on conditions that present the greatest health risks?

1.4 Research Focus

IAQ addresses a vast number of contaminants and conditions. This study only looked at substances that would normally be found in indoor air in non-industrial workplaces. There are other sources of occupant health and comfort. This potentially may include electromagnetic radiation, ergonomic conditions, noise, lighting, and temperature.

This study also focused on indoor air contaminants that are normally greater indoors than they would be outside of occupied structures. As a result, although substances such as particulate matter, nitrogen oxide, nitrogen dioxide, ozone, and pollen may present significant health risks and are discussed, they are largely excluded from consideration within the health risk comparison.

Finally, this study centered on indoor air contaminants that are most common in the workplace. In specific situations, air contaminants that are not addressed in this study have had and will continue to present substantial health risks to occupants of facilities where such contaminants are present. Examples include contaminants such as asbestos, isocyanate products and carbon monoxide.

1.5 Reference Limitations

The list of reference material used to prepare this thesis is extensive. Wherever possible, the research, findings, and conclusions identified by responsible agencies were used. These agencies included the EPA, OSHA, NIOSH, CalEPA, CDC (see definitions in next section), the American Industrial Hygiene Association, American Lung Association, World Health Organization and others. There are, however, important limitations to

information presented by these agencies and others. For example, as discussed in Section 3.7.1, there are large uncertainties in developed standards. Effects anticipated for low-level, chronic exposures are often extrapolated from much larger, accident-based exposures. For carcinogenic effects, a linear dose-response model is often used. Some believe that this model is overly conservative and does not take into account the body's capability to repair and resolve damage resulting from low-level doses. Results of similar research efforts may not be complimentary and may even be contradictory. For example, within the numerous studies reviewed by NIOSH on ETS exposure, the relative risk ranged from about 1 to 4 (i.e., essentially no risk to 4 times the risk of developing lung cancer than someone not exposed to ETS). Some specific limitations of supporting studies are discussed within the text.

1.6 Definitions

ACGIH – American Conference of Governmental Industrial Hygienists

AIHA – American Industrial Hygiene Association

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers.

BASE - Building Assessment Survey and Evaluation

Bioaerosol – Airborne and or settled particulate material of microbial, plant, or animal origin (Breeding 58).

BRI – building related illness – Term used to describe a condition where a clinically defined illness of known etiology is found to be associated with building conditions, e.g. legionellosis (OSHA "IAQ").

CalEPA – California Environmental Protection Agency

CDC – Centers for Disease Control

CO – carbon monoxide

CREL – Chronic Reference Exposure Level, established by CalEPA

DHHS – U.S. Department of Health and Human Services

EHS – Environmental Health and Safety

EPA – U.S. Environmental Protection Agency

ETS – environmental tobacco smoke.

HVAC – heating, ventilation, and air conditioning.

IAEA – International Atomic Energy Agency

IAQ – indoor air quality – Generally refers to quality, which can be described by numerous factors, of air inside of a structure. For the purposes of this document, IAQ discussions will be centered on general office and commercial spaces that are occupied by non-industrial employees.

I-BEAM - Indoor Air Quality Building Education and Assessment Model (developed by EPA)

ICRP – International Commission on Radiation Protection

IEQ – indoor environmental quality – Term preferred by NIOSH and others that takes into account not only indoor air quality but also other factors, such as comfort, noise, and lighting.

LOAEL – lowest observable adverse effect level

MIBK – methyl isobutyl ketone

NIOSH – National Institute of Occupational Safety and Health

NOAEL – no observable adverse effect level

NRC – Nuclear Regulatory Commission

OSHA – Occupational Safety and Health Administration

pCi – picocurie (a measure of radioactivity)

PEL – Permissible Exposure Level, established by OSHA

REL – Reference exposure level

RfC – inhalation reference concentration, established by EPA

SBS – sick building syndrome – Term used to convey a wide range of symptoms that are believed to be attributable to building conditions.

TCD – Toxicity Criteria Database (from the California EPA)

TLV – Threshold Limit Value, established by the ACGIH

TVOC – Total volatile organic compounds

VOC – volatile organic compound

WHO – World Health Organization

2.0 BACKGROUND

Concerns over air quality have been around for millennia. In the Bible (Leviticus 14), the danger of living in a damp dwelling is noted (Sundell 52). In 61 A.D., the Roman writer, Lucius Annaeus Seneca, noted that "as soon as I escaped from the oppressive atmosphere of the city....I perceived that at once that my health was mended" (Heidorn 1589). During the medieval era, it was determined that bad air in poorly ventilated rooms was responsible for the spread of disease and unpleasant sensations. It is interesting to note that during this period, fresh air was thought to "cool the heart" and that the substance of air was not required, only its coolness (Sundell 52).

In 1781, Parisian, Antoine-Laurent Lavoisier identified the necessity of "fresh air" and identified the metabolic roles of oxygen and carbon dioxide. In the decades that followed this discovery, carbon dioxide became a marker in deciding whether the air was fresh or stale (Sundell 52). In addition, studies were conducted of carbon dioxide to determine its toxicity. When it was determined that carbon dioxide itself was harmless, attention turned towards odorous body emissions as a potential source of illness.

These emissions along with the warmth of crowded rooms often resulted in nausea, which demonstrated a connection to health effects. (Sundell 53). In 1853, Munich's first professor of hygiene, Max Joseph von Pettenkofer, lectured that the effects of bad air were due to trace amounts of organic material emitted from the lungs and skin (Sundell 52). He also added that these air impurities did not cause illness but instead weakened the body's defensive capabilities. During the same period as Pettenkofer, John Griscom, a New York Surgeon, noted that "deficient ventilation" caused more fatalities that all other causes combined (Sundell 52).

Air quality concerns quickly multiplied during the industrial revolution of the 18th Century. Technological advancements during this period resulted in rapid outdoor air quality deterioration. Large quantities of fossil fuels, primarily coal, were burned to make steam to pump water and operate machinery. Industrial revolution emissions resulted in indisputable health impacts. In London, air pollution led to thousands of deaths and, at times, unbearable living conditions.

Throughout the 19th and early 20th centuries, while outdoor air quality was diminishing, indoor building ventilation was seen as a means to achieve comfort. Ventilation standards noted that "Occupied rooms should give a favorable impression on entering, taking into consideration such factors as odor, freshness, temperature, humidity, drafts, and other factors affecting the senses" (Sundell 53). Human body odors were accepted as the primary source of indoor air pollution and that ventilation was necessary to remove this pollution.

At the turn of the 19th century in Pittsburgh, street lights were lit during the day to see through the smoke (McCabe). In 1948 in Donora, Pennsylvania emissions from a local zinc smelter, the primary town employer, combined with unusually stable atmospheric conditions to smother and choke the town's population. The Donora event hospitalized 7,000 people, half of the town's population (McCabe). The resulting respiratory distress led to 20 deaths. This and other events led to programs to control air pollution in 1955 (Heidorn 1593) and eventually the Clean Air Act in 1970. The importance of clean breathing air became solidified during this period.

As a result of the energy conservation measures that began, in earnest, during the 1973 Oil Embargo, building occupants began to identify health impacts resulting from indoor, instead of outdoor, air pollution. Measures to reduce dependency on foreign oil resulted in

tightly sealed structures to prevent the loss of conditioned air or the infiltration of unconditioned air. The measures that allowed buildings to become effective barriers to outside conditions also trapped unhealthy substances inside. As a result, hundreds of illness outbreaks from the occupants of new and remodeled structures began to be reported (Miller 1). These outbreaks were later to be identified with the "sick building syndrome."

Today, it is easy to understand how air quality can rapidly deteriorate within a modern, energy-efficient building when a number of contaminant sources within this "ecosystem" are examined. Indoor building air is normally rich in bioaerosols. Occupants act as carriers of viruses and bacteria, animal dander (from pets), and pollen. They directly affect temperature and humidity, increase concentrations of carbon dioxide, and shed a stream of biological materials. Buildings often also house several other sources of bioaerosols including insects and insect waste, dust mites, rodent and rodent excreta, and mold and mold spores. If localized areas remain wet or damp, mold and bacteria populations can grow exponentially and quickly.

Building materials, furniture, and carpet emit VOCs, which are used in their manufacture. VOCs also originate from dry-cleaned clothes, perfumes, solvents, cleaners, and a wide variety of other consumer products. More than 500 VOCs have been identified in indoor air (Samet 259). Building material not only supplies sources of VOCs, they also act as VOC sinks, acting as reservoirs for these chemical substances (Samet 255). Copying machines can generate ozone and carbon particulates. Cleaning cleansers and solvents, and pesticides add to the contaminant mix.

Since the 1970's, concerns over the air quality in indoor workspaces rapidly expanded. NIOSH has seen the requests for indoor air assistance rise dramatically (NIOSH "Indoor").

NIOSH notes that television coverage of IAQ issues "profoundly influences" the number of phone calls and the requests for assistance that they receive ("Indoor" Par. 8). In evaluating the results of about 500 IAQ investigations, NIOSH found that IAQ problems were due to the following (OSHA):

- 52% Inadequate ventilation
- 16% Contamination from inside the building
- 10% Contamination from outside building
- 5% Microbial contamination
- 4% Contamination from building fabric
- 13% Unknown sources

NIOSH has connected the "revolution" in office work to degrading indoor environmental quality. A large increase in white-collar work combined with extensive use of the computer and other new work technologies has lead to new work procedures and productivity expectations. Such conditions and tighter, more energy efficient buildings have lead to both ergonomic and organizational stress, and decreasing indoor environmental quality (NIOSH "Indoor"). OSHA hinges air quality problems on the wide use of chemicals in products; tighter, less ventilated buildings; and pressures to reduce operating costs by deferring building maintenance.

3.0 LITERATURE REVIEW

The modern office building contains numerous airborne materials that can affect occupant health. Air pollutants such as carbon monoxide and nitrogen dioxide that are common in outside air also make their way into buildings. Chemical substances are an inherent part of many structural materials, cleaning agents, and a host of consumer products. Ventilation intakes can draw in vehicle exhaust from garages, heating system exhaust, or gases from plumbing vents. Bioaerosols, such as animal dander and plant pollen, are also prevalent. Bacteria and fungi have a widespread presence and will increase their numbers in wet or damp locations.

This section provides background information on some of the most important IAQ substances, their sources, and their health impacts. It then highlights issues that are prevalent in IAQ, including Sick Building Syndrome, Building-Related Illness, the physiological aspects of IAQ complaints, exposure standards, and conditions believed to be related to poor IAQ.

3.1 Chemicals

Building occupants are routinely exposed to a wide variety of chemicals. The most prevalent class of chemical compounds affecting IAQ is VOCs. VOC is a widely used term. It refers to any carbon compound with a relatively high vapor pressure at room temperature. Some VOCs emit unique odors. Some are odorless. Both can be harmful. The use of VOCs is widespread. VOCs are common in many consumer and building products including cleaners and waxes, paints, adhesives, personal care products, automotive products, building materials, tobacco smoke, vehicle exhaust, and pesticides. That new-car

and new-carpet smell can be attributed to VOCs. Toilet deodorizers are made from VOCs. Paint, hairspray, fingernail polish, window cleaner, copier toner, modeling clay, shampoos all contain VOCs (Miller 37-8).

The list of VOC-containing products continues and is very long. The variety of VOCs is steadily increasing. According to Miller, there are currently more than 1,000 types of VOCs (36). In any given workspace, one can expect to see between 50 and 150 different VOCs (Australia Sec. 7.3.5). Although VOCs are often measured and evaluated in an isolated manner, many believe that multiple VOCs present will have additive or even synergistic effects and that the total VOC concentration should be evaluated. The European Commission, for example, has recommended the use of a total VOC concept in regards to IAQ (Australia Sec. 7.3.5).

Acute health effects of VOCs include irritation of the eye, nose, throat or lungs; dizziness and nausea; headache; and fatigue (OSHA "IAQ Investigation" II(B)8). Many VOCs are strong narcotics and can impair memory (Miller 39). As identified in Chapter 5, many VOCs are classified as known or probable human carcinogens. Since VOCs are common in building materials, carpet and furnishings, IAQ complaints related to VOCs are common shortly after construction or after remodeling efforts (Pike-Paris). Because of their wide-spread prevalence and potential health effects, VOCs are an important part of indoor air quality. The "Chemical Substances" section of Chapter 5 will discuss some of the more important VOCs and other chemical substances along with associated health effects.

3.2 ETS

There are a plethora of gaseous chemical substances in tobacco smoke that are harmful to human health. Tobacco smoke also produces volumes of fine particulate matter that also have a negative health impact. Because of the health effects, there is an increasing push to prohibit smoking in public places and workplaces. If smoking is allowed in the building, however, environmental tobacco smoke (ETS) becomes a very important IAQ issue.

Overwhelming evidence links ETS to chronic and acute diseases in nonsmokers (CDC "Tobacco" 193). Moreover, nonsmokers who are exposed to ETS are increasingly unwillingly to accept the discomfort, annoyance, and the health risks that stems from passive smoking. This has lead to wide level of support against public smoking by both nonsmokers and smokers (CDC "Tobacco" 195). Employers are often expected to limit ETS exposure in the workplace. In addition to the health effects, smoking can increase building cleaning and maintenance costs, increase insurance rates, and reduce worker productivity (CDC "Tobacco" 195).

At the end of 2005, thirty-nine percent of the nation's population lived in states where smoking in indoor workplaces or public indoor places has been restricted (Koch). The smoke-free trend is expected to continue and expand into other states. In addition, many states have adopted requirements on ETS in the workplace. Washington State laws, for example, compel employers to control ETS exposure and provide specific requirements on smoking areas and ventilation rates (Wash.). The standard-setting organization for ventilation system design and operation, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE "62"), is developing guidance to address ETS. This is expected to provide requirements for area classification, signage, and separation for

areas where ETS is present (ASHRAE “62”). At one point, OSHA did attempt to promulgate regulations on IAQ, which included ETS (OSHA “Reiteration”). This action was later abandoned. In its reiteration, OSHA notes that exposures normally do not exceed PELs for ETS constituents and that it will not apply the General Duty Clause to ETS. Nevertheless, ETS hovers near or at the very top of IAQ health threats.

3.3 Bioaerosols

Bioaerosol is a term used to describe any airborne material whose origin is either plant, animal, or microbial (Breeding 58). Examples of bioaerosols include mold and mold spores, fungi, bacteria, viruses, algae, yeasts, protozoa, pollens, dust mite allergens, arthropod antigens, animal dander, and rodent hairs and excrement. Bioaerosols can be microorganisms like bacteria or fungi, or can be remnants of larger organisms, like flakes of human skin. They are prevalent both indoors and outdoors but little can be done to control concentration levels outdoors. Outdoor bioaerosols can be brought into a workspace through the introduction of untreated outside air. People, pets, and insects, however, are also important carriers for bioaerosols (Miller 21).

Bioaerosols can be viable or non-viable. Given the proper conditions, viable populations of biological agents can grow quickly and exponentially. These conditions include a reservoir, for storage; an amplifier, for reproduction; and a means of dispersal (Miller 20). Areas that best meet these conditions include warm, damp areas such as kitchens, bathroom and shower areas, drip pans for HVAC systems, damp carpets, or leaky plumbing. Humans directly provide an effective host for many bacteria and viruses (Miller 20).

Bioaerosols can result in three types of human health effects (American Lung Association "Indoor" 11). The first of which is infection. This happens when a pathogen invades a human host. The common cold and tuberculosis are examples of this health effect. The second effect is hypersensitivity, which is an autoimmune response to a particular bioaerosol, such as animal dander or dust mites. Such a response can be mild, such a watery eyes, to life threatening up to and including severe respiratory distress. The third type of health effect is toxicosis, where a biologically-produced chemical agent has a direct toxic effect. Such an agent is mycotoxins. Mycotoxins are a fungal metabolic byproduct and are believed to be responsible for human effects ranging from short-term irritation to immunosuppression to cancer (American Lung Association "Indoor" 12). Mycotoxins are discussed further in Chapter 5.

3.3.1 Bacteria and Viruses

Bacteria are an important bioaerosol that is ubiquitous in the environment and in breathing air. They are needed to make cheese and yogurt and help us digest food. They are also responsible for the bubonic plague (Yersinia pestis); meningitis (N. meningitides); cholera (Vibrio Cholerae); and infections of the lower respiratory tract (Moraxella catarrhalis) (Emery).

Bacteria have many sources. These include the human respiratory system, especially during a cold. They are swept into the air from a wide variety of sources including soil, decaying organic material, landfills, and sewage treatment facilities (Australia Sec. 7.4.1). The presence of dense bacteria aerosols can be seen in operations that involve the handling or processing of organic materials (Miller 21).

Bacteria need moisture and thrive in moisture-laden areas of buildings. They are often capable of producing spores, which have a tough outer shell that allows them to remain viable for up to 100 years (Emery). According to Miller, recent epidemics of airborne disease in office buildings with poor ventilation characteristics have shown that airborne bacteria remain a serious potential health threat (22).

Viruses cause the common cold (rhinoviruses) and the flu (influenza viruses) (Australia Sec. 7.4.1). Because of their prevalence, they have an important contribution to occupational absenteeism. The virus relies on a living host in order to survive and multiply although it can survive and remain infective for extended periods within the circulating air of an office space (Australia Sec. 7.4.1). Mumps and measles are viruses. According to Burroughs, a documented case appears to have shown that a central heating system can effectively distribute measles throughout a school (36).

There is a current concern specifically over Avian Influenza A, which is also known as the Bird Flu or HN51 virus. Officials are concerned that this strain of influenza, which is common in bird populations, can mutate such that it could easily spread from human to human. Since humans have little immunity to such a virus, the mutation could lead to an influenza pandemic (CDC "Key"). If such a pandemic were to be realized, workplace IAQ, especially in health care settings, would become increasingly important in order to protect employee and occupant health.

3.3.2 Mites and Animal Allergens

Dust Mites are not insects but are microscopic organisms that are closely related to spiders and ticks (Boyd Par. 1). Mites are found everywhere in the world and are transported by dust particles (Miller 24). They often live in carpets, on upholstered

furniture, and mattresses. They feed on the dead skin of humans and animals and other organic material (Boyd Par. 1). When dust mites grow, they shed their skin. This skin and their feces are what cause the allergic reactions in humans (Boyd Par. 2). Although dust mites are most prevalent in households, they also appear in workspaces. Since a fraction of the workforce will demonstrate a sensitivity to dust mites, the presence of dust mite allergens in building air can be problematic.

Most non-human proteins, like those of dust mites, have the potential to elicit an allergic reaction in a portion of an exposed population (American Lung Association "Indoor" 11). This is also true for animals including household pets; namely dogs and cats. The offending proteins originate in animal hair, saliva, urine, and dander, which are small scales of sloughed skin (Miller 25). NIOSH has reported that among those who handle animals regularly, 33% have allergic symptoms and 10% have symptoms of animal-induced asthma ("Preventing" par. 3). Although many workplaces are free of animals, animal-produced antigens are freely brought into the workplace by those with pets.

3.3.3 Mold

Mold belongs to the fungi kingdom and feed off of plant and other organic material (EPA "Mold" 39). Mold is not a new phenomenon. It was one of the participants when life began on earth. The Bible mentions mold in Leviticus 14, noting "If mildew has spread on the walls, he is to order that the contaminated stones be torn out." If mildew reappears, "the house must be torn down" (Hevesi par. 45).

According to the EPA, "without molds, our environment would be overwhelmed with large amounts of dead plant matter" ("Mold" 39). Molds need food and water to survive.

Since they can digest just about anything, water is the critical element for mold growth. Tiny mold spores can do well in just about any damp or humid location.

So called "toxic molds" have recently been making headlines. The term "toxic mold", which also may be known as black mold, normally refers to Stachybotrys chartarum (also known as Stachybotrys atra). Popular media articles suggest that mold, including Stachybotrys, could be a factor for nearly every ailment affecting mankind. A USA Weekend article asserted that mold causes everything from hearing loss to difficulty speaking (Mann). An article in the Philadelphia Inquirer suggests that "black mold" can create numbness in the fingers and widespread rashes (Fallik). A man who was interviewed by the Orlando Sentinel after finding mold in his home noted that his family experienced "fevers and chills" and "got wobbly sometimes" (Erickson).

Reputable organizations, such as the CDC, suggest that it is highly unlikely that mold exposures would lead to such symptoms (CDC "Questions"). The CDC and others agree, however, that mold in indoor environments should be removed.

3.4 Sick Building Syndrome

SBS is characterized by an increased prevalence of non-specific symptoms in more than 20% of the building's population. The most common symptoms include eye irritation, irritation of the nose and throat, lethargy, and headache (Samet 308). Symptoms also include nausea, dizziness, dermatitis, sensitivity to odors, muscle pain, and fatigue (OSHA "IAQ"). The primary identification of SBS stems from the condition that occupant symptoms are associated with their time spent in a particular building. Such symptoms often disappear soon after the occupants leave the building. Ventilation system adjustments

to improve air flow or allow increased outside air exchange often resolve the occupant's symptoms.

The onset of SBS is believed to coincide with the energy conservation initiatives during the energy crisis of the 1970's. During this period, the U.S. Government determined that energy conservation measures were necessary to reduce America's dependence on world oil markets, which were subject to interruption (Miller 113). A key portion of these conservation measures were the implementation of improvements to improve the energy efficiency of structures. This was partially accomplished by tightly sealing occupied structures to prevent the loss of conditioned air.

An undesirable side effect of the energy conservation measures was the degradation of IAQ. The concentrations of airborne chemicals, allergens, and other indoor air contaminants subsequently increased due to the reduced volumes of incoming dilution air. This is believed to be the basis for SBS; however, the specific cause or causes of SBS has yet to be definitively shown. A study by Erdmann, et al., identified an association between SBS and carbon dioxide levels, a marker that is often used to determine the amount of fresh air or the lack thereof (Erdmann 433). Another study identified a correlation between SBS and elevated indoor levels of fungi, specifically Penicillium and Stachybotrys (Schwab 215). There does, however, seem to be a general consensus in related literature that SBS is most likely caused by an additive or synergistic effect of the numerous airborne contaminants that occupy workspaces. This issue is discussed in later sections of this work.

3.5 Building Related Illness

In an attempt to standardize IAQ-related terminology, the National Research Council established two distinct categories to identify illness related to building problems; SBS and

Building Related Illness (BRI). SBS was discussed in the previous section. The difference between SBS and BRI is that the latter results in a specific clinical syndrome.

Common types of BRI include nosocomial (hospital related) infections, humidifier fever, hypersensitivity pneumonitis, and Legionnaires' disease, which all result from exposure to bioaerosols (Samet 307). Building related illness has also been associated with exposures to carbon monoxide, formaldehyde, chlordane, endotoxins, and mycotoxins. The symptoms of building related illness frequently do not disappear when individuals leave the building (Samet 307).

The identification of a BRI can help lead investigators to the source of the problem and may also help identify potential remedies. For example, the medical diagnosis of Legionnaires' disease would direct investigators to locations where stagnant water might be present. According to Burroughs, a building with BRI almost always passes through a SBS stage and will likely still have other contributing factors to IAQ beyond those specifically linked to BRI (29).

3.6 Psychological Aspects of IAQ Complaints

Reports about symptoms related to poor air quality are often subjective and may actually have little to do with actual air contaminants. According to Kirch in the ABC's of IAQ (par. 3):

> Once we believe that the air we breathe contains a colorless, odorless, yet noxious pollutant that causes eye irritation, we will selectively attend to eye sensations for confirmation of exposure, and unconsciously we even may behave to this information by rubbing our eyes more frequently than normal, which increases irritation

> sensations. Because we cannot directly sense many indoor air quality hazards…we rely on beliefs and imagination to help us anticipate and avoid invisible hazards.

Other work suggests a possible psychological basis for IAQ-related symptoms. For example, Burroughs identifies a connection between SBS and worker satisfaction, adding that a worker who is ill, under stress, uncomfortable or otherwise unhappy is more likely to develop IAQ-related symptoms (23, 28).

An Occupational Health and Safety article notes, however, that EHS professionals are simply not qualified to determine the psychological basis of reported IAQ problems. It is the responsibility of EHS professionals to anticipate, recognize, evaluate, and control potential workplace hazards and to "treat employees with respect and professionalism." "Being dismissive or evasive will destroy the employee's confidence in us" (Richey 80). Richey contends that we should respond quickly and decisively to IAQ complaints and communicate findings to employees (Richey 82).

3.7 Standards of Exposure

As part of the Air Toxics Hot Spots Information and Assessment Act, CalEPA's Office of Environmental Health Hazard Assessment has developed chronic reference exposure levels (CREL) for many indoor air contaminants. A CREL is an airborne concentration that poses no significant noncancer health risk to individuals indefinitely exposed to that concentration. CRELs are based "solely on health considerations" and are developed from the best available data in scientific literature (CalEPA "Adoption" par. 3). The CRELs tend to draw off of scientific studies that have developed concentration values for no observable adverse effect levels (NOAEL) and or lowest observable adverse effect levels (LOAEL).

The EPA has a corollary to the CREL; it is known as the inhalation reference concentration (RfC). For common IAQ contaminants, the CREL database is generally better populated than the RfC database.

For carcinogens, both the CalEPA and the EPA use cancer potency factors to help quantify exposure risk. The text in Section 5.0 notes the cancer classes of many substances, e.g., possible, probable, or known carcinogen. It should be noted that a known carcinogen may or may not be more apt to cause cancer than a possible carcinogen. The data for the "known carcinogen", however, presents a greater weight of evidence than a "possible carcinogen" (EPA "Risk").

For bioaerosols, the ACGIH, which has developed Threshold Limit Values (TLV) for numerous substances, notes that there is a lack of TLVs for most biological materials including the most hazardous infectious agents and endotoxins (182-183). In part, this is due to the fact that concentrations of bioaerosols vary widely over time with some bioaerosols exhibiting "concentration bursts" that may be improperly measured with limited grab sampling (183). In addition, reliable human dose-response data, which would help establish a safe exposure level, are not available (182-183). ACGIH does note that sampling and analysis techniques for antigens and endotoxins are "steadily improving" and that there may be TLVs for these and other bioaerosols in the future (183).

3.7.1 Uncertainties in Standards

Reference exposure levels and cancer potency factors have been developed to help estimate exposure risk. There are, however, high levels of uncertainty associated with these developed values. The CREL development process, for example, typically includes the use of uncertainty factors. A NOAEL may be derived from a known LOAEL by assuming a

factor of ten exists between the two values. Factors of ten are also added if animal studies are the basis of the LOAEL (interspecies uncertainty) or if the study did not include a wide variety of receptors (intraspecies uncertainty). The RfCs used by the EPA are presented with the caveat that they have a level of uncertainty "spanning perhaps an order of magnitude" (EPA "Glossary").

Although most risk managers and the public would like an absolute value for cancer risks associated with certain substances, there is a large degree of uncertainty associated with the development of cancer potency factors. According to the Illinois EPA, an American's chance of getting cancer is 1 in 3 (par. 14). Because of this high "background," it is easy to see the difficulty in detecting a cancer rate increase in the 1 in 10,000 to 1 in 1,000,000 range (range that is normally deemed acceptable by the EPA). Regulatory agencies have largely taken a conservative approach in developing risk factors. The EPA's cancer potency factors are based on the 95% upper confidence limit of a dose response curve but the "true risk is likely below this level and may even be zero" (Felter 247). Given the levels of uncertainty in identifying "safe" levels for chronic exposure to substances and the seriousness of potential effects, most within the exposed population would rather err on the safe side.

3.8 Sources for Poor IAQ

The following section describes the two most prevalent sources of IAQ problems; insufficient fresh air and excessive moisture.

3.8.1 Insufficient Fresh Air

As noted previously, NIOSH found that 52% of IAQ problems were related to inadequate ventilation. Williams notes that the cliché "dilution is the solution to pollution"

is quite accurate in the realm of IAQ (66). One of the best ways to mitigate poor IAQ is the introduction of fresh, outdoor air (Hughes 42). Outside air can dilute the concentrations and effects of bioaerosols, VOCs and other indoor air contaminants. Carbon dioxide is a good indicator of this dilution by gauging whether the ventilation system is bringing in and distributing sufficient amounts of fresh air (OSHA "IAQ Investigation" IV (C) 3).

No federal standards exist for IAQ or required quantities of dilution air (Pike-Paris 431). ASHRAE, however, has developed a new standard called "Ventilation for Acceptable Indoor Air Quality", identified as Standard 62.1. Prior to this, standards called for a minimum number of cubic feet per minute of fresh air per structure occupant. The new 62.1 Standard takes into account the fact that occupants *and* the building's contents generate air pollutants. As such the new standard provides fresh air requirements based on number of occupants and the building's square footage (ASHRAE "62"). It also has requirements for humidity, water and moisture control, proper pressurization, and outdoor air quality (Turpin "62.1" 2004).

For broad scope guidance on improving IAQ, AIHA has recently published new guidance entitled "Recommendations for the Management, Operation, Testing, and Maintenance of HVAC Systems for Maintaining Acceptable IAQ in Non-Industrial Occupancies through Dilution Ventilation" (D. Burton 1). Although this document does do what its title implies, it also includes advice on establishing programs for smoking, building renovation, and responding to IAQ complaints (D. Burton). The end-user of this document sets the "acceptable levels" for IAQ. The AIHA complements and defers to the ASHRAE standard for some issues. According to D. Burton, AIHA and ASHRAE are

currently working on a joint standard or guideline, which can be used my members or both disciplines (24).

3.8.2 Moisture

ACGIH, OSHA and others suggest that the most effective way to combat bioaerosols is to conduct routine facility inspections to identify sources of moisture. Harriman notes that "after years of confusion, it is now clear that mold only grows inside buildings where excess moisture has accumulated (23)." He also writes that "water ends up in the oddest places through complex mechanisms" (23).

There are nearly limitless routes for moisture entry into occupied spaces. Water can enter a building through a damaged or improperly sealed foundation or roof. Water vapor can enter through doors, walls, windows, and the roof. Buildings have internal sources of water including bathrooms, showers, kitchens, leaking pipes, condensate on pipes, and even people. In order to effectively control mold and its potentially hazardous byproducts, sources of moisture in a building must be addressed.

Instead of specifying a humidity range, like the old standard, the new ASHRAE 62.1 Standard requires that the "system be designed such that at a specific outdoor condition, which is the design dew point condition, your system design has to result in space relative humidity that is below 65%" (ASHRAE "62"). The new standard also attempts to limit moisture by providing requirements to ensure that condensate from cooling coils is collected and drained properly, that cold water pipes are insulated to prevent condensation, and that liquid water intrusion is limited (Turpin "62.1" 34).

4.0 METHODOLOGY

This section identifies the methodology used to answer the primary research question: Does scientific research substantiate a causal link between common IAQ contaminants and human health and which indoor air contaminants appear to present the greatest health risks? Secondarily, it examines the response efforts of IAQ professionals to determine if these actions are effectively reducing human health threats.

4.1 IAQ Health Effects Research

The first part of the research effort focused on the link between exposures to IAQ contaminants and health effects thought to be related to such exposure. Exposure/risk relationships developed by the EPA and others were reviewed. In addition, typical indoor air concentrations for workplace settings were examined to determine if typical indoor air concentrations approach levels that are believed to present a significant risk. The research weighed the risks of important indoor air contaminants relative to each other.

4.2 IAQ Response Methodologies

The research done to answer the first question was used to determine which IAQ contaminants (mold, VOCs, ETS, etc.) pose serious health threats. Based on these results, common methods used in response to IAQ concerns were identified and evaluated in an attempt to determine if IAQ professionals are focusing their efforts on appropriate health threats.

4.3 Information Sources

CRELs, RfCs, and cancer potency values, where available, were used to help develop a correlation between exposure concentrations of typical IAQ contaminants and associated

health effects. This information was paired with data regarding typical concentrations of IAQ contaminants in the workplace.

Typical building concentration information was found within several sources including an EPA study, which conducted a broad assessment of indoor air parameters in office environments. The study is known as the Building Assessment Survey and Evaluation (BASE) study. The BASE study was an extensive survey of the indoor air characteristics of randomly selected office buildings across the United States (L. Burton). The Indoor Air Quality Handbook (Spengler) and other documents also contained useful information regarding typical indoor air conditions.

For evaluation and remediation methodologies, recommendations from the AIHA, OSHA, and the EPA were examined. In addition, practicing IAQ professionals were polled to determine common methods used in response to IAQ concerns.

5.0 RESULTS - IAQ HEALTH EFFECTS

The following text identifies substances that, from the research effort, have been shown to present health risks that are in the top tier of common indoor air contaminants. To the extent possible, data on workplace conditions was used. For some indoor air contaminants, this information was limited or not identified. In these circumstances, contaminant concentrations in homes was considered and noted in the text.

5.1 ETS

Despite well-document health risks, 21% of Americans smoke (CDC "Smoking"). This is far worse in developing countries, like China, where men smoke at a rate of more than 60% (Dongfeng). The health effects of smoking are grim. NIOSH reports that 87% of lung cancers are related to smoking as are 30% of all cancer deaths. The Surgeon General notes that "smoking harms nearly every organ of the body, causing many diseases and reducing the health of smokers in general (CDC "Reducing").There is also a weight of evidence that identifies substantial levels of health risk to those exposed to second-hand smoke, or ETS.

ETS is a complex mixture of gases and particulate matter containing over 4,000 chemical compounds, including carcinogens, irritants, and toxins (Jaakkola 2055). According to an article in Morbidity and Mortality Weekly Report, ETS remains a common but preventable public health hazard and is "responsible for an estimated 3,000 lung cancer deaths and 35,000 coronary heart disease deaths among American never smokers each year" (Travers 1038). Besides lung cancer and heart disease, nasal sinus cancer and impaired fetal development have been found to have a causal association to ETS (CalEPA "Health Effects" ES-xv). Spontaneous abortion, decreased pulmonary

function, and cervical cancer have also been linked to ETS (CalEPA "Health Effects" ES-xv).

A 2003 Finnish study of an entire region of more than 400,000 people concluded that of all new cases of adult asthma, 49% are attributable to ETS (Jaakkola). This study found that both home and workplace exposures were important contributors to adult-onset asthma but the strongest correlation was tied to cumulative workplace exposure. Compounds in ETS are believed to facilitate asthma by promoting airway inflammation while increasing "epithelial permeability" to allergens in the environment (Jaakkola 2058).

The relative risk of lung cancer for a smoking male is an extraordinary 22.4, i.e., smoking males' odds of developing lung cancer are more than 22 times that of a nonsmoking male (NIOSH "ETS"). The value for smoking females is 11.9. Relative risk values for heart disease are 1.9 and 1.8, respectively for men and women (NIOSH "ETS"). In a compilation of ETS-related studies, NIOSH determined that regular ETS exposure results in a relative risk of 1.3 for lung cancer, although the results of the individual studies were generally higher and topped out at 4.0 ("ETS"). NIOSH also noted the correlation to ETS-related heart disease but did not provide a relative risk value.

The average smoker inhales 21 cigarettes per day. NIOSH estimates that ETS exposure results in the exposure equivalent to the nonsmoker of about 0.1 to 1.0 cigarettes per day. Cotinine is a metabolic byproduct of nicotine, which is highly specific to tobacco smoke. NIOSH has published study data about cotinine levels in smokers, nonsmokers, and those regularly exposed to ETS (NIOSH "ETS"). This 1991 data is provided in Table 5.1 below.

Table 5.1 – Relative Cotinine Levels

Population	Average Cotinine Levels (ng/ml)
Nonsmokers	8
ETS-exposed nonsmokers	25
Nonsmoking restaurant workers	56
Smokers	1,200

The growing intolerance to ETS and a reduction in overall smoking levels has resulted in significant reductions in ETS exposure. The CDC reported that the levels of cotinine have dropped 75% in adults between their 1988-1991 monitoring period and their 1999-2002 monitoring period (DHHS "CDC"). Unfortunately, the CDC also reported that, although they declined 68% during the monitoring periods noted, children's cotinine levels are twice those in adults, presumably from ETS exposure at home. Restaurant and hospitality workers are also at a higher risk since they work in the haze of bars and sections of eating establishments where smoking is still allowed. Bates notes that such workers are exposed to ETS at concentrations between 1.5 – 4.4 times greater than the exposures received by someone living with a smoker (128).

The EPA has classified ETS as a Class A carcinogen (known human carcinogen) (Turpin "62.1" 31). This action brought on a fierce response from the Tobacco industry, which has made many attempts to discredit the EPA's findings. The EPA designation means that there is no known safe minimum concentration of ETS. As a result, no cognizant authority has set an acceptable ETS concentration (Turpin "62.1" 31). NIOSH's position on ETS is that workers should not be involuntarily exposed to tobacco smoke adding further that (NIOSH "ETS"):

> The risk of developing cancer should be decreased by minimizing exposure to ETS. Employers should therefore assess conditions that may result in worker exposure to ETS and take steps to reduce exposures to the lowest feasible concentration.

Because of the known health effects and general irritation associated with ETS in places where smoking is still allowed, employers and building managers are trying to curtail ETS exposure to workers and business patrons. In the Turning Stone Casino in Verona, New York, for example, extensive and expensive modifications to the casino's ventilation system were made to continue to allow customers to smoke in the gaming rooms (Turpin "Odds"). Channels were chiseled into the casino's slab floor to allow ventilation supply ducts to push fresh air up from the floor.

Many have tried to effectively segregate those who smoke from those that do not. Separate smoking areas, however, are often viewed to be ineffective in preventing ETS exposure. The Surgeon General has noted the simple separation of smokers and nonsmokers within the same airspace may reduce, but does not eliminate, the exposure of nonsmokers to ETS and that separate isolated rooms are necessary.

Even with such rooms, precautions are necessary. Most importantly, the room must have negative ventilation with respect to the rooms surrounding it (Wagner). After that, the primary method of ETS movement into nonsmoking spaces is the "pumping action" of a standard door (Wagner). Wagner found that this ETS transport mode can be reduced by 77% by using a sliding instead of a swing-type door (118). Many workplaces avoid such complexities by banishing smokers to outside areas.

5.2 Radon

Radon is a naturally occurring radioactive, noble gas that is a decay daughter of terrestrial uranium and thorium. Radon penetrates all ground surfaces and permeates into structures. As an inert gas, Radon flows freely in and out of the respiratory tract. Radon decay daughters, which are particles, can deposit on surfaces of the lung. Because of the high charge and large mass of the radon daughter emissions (alpha particles), relatively large amounts of energy, and hence cellular damage, are delivered to lung tissue.

According to the EPA, radon is responsible for 20,000 lung cancer deaths each year; second only to smoking ("Radon" par. 1). The EPA recommends that homeowners take action to reduce radon if levels reach 4 picocuries per liter (pCi/l). However, since radon is a carcinogen with no known safe exposure level, they also recommend action at levels between 2 and 4 pCi/l (EPA "Radon" par. 2). For almost 4,000 public buildings tested in the U.S., 22% were over the 4 pCi/l criterion and 0.2% were over 27 pCi/l (IAEA 7). Of 927 U.S. schools surveyed, about 19% had at least one ground-contact room that measured radon over the 4 pCi/l criterion (School Library Journal 14). A summary of action levels and some typical concentration values are provided in Table 2.2.

Table 5.2 – Action Levels and Typical Radon Concentrations

Limit or Level Description	Concentration (pCi/l)	Source
EPA home action level	2	EPA "Radon" par. 2
EPA home remediation level	4	EPA "Radon" par. 2
IAEA workplace action level	27	IAEA 11
ICRP workplace action level	14 - 41	IAEA 11
USNRC and OSHA limit	30	NRC, Table 1
Utility manholes (U.K.)	38	Wiegand 569
Tunnels (Europe)	6 - 189	IAEA 6
Tourist caves (U.S.)	1 - 50	IAEA 6
Subways (Europe)	1 - 21	IAEA 6

For the general population, 4 pCi/l equates to a risk level of about 2.3×10^{-2} (EPA "Assessment"). This is much higher than the typical range EPA normally promotes (10^{-4} to 10^{-6}). Smoking and radon have a synergistic effect increasing the already burdensome risk shouldered by smokers (American Lung Association "Indoor" 18).

Since radon is ubiquitous in the environment, all buildings have radon in varying concentrations. Concentrations of radon in structures are highly variable. The same energy-saving initiatives that helped trap other IAQ contaminants inside have also helped to increase the concentrations of radon in almost all occupied structures. For above-ground structures, the primary contributor to radon is soil (IAEA). Significant contributions can also stem from the use of radon-bearing groundwater and building materials such as granite. Historically, radon exposure has been an important issue for mining operations. High levels of radon, however, can be seen in underground structures such as tunnels,

tourist caves, and underground shopping centers. Kitchens and laundries that use well water with high natural radioactivity also have indicated high levels of radon (IAEA 5).

Most studies and health concerns related to radon focus on exposure in the home. Radon will, however, result in some exposure at work. For offices, radon concentrations will vary depending on such things as the radon emanation rate, the type of construction, the distance from the ground level, and the ventilation system's air exchange rate. OSHA applies its ionizing radiation standards to workplaces that have radon problems. At 25 pCi/l, an area must be posted as an "airborne radioactivity area" (OSHA "Occup. Exp."). In additions, surveys and personnel monitoring must be conducted to demonstrate compliance with the regulation.

There is often a natural drive for radon to enter a structure since higher indoor temperatures, relative to soil, create an indoor low-pressure zone (IAEA 5). As noted by IAEA, the distribution of radon concentration values is skewed so there may be a small number of workplaces that have concentrations well above the average. The only way to know is to measure it.

5.3 Chemical Substances

The most prevalent class of chemical substance in the IAQ arena is VOCs, the term "VOC" covers a wide class of chemicals. Some of these are known carcinogens while others are believed to be relatively harmless (EPA "Organic"). In addition, there are often tens or hundreds of VOCs co-existing in typical indoor air. These mixtures may be problematic but the combined effect of such compound mixtures has not been well studied (Alevantis 3).

An important issue with VOCs is individual sensitivity. Some individuals are clearly more sensitive to some chemical contaminants than others. Groups of individuals that tend to be more sensitive to chemical exposures include (American Lung Association "IAQ Basics"):

- Allergic or asthmatic individuals
- Those with a respiratory disease
- Those with suppressed immune systems
- Contact lens wearers

Acceptable air quality for individuals such as these must be defined differently than it is for the general population.

Johnston and others ranked toxic chemicals that are often found indoors according to the health risk they present. The Johnston ranking developed a "priority" list by evaluating the prevalence of typical indoor air contaminants and by comparing this data to health indexes. This ranking was used as a cornerstone of this thesis effort to identify higher-risk indoor air contaminants. Most of the chemical substances identified in the ranking were VOCs. There were several important limitations to the Johnston ranking including the following:

- Certain inorganic chemicals, such as ozone, nitrogen oxides and CO, were excluded from the ranking for programmatic reasons
- Health effect information was not available for all chemicals
- Only a limited number (112) of chemicals were evaluated
- The ranking only included chemicals that were identified at least 10% of the time

- Several studies with older concentration data were used

Because of the uncertainty levels in the analysis, the chemicals are only identified as higher-risk and are not ranked against each other (Johnston 933). The study presented the higher-risk chemicals in two lists according to different levels of cancer (10^{-4} or 10^{-6}) and non-cancer risk. For the purposes of this thesis, substances in both lists are identified.

The data used to develop the report's conclusions are not provided in the report. As such, the data developed in this thesis were done so independently of the report and are not always complete. It should also be noted that four of the chemical substances identified in the Johnston study (arsenic, carbon tetrachloride, chloromethane, and manganese) originate predominately outdoors (933). Arsenic and manganese were excluded from evaluation because of their outdoor prevalence. Carbon tetrachloride and chloromethane were included in the evaluation that follows because of their common use in products that often result in elevated indoor concentrations.

The text in the sections that follow provides summary information about the substances that were initially identified in the Johnston ranking.

5.3.1 Pesticides

Pesticides include products used to control insects (insecticides), rodents (rodenticides), fungi (fungicides), and microbes (disinfectants). Pesticides employ a variety of active ingredients that work in different ways. Potential health effects from exposure to pesticides include headache, respiratory and skin irritation, dizziness, muscular weakness and nausea (American Lung Association "Pesticides"). Besides active ingredients, pesticides also contain carrier agents are called "inerts." Some of the inerts may be harmless to the intended receptor but are capable of causing health effects in humans.

The Johnston ranking included six types of pesticides including:

- Aldrin
- Alpha- and gamma-BHC
- Chlordane
- Dichlorvos
- Dieldrin
- Heptachlor

From 1950s to 1970, aldrin and dieldrin were widely used for controlling insects (DHHS "Aldrin" sec. 1.1). These chemicals are classified as probable human carcinogens (DHHS "Aldrin" sec. 1.5) and are suspected of reducing fertility in humans (NJ "Aldrin" 1). Because of health concerns, the EPA banned their use on everything but termite control in 1974 (DHHS "Aldrin" sec. 1.9). In 1987, the EPA banned all uses (DHHS "Aldrin" sec. 1.1). Aldrin breaks down to dieldrin under sunlight or exposure to bacteria; however, dieldrin degrades very slowly in the environment and can still be found where it was applied (DHHS "Aldrin" sec. 1.2).

Alpha-BHC, which is used to treat scabies and lice (NJ "Alpha-Hex."), is a probable human carcinogen (EPA "Alpha-Hex"). Gamma-BHC, commonly known as Lindane, is a confirmed animal carcinogen (ACGIH 35). Lindane is used to control insects on seeds and in treated insect baits (NJ "Lindane").

Chlordane was widely used as an insecticide until its use was banned by the EPA in 1988 (DHHS "Chlordane" sec. 1.1). It is a known human carcinogen (ACGIH 18). Chlordane is known to reside in soil for at least 20 years (DHHS "Chlordane" sec. 1.2).

Dichlorvos is a probable human carcinogen that is used as an insecticide in food storage areas, barns, greenhouses, and in workplaces and homes (DHHS "Dichlorvos" sec. 1.1). After application, it evaporates relatively quickly into air (DHHS "Dichlorvos" sec. 1.2).

Heptachlor was used until 1988 as an insecticide in homes, buildings, and on crops (DHHS "Heptachlor" sec. 1.1). It is now banned for all uses except for controlling fire ants in power transformers (EPA "Heptachlor Fact Sheet" 1). It is a confirmed human carcinogen (ACGIH 31) and breaks down very slowly in the environment (DHHS "Heptachlor" sec. 1.2).

An EPA newsletter entitled *Inside IAQ* examined several studies conducted on indoor air (EPA "Comparison"). This newsletter provided typical concentrations of indoor air for chlordane, dichlorvos, and heptachlor. This data, which is provided in Table 5.2 below, represented indoor spaces that didn't involve industrial, manufacturing, or commercial operations (EPA "Comparison" 1). No typical workplace concentration data for the other identified pesticides were located. Data on residential concentrations of the other identified pesticides, however, were found in Spengler (Table 35.2a). This source provided concentrations over three seasons in 1986 and 1987 for 175 homes in Jacksonville, Florida. These data are also provided below in Table 5.2.

The first column in Table 5.2, nominal concentration, is derived from the mean of the data provided in *Inside IAQ* or Spengler. As a side note, where data was provided in both reports (for three substances), there was good agreement in the data. The cancer potency values noted in this table were taken from the CalEPA Toxicity Criteria Database (TCD), except for heptachlor, which was found in the EPA's Integrated Risk Information System

(EPA “Heptachlor IRIS”). The “relative risk” provided in Table 5.2 is the product of the typical concentration and the cancer potency, provided in terms of the excess potential for developing cancer. For example, exposure to the nominal concentration of Aldrin (noted as 73 in Table 5.2) continuously for a lifetime would lead to the development of no more than 73 excess tumors per 1 million exposed people (EPA “Risk”). This assumes that the cancer potency factor is based on a linear dose-response relationship. The relative risk value was not adjusted for time in the workplace since exposures to pesticides are common both in the workplace and at home.

Table 5.3 - Pesticide Risk Comparison

Pesticide	Nominal Concentration (ng/m^3)	Cancer Potency $(ug/m^3)^{-1}$	Relative Risk (10^{-6})	Other Notes
Aldrin	15	4.90E-03	73	banned
Alpha-, gamma-BHC	13	3.10E-04	4	--
Chlordane	200	3.40E-04	68	banned
Dichlorvos	50	8.30E-05	4	--
Dieldrin	10	4.60E-03	46	banned
Heptachlor	100	1.30E-03	130	banned

5.3.2 Aldehydes

Two aldehydes were identified in the Johnston study including:

- Acetaldehyde
- Formaldehyde

Acetaldehyde is a colorless, flammable liquid with a fruity, pleasant odor at low concentrations (EPA "Acetaldehyde"). It is ubiquitous in the environment since it is a common combustion byproduct and is used in many products including perfumes, polyester resins, dyes, food preservatives and food flavorings (EPA "Acetaldehyde"). It is a confirmed animal carcinogen (ACGIH 10) and a probable human carcinogen (EPA "Acetaldehyde"). The CREL for acetaldehyde, 9 ug/m^3, is based on exposure related effects to the respiratory system (CalEPA "Air"). Acetaldehyde concentrations of 58 ug/m^3 have been measured in ambient air in Los Angeles, California (EPA "Acetaldehyde").

Formaldehyde is a colorless gas with a pungent odor (EPA "Formaldehyde"). It is used in resins that are, in turn, used to manufacture building materials, especially particle board, and in furniture (EPA "Formaldehyde"). Formaldehyde is found in upholstery, permanent press fabrics, carpets, pesticides, and paper products (CalEPA "Air" A-71). It was widely

used as urea-formaldehyde foam insulation up until the 1980's (American Lung Association "Indoor" 13). It was recently listed as a known human carcinogen by the International Agency for Research on Cancer (Nat. Cancer Inst. par. 4). The CREL for Formaldehyde, 3 ug/m^3 is based on exposure related effects to the respiratory system and the eyes (CalEPA "Air"). Formaldehyde concentrations of 120 to 4,500 ug/m^3 have been measured in indoor home air (EPA "Formaldehyde").

5.3.3 Chlorinated Solvents

Four chlorinated solvents were identified in the Johnston study including:

- Carbon tetrachloride
- Methylene chloride
- Tetrachloroethylene
- Trichloroethylene

Carbon tetrachloride is a clear, flammable, liquid with a sweet characteristic odor (EPA "Carbon Tet."). The EPA notes that exposure to carbon tetrachloride appears to be from building or other materials, such as cleaning agents (EPA "Carbon Tet."). It is listed as a suspected (ACGIH 18) and probable (EPA "Carbon Tet.") human carcinogen. The CREL for carbon tetrachloride is based on exposure related effects to the alimentary (digestion) system (CalEPA "Air"). All CRELs for substances listed in this section are provided in Table 5.2.

Methylene chloride, also known as dichloromethane, is a nonflammable, colorless liquid with a sweetish odor (EPA "Methylene Chloride"). Considered a probable human carcinogen, it is used as a paint remover and as an aerosol propellant (EPA "Methylene

Chloride"). The CREL for methylene chloride is based its effect on the cardiovascular and nervous systems (CalEPA "Air").

Tetrachloroethylene, also known a perchloroethylene, is a nonflammable, colorless liquid with a sharp, sweet odor (EPA "Tetrach."). Tetrachloroethylene is primarily used as a dry cleaning solvent. As a result, a primary source of exposure for tetrachloroethylene is wearing and storing dry-cleaned clothes (Samet 261). Tetrachloroethylene is also used in paints and coatings, adhesives, silicones, and rug shampoos (EPA "Tetrach."). Tetrachloroethylene is a confirmed animal carcinogen (ACGIH 54). Tetrachloroethylene is classified as a probable human carcinogen (EPA "Tetrach."). The CREL for tetrachloroethylene is based on effects to the kidney and alimentary system (CalEPA "Air").

Trichloroethylene, also known as TCE, is a nonflammable, colorless liquid with a sweet odor (EPA "Trich"). Although the EPA doesn't currently classify trichloroethylene as a carcinogen, it is reassessing its position and the latest data suggest that it is a probable human carcinogen (EPA "Trich."). Although its primary use is vapor degreasing of metal parts, it is also used in a wide variety of products, including correction fluid, paints removers, adhesive, and rug cleaning agents (EPA "Trich."). The CREL for trichloroethylene is based on exposure related effects to the central nervous system and eyes (CalEPA "Air").

5.3.4 Other VOCs

Nine other VOCs that were not otherwise classified were also included in the Johnston report including:

- Benzene

- Chloroform
- Chloromethane
- 1,4-dichlorobenzene
- N-hexane
- Methyl isobutyl ketone
- Naphthalene
- Toluene
- Methyl chloroform
- Mixed xylenes

Benzene is one of the few VOCs that is a known human carcinogen (ACGIH 13). It is used in a wide variety of chemical products including dichloro-diphenyl-trichloroethane (DDT), detergents, insecticides and motor fuels (Vermont, par. 3). It was once widely used as a solvent in paints, paint removers, and adhesives but that use is diminishing (Vermont, par. 3). The primary source of benzene in indoor air is ETS (Samet 260). Other sources include stored fuel and paint supplies, and vehicle exhaust (EPA "Benzene"). The CREL for benzene is based on hematopoietic system effects (CalEPA "Air").

Chloroform is a colorless liquid that is highly volatile and has a pleasant, non-irritating odor (EPA "Chloroform"). When chlorine is added to water to kill microbes and other potential pathogens, chloroform becomes an inevitable byproduct. As a result, chloroform is released whenever chlorinated water is used, e.g., showering, washing clothes or dishes, swimming pools. Chloroform is classified as a confirmed animal carcinogen (ACGIH 19) and as a probable human carcinogen (EPA "Chloroform"). The CREL for chloroform is based on alimentary system and other system effects (CalEPA "Air").

Chloromethane, also known as Methyl Chloride, is a colorless gas with a faint sweet smell. Exposure to chloromethane may come from cigarette smoke, polystyrene insulation, and aerosol propellants (EPA "Methyl Chloride"). Chloromethane is not classifiable as a carcinogen (ACGIH 38). Chronic exposure has led to the liver, kidney, spleen, and CNS effects in studied animals (EPA "Methyl Chloride").

1,4-dichlorobenzene, also known as para-Dichlorobenzene, is a white solid with a sweet taste and a strong odor (EPA "1,4-Dich"). This compound is used in mothballs and in toilet and garbage can deodorizers (EPA "1,4-Dich"). It is a confirmed animal carcinogen (ACGIH 23) and a possible human carcinogen (EPA "1,4-Dich"). The CREL for 1,4-dichlorobenzene is based on exposure related effects that include the nervous system (CalEPA "Air").

N-Hexane (normal hexane), an isomer of hexane, is a colorless liquid that is insoluble in water (EPA "Hexane"). It is used primarily in the extraction of vegetable oil from a variety of seeds but is also used as a solvent in glues (rubber cement), adhesives, varnishes, and inks (EPA "Hexane"). It is not classifiable as a human carcinogen (EPA "Hexane"). The CREL for N-hexane is based on exposure related effects to the nervous system (CalEPA "Air").

Methyl isobutyl ketone (MIBK), also known as 4-methyl-2-pentanone and Hexone, is a colorless, flammable liquid with a faint camphor odor (EPA "MIBK"). It is not classifiable as a human carcinogen (EPA "MIBK"). MIBK is used as a solvent in a wide variety of consumer products such as paints, lacquers, varnishes and resins. EPA has an established an RfC for MIBK based on neurotoxicity in humans and in nasal lesions in studied mice (EPA "MIBK").

Naphthalene is a white solid or powder than has a strong mothball odor. It is classified as a possible human carcinogen by the EPA ("Naphthalene"). It is used to manufacture mothballs and is also used in ink and dyes, and insecticides (EPA "Naphthalene"). The CREL for naphthalene is based on respiratory system effects (CalEPA "Air").

Toluene is colorless, flammable liquid with a sweet, pungent odor (EPA "Toluene"). It is not classifiable as a human carcinogen (ACGIH 55). It is used as a gasoline additive and as a solvent in paints, coatings, synthetic fragrances, adhesives, inks, and cleaning agents (EPA "Toluene"). The CREL for toluene is based on exposure related effects that include the nervous system (CalEPA "Air").

Methyl chloroform, also known as 1,1,1-trichloroethane, is a nonflammable, colorless liquid with a sweet, sharp odor (EPA "Methyl Chloroform"). Methyl chloroform is widely used in home and office products including correction fluid, paints, glues, and cleaning products (EPA "Methyl Chloroform"). Methyl chloroform is not classifiable as a human carcinogen (ACGIH 38). The CREL for methyl chloroform is based on nervous system effects (CalEPA "Air").

Mixed xylenes are colorless liquids that have a sweet odor and are nearly insoluble in water (EPA "Xylenes"). The three isomers of xylene include m-, o-, and p-xylene. They are not classifiable as human carcinogens (ACGIH 58). Xylenes have been widely used in many home and office products such as fragrances and paints. The CREL for mixed xylenes is based on exposure related effects that include the nervous system (CalEPA "Air").

Table 5.2 provides a comparative risk analysis between the higher-risk VOCs identified from the Johnston report. In the table, nominal concentrations were taken from

Girman, Table 1, except for trichloroethylene and chloromethane. Nominal concentration data for trichloroethylene were taken from California Toxics Fact Sheet (Cal. ARB "Toxics"). Chloromethane data was taken from Spengler (31.16). Column 2, the concentration range mean, simply uses the approximate mean of the range identified. This may or may not be the accurate since the distribution of the range is unknown. Column 3 presents the REL levels, which are CRELs except for chloromethane and MIBK, which are RfC values (EPA "Methyl Chloride" "MIBK").

Column 4, the fraction of the REL, divides column 2 by column 3. Column 5, inhalation cancer potency, was taken from the EPA's Technology Transfer Network Air Toxics Website for the respective VOC listed (e.g., EPA "Formaldehyde" for formaldehyde) except for chloroform, 1,4-dichlorobenzene, and naphthalene. These were taken from the California EPA Toxicity Criteria Database (CalEPA "TCD"). The EPA noted that Tetrachloroethylene and trichloroethylene were provisional values ("Tetrach.", "Trich"). Also, the Benzene cancer potency was given as a range (EPA "Benzene"). The greatest cancer potency value in the range was used.

The last column, relative risk, is the product of the mean concentration and the cancer potency adjusted for a 40-hour workweek, versus continuous exposure. It should be noted that since the mean of the identified range is used in the calculations, concentrations at the higher end of the range would result in substantially higher relative risk values for certain chemicals. The 1990 Clean Air Act Amendment identified carbon tetrachloride and methyl chloroform as ozone-depleting substances and have severely restricted their production and use (Clean Air Act). As a result, current concentrations and risk values associated with

these substances should currently be lower than that shown on Table 5.2, which draws from data that is several years old.

Table 5.4 - VOC Risk Comparison

VOC	Nominal Conc. (ug/m^3)	Conc. Range Mean (ug/m^3)	REL (ug/m^3)	Fraction of REL	Cancer Potency $(ug/m^3)^{-1}$	Relative Risk (10^{-6})
Acetaldehyde	3-12	7.5	9	83%	2.20E-06	4
Formaldehyde	5-27	16	3	533%	1.50E-05	57
Carbon tetrachloride	1.2-3.9	2.5	40	6%	1.50E-05	9
Methylene chloride	.5-360	180	400	45%	4.70E-07	20
Tetrachloroethylene	.3-50	25	35	71%	5.80E-07	4
Trichloroethylene	8-38	23	600	4%	1.70E-06	9
Benzene	0.6-17	9	60	15%	7.80E-06	17
Chloroform	0.3-9.6	5	300	2%	5.30E-06	6
Chloromethane	2.1-3.8	3	90	3%	--	--
1,4-dichlorobenzene	0.3-85	43	800	5%	1.50E-05	154
N-hexane	0.6-21	11	7000	0%	--	--
MIBK	0.2-28	14	80	18%	--	--
Naphthalene	0.3-9.7	5	9	56%	3.40E-05	40
Toluene	1.6-360	151	300	50%	--	--
Methyl chloroform	0.6-450	225	1000	23%	--	--
Mixed Xylenes	0.3-96	48	700	7%	--	--

5.3.5 Chlorofluorocarbons

Two chlorofluorocarbons (CFC) were identified in the Johnston study including:

- Dichlorodifluoromethane
- Trichlorofluoromethane

Dichlorodifluormethane, also known as Freon-12 or R-12, is a colorless gas with practically no odor. Although it is an irritant and can disrupt cardiac functions at high concentrations, dichlorodifluormethane has not been shown to cause cancer in humans or animals (NJ "Freon 12").

Trichlorofluoromethane, also known as Freon-11, is also a color liquid or gas with somewhat of an etheral odor. It is an irritant and can disrupt cardiac functions at high concentrations but has not been tested for cancer effects in humans or animals (NJ "Freon 11").

Because of their ozone-depleting effects, the use of dichlorodifluormethane and trichlorofluoromethane has been severely restricted (Clean Air Act). Recent "typical" exposure data was not available for these substances but is expected to be small because of the current restrictions.

5.4 Bioaerosols

Bioaerosols are airborne substances that are or originate from living organisms. They include a broad range of potentially offending agents including such things as fungi or mold (cladosporium), viruses (influenza), bacteria (mycobacterium which causes tuberculosis), animal excreta and dander, dust mites, and insects and their excreta.

Human exposure to bioaerosols may lead to infections, toxicosis, and hypersensitivity (allergies). Respiratory allergies, including asthma, rhinitis, and sinusitis, are most frequent in individuals who have an inherited tendency to form immunoglobulin E against bioaerosols (Samet 286). These individuals are termed atopic and constitute between 5 and 22 percent of the general population (Samet 286). Known indoor air allergens include dust mites, animal dander, rodent urine, cockroaches, and mold (Samet).

Many studies have reported that the prevalence of asthma and allergies has increased dramatically over the past few decades. This has been attributed to several factors including landscape changes from forest to pasture and the trend of individuals living and working in climate-controlled environments where allergens often concentrate (Australia Sec. 7.4.2).

5.4.1 Bacteria and Viruses

Bacteria occur naturally in the environment and air. Bacteria seldom result in human illness although they can cause allergic reactions, infections, and inflammatory diseases (Tsai 353). They normally do not become a problem unless they are allowed to multiply. As sources of indoor air contamination, bacteria normally proliferate well in areas with warm, standing water such as the conditions found in cooling towers for air conditioning plants or in spas (Australia 7.4.1).

Exposure to legionella bacteria can result in legionnaire's disease or a milder illness known as Pontiac Fever. Legionnaire's disease is a form of pneumonia that accounts for about 1% of all pneumonia and has a mortality rate of about 20% (Australia 7.4.1). Tuberculosis is another bacteria-related disease. According to Indoor Air Pollution, the "the rising incidence of tuberculosis is a least in part a problem associated with crowding and inadequate ventilation" (Samet 11).

Viruses are an important source of occupational absenteeism because they are responsible for the common cold and influenza. Poor building ventilation can support the effective transmission of viruses between humans.

Although common colds and flu are not normally life threatening to healthy adults, strains of new, immunoresistent and drug-resistant viruses, such as the feared "Bird Flu,"

can result in considerable mortality. Of the limited number of infected individuals affected by the outbreak in 2005 in Asia and Europe, more than half died (CDC "Key" Par. 14). To respond to a potential Bird Flu pandemic, health care facilities are advised to use respiratory protection and an airborne isolation room to care for potentially infected patients (CDC "Key" "Infection Control in Healthcare Facilities").

5.4.2 Mites and Animal Allergens

Dust mites have been known to be a human allergen for more than 20 years (American Lung Association "Indoor" 11). According to Boyd, dust mites are the second leading cause of allergic reactions, behind pollens (Par. 2). An evaluation done as part of BASE identified dust mite allergens in about one-half of the 93 buildings evaluated. In addition, the allergen concentrations were greater than the identified "sensitization limit" in five of the buildings and greater than the "symptom threshold" in three of the buildings (Macher 359).

According to Miller, 45-85% of those with asthma are affected by the presence of dust mites (25). Dust mite concentrations generally range from about 10-1000 mites per gram of dust. A concentration of 500 mites/gram is considered sufficient to provoke an acute attack in sensitized individuals (Miller 25).

Like mites, animals and animal products such as dander, saliva and urine contain powerful human antigens. After periods of exposure (sometimes months or years), an individual has inhaled sufficient quantities of the allergen to become "sensitized." Subsequently, even exposures to small quantities of the allergen can cause a severe reaction (NIOSH "Preventing" par. 6). As noted in Section 3, there is a substantial portion of the population that is sensitive to animal proteins, especially those found in cats. The

National Academy of Sciences concluded that a causal relationship does exist between exposure to cat, cockroach, and dust mite and the exacerbation of asthma in sensitized individuals (Australia Sec. 7.4.2).

Because workers with pets bring allergens with them to work, non-pet owning, sensitive workers can and do have reactions to these allergens. For example, 94% of samples from BASE buildings were found to contain cat allergens; however only 2% of the buildings were found to be above what is considered to be a "sensitization threshold" (Macher 359). When the widespread presence of cat allergens is combined with the fact that 10-15% of the population will show a positive skin reaction to cat allergens (Miller 25), the need to control such allergens becomes apparent.

5.4.3 Mold

Mold, which is a type of fungi, can be a potent human health hazard. Molds produce allergens, irritants, and in the case of certain mold species, human toxins (EPA "Mold" 40). In assessing the allergic reaction potential in molds, the EPA notes the following ("Mold" 40):

> Mold spores and fragments can produce allergic reactions in sensitive individuals regardless of whether the mold is dead or alive. Repeated or single exposure to mold or mold spores may cause previously non-sensitive individuals to become sensitive. Repeated exposure has the potential to increase sensitivity.

Mold can cause irritation of the eyes, skin, nose, throat and lungs (EPA "Mold" 41). It is known to cause opportunistic infections in those who have weakened immune systems (EPA "Mold" 41). Mycotoxins are toxic substances produced by some mold species. There

are at least 200 types of mycotoxins produced from common molds (EPA "Mold" 41). One of these, Aflatoxin B, which is not commonly found in buildings, is one of the most potent carcinogens known to man (EPA "Mold" 41).

According to the CDC, certain molds like Stachybotrys are toxogenic since they produce toxins, specifically mycotoxins (CDC "Questions" par. 2). The CDC's believes that molds may cause symptoms that are nonspecific, such as hay fever-like allergic symptoms, but there is no causal link between mold and unique health problems, such as pulmonary hemorrhage or memory loss (CDC "Questions" par. 2).

There is, however, controversy about mold and its relationship to health effects. A report in the Journal of Nutritional and Environmental Medicine notes that several studies have indicated that exposure to Stachybotrys' mycotoxins can "alter brain blood flow, autonomic nerve function and brain waves, and worsen concentration, attention, balance, and memory" (Curtis 261).

Despite the known relationship between mold and moisture, EPA BASE researchers found that 45% of surveyed office buildings were reported as having current water damage or ongoing leaks (Girman, Table 4).

5.5 Particulate Matter

An Italian paper on IAQ examined a large number of worldwide epidemiological studies (Maroni). The results of the review showed a link between daily variations of concentrations of fine and ultra fine particles and the morbidity and mortality of the general population. This is attributed to the toxic effects on the respiratory and cardiovascular systems; however, the mechanism by which these airborne materials induce detrimental health effects has not yet been identified (Maroni). The EPA notes that fine,

particulate airborne matter is associated with serious health effects, increased hospital and emergency visits for susceptible individuals, and lost work days (EPA "How Particulate Matter" par.1).

Lawmaking is currently being undertaken by the EPA to develop new standards for environmental particulate matter. The EPA staff has recommended a 15 ug/m^3 annual limit for fine (respirable) particles that are 2.5 microns in diameter and smaller (PM2.5) (EPA "Draft Staff Paper" 2). For particulate matter between 2.5 microns and 10 microns (PM2.5-10), the EPA Staff has recommended a level in the range of 65 to 85 ug/m^3 (EPA "Draft Staff Paper" 3). Indoor concentrations are generally lower than outdoor concentrations unless a source of particulate matter, such as ETS, is present indoors. According to a paper from the EPA's BASE study, indoor concentrations of PM2.5 range from about 1 to 25 ug/m^3, with a geometric mean of 7.2 ug/m^3 (L. Burton 158).

It should be noted that the quantity of respirable particulate matter markedly improved where ETS had been banned. For example, monitoring of hospitality venues after a public smoking ban in New York showed, on average, that respirable particulate matter dropped 84% (Travers 1038).

5.6 Carbon Monoxide

Carbon monoxide (CO) is a chemical asphyxiant whose health effects have been well studied. Relatively low concentrations of CO results in fatigue and chest pain in people with chronic heart disease (American Lung Association "Carbon Monoxide"). For healthy individuals, higher concentrations of carbon monoxide cause flu-like symptoms such as headaches, dizziness, and weakness (American Lung Association "Carbon Monoxide"). Chronic exposure to carbon monoxide may cause persistent signs and symptoms, such as

anorexia, headache, lassitude, dizziness, and coordination difficulties (OSHA "Occup. Safety").

The U.S. National Ambient Air Quality Standards for CO are 9 ppm for 8 hours and 35 ppm for 1 hour (EPA "Carbon"). Typical concentrations in an office building are about 0.5 to 3 ppm; however, heavy outside traffic or an idling truck in a loading bay can drive levels up to 15 to 20 ppm (Building Air Quality par. 6).

6.0 DISCUSSION – RELATIVE RISK

Scientific-based examinations have established links between indoor air contaminants and health effects. The issue becomes "at what concentration are common indoor contaminants harmful"? For many indoor contaminants, high concentrations will have consistent and verifiable affects on human health. For low concentrations, the answer to this question is far more elusive. Using available standards, which are based on potential health affects, and nominal workplace concentration values, the following information highlights some of the indoor air contaminants that appear in the top tier of the relative risk ranking.

6.1 ETS

ETS and Radon top the IAQ risk list. If smoking is allowed indoors, then ETS does present a health hazard to the building's occupants. The risks are delivered by a wide variety of harmful chemical substances and particulate matter. Health risks cannot be eliminated by removing ETS through the application of standard ventilation methods (American Lung Association "Indoor" 5). According to IAQ professionals who responded to the questionnaire described in the next section, ETS is becoming less of a problem because of smoking bans or limitations in the workplace. The problem, however, does remain for those who work in bars, nightclubs, and other hospitality venues where local regulations continue to allow smoking at these locations.

6.2 Radon

Radon is also a well-documented IAQ health risk. Radon has a steep cancer potency slope and concentrations can sometimes exceed values that are deemed acceptable. This results in high relative risk for some buildings.

6.3 Chemical Substances

Given the study limitations discussed, the Johnston screening-level ranking did provide useful information on chemical substances that present the highest levels of risk to building occupants. In the Johnson ranking, ETS and radon were purposefully excluded from the screening process. The risk from these two substances, however, is noted as being 2 orders of magnitude greater than the highest-risk substance on that list (Johnston 930-31). Of the 112 chemical substances in indoor air that were evaluated, 26 substances were identified in the report as being both hazardous and common in unhealthy quantities in indoor air.

Of this list of 26, several stood out because typical concentrations were near or above the established criterion (REL). These include:

- Acetaldehyde
- Formaldehyde
- Chloromethane (methyl chloride)
- Tetrachloroethylene (perchloroethylene)
- Naphthalene
- Toluene

Of these, formaldehyde and naphthalene also presented relatively high cancer risks. One additional chemical substance, 1,4-dichlorobenzene, also presented a high level of cancer risk. In fact, this substance presented the greatest cancer risk at nominal concentrations and slightly exceeded the EPA's generally accepted upper risk limit (1 in 10,000 excess morbidity).

6.4 Bioaerosols

Bioaerosols have a strong tendency to trigger allergic reactions, which are common. More than half of all Americans are allergic to one or more of ten common allergens, most of which can be present in indoor air (Arbes 377). Exposure to allergens can not only trigger an allergic reaction, it can create the initial hypersensitivity.

Chang notes that beneath the "mass hysteria" related to IAQ, the "real" health issues associated with IAQ are allergies and asthma resulting from exposure to bioaerosols (219). According to Chang, "indoor allergens can cause severe allergic symptoms" and also have a "priming effect" to an individual's susceptibility to outdoor allergens (219).

Although molds can cause irritation and may be toxic, the greatest health threat they pose to workers is normally the allergic reaction they can initially create and then later trigger. Stachybotrys, despite its well-publicized threat, was not even detected during the wide spread sampling conducted as part of the BASE study (Womble).

Viruses, such as the common cold and flu, most often have a short-term effect on health and contribute to absenteeism. Bacteria, such as legionnella, are normally only a problem if warm, moist conditions allow multiplication. Although transmission of viruses and bacteria is thought to happen through airborne transport and inhalation, and through direct contact of affected surfaces, the degree to which each contributes to the overall transmission effect is not clear (Spengler 11.2). The most serious health affects from viruses and bacteria appear to stem from cases where untethered bacteriological growth is allowed or in settings, such as hospitals, where substantial quantities of infectious particles exist.

6.5 Particulate Matter

A causal relationship between health and concentrations of fine, particulate matter has been established. In terms of indoor air, however, unless there is an internal source of particulate matter such as ETS, individuals receive less particulate matter exposure inside than outside.

6.6 Combined Exposures

No attempt by regulators to develop standards for mixtures of airborne substances was identified. Exposures rarely involve a single potentially harmful substance. Science knows little about the human health effects of complex mixtures of indoor air contaminants that we all breathe. Since many VOCs share common target organs including the lungs and respiratory tract, the combined effects of these compounds may very well be additive. Available standards, however, do not address the combined effects of multiple VOCs. They also do not address the effects of multiple classes of indoor air contaminants (e.g., VOCs and particulate matter). Such situations have not been studied well with some exceptions (e.g., smoking and asbestos).

If indoor air were treated similarly to Superfund cleanup sites, carcinogenic risk would be added and then assessed for acceptability. Toxicity risks would also be looked at collectively if substances targeted the same tissue or organ. This difference in approach may be due, at least in part due to public perception of these different risks. The general public perceives indoor air contamination as less of a threat than say a hazardous waste site. EPA experts, on the other hand, put indoor air pollution at the top of their risk-concern list while the waste site goes towards the bottom (Spengler 33.24).

7.0 RISK-BASED IAQ RESPONSE

With an understanding of the relative risks, a model IAQ response protocol can be envisioned. As previously noted, IAQ investigations are typically initiated when building occupants suffer and report acute illness that is believed to be associated with their presence in the building. Employers, building managers and IAQ practitioners, however, should also consider chronic, long-term exposures to unhealthy substances during the evaluation process since it is the overall health of occupants that is the focus of concern. Based on overall health risks, the actions described in the following text should be considered when conducting an IAQ evaluation.

7.1 Basic Information

The first step in most IAQ evaluations is to answer the basic questions, including the following:

- Is anyone complaining? What are their symptoms? Do they have allergies?
- What time of day are symptoms present?
- What area of the building is involved?
- Is the building thermally comfortable? What is the relative humidity?
- Are there any odors that could indicate the presence of an IAQ contaminant?
- What is the building's level of cleanliness?

EPA's IAQ investigation protocol, which is discussed in Section 8.3, has an extensive section dedicated to linking symptoms and potential causative agents.

7.2 HVAC System

The HVAC system should be examined. Is condensate draining properly from the unit? Is the system providing quantities of outside air in accordance with ASHRAE

requirements? Does the system filter or otherwise treat incoming dilution air in areas with poor outside air quality? Are the intake and discharge registers free from obstructions? Are there pockets of stagnant air in the structure? Does the system allow local control of temperature? Is the system being maintained in accordance with the manufacturer's instructions? Is a biocide being used in the condensate drip pan?

7.3 Moisture

As noted, moisture can result in untethered growth of bacterial agents and fungi, namely mold. The building should be examined for areas of uncontrolled moisture. This includes kitchens, bathrooms and mechanical rooms. The roof and windows should be checked for leakage. Sub-grade floors and walls should also be examined. Indications of moisture may include the presence of standing water or mold, a musty smell, high humidity, stained surfaces, or damp materials.

There is also a selection of instruments available to determine the moisture content of building surfaces. Principal among these is a moisture meter and relative humidity meter. Moisture meters generally use one of two technologies. One of these uses metal pins that make contact with building surfaces (e.g., sheetrock wall, wooden floor, etc.). This instrument measures the conductivity of the surface and converts this to units of "wood moisture equivalent." The other technology uses a radiofrequency to identify moisture to about ¾" from the surface. Moisture measurements can be erroneous if the surface is naturally conductive or contains hygroscopic salts (Inspector Tools). Infrared cameras have also been used to detect thermal gradients caused by unseen moisture.

7.4 Outside Sources

It is important that outside sources of potential air contaminants be identified and evaluated. Intake air for the ventilation system may be bringing in contaminants that are normally outside problems like unfiltered pollen, oxides of nitrogen, fine particulate matter and more. Nearby heavy traffic can exacerbate this problem. Parking garages or loading docks might be providing a pathway for vehicle exhaust including fine particulate matter and carbon monoxide. The structure may be in close proximity to industrial emission sources. Smoke from outside smoking areas may be entering through doorways or windows. Nearby or adjacent construction activities may be driving up levels of outdoor air contaminants. Sewer vents or boiler exhausts may not exhaust at a sufficient height or at an optimal location. Trash dumpsters can also contribute to indoor odors and bioaerosol levels.

7.5 Inside Sources

Key inside sources for acute and chronic health effects include ETS, radon, VOCs, and bioaerosols.

7.5.1 ETS

The IAQ professional should check to ensure that non-smoking workers are not exposed to tobacco smoke in the workplace. This is normally accomplished through a smoking policy that is understood and followed. This policy can restrict smoking to specific, designated areas or can prohibit smoking entirely. The latter approach may seem easy but the needs of smokers should be considered. Costly legal battles have been mounted against employers based on smoking being an addiction and is a disability and, therefore, covered under the Americans with Disabilities Act (Smoke Free par. 9). In

addition, there may be numerous smokers who take offense to the ban and look for employment elsewhere. Collective bargaining units should also be expected to provide some input on any proposed smoking ban. That said, many employers have successfully banned workplace smoking.

If an employer allows smoking, measures should be taken to isolate smoke and non-smokers. As noted in Section 5, simply designating areas for smoking is not sufficient to prevent exposure. If smoking is allowed indoors, a special smoking room should be provided. This room should have no other use that would compel workers to enter as part of their job. The room should exhaust directly outside and the exhaust rate should be about 60 cubic feet per minute per smoker (EPA "What"). If a smoking area is established outside of the building, workers should not have to pass through it to get to the building. In addition, it should be established away from doors, windows, or ventilation intakes that could provide a pathway into the building's breathing air.

Because both the chronic and acute effects of exposure to tobacco smoke are well-established, if non-smoker exposure to ETS is ongoing, it should be considered highly suspect when identifying potential causal agents in an IAQ investigation.

7.5.2 Radon

There is no way of knowing or estimating the risk from radon without testing. The testing is simple and inexpensive. Short-term or long-term tests are available. Since radon concentrations can vary substantially due to climatic conditions, the long-term testing will provide results that better represent actual exposure conditions. The short-term tests generally last from 2 to 7 days.

The most common method for the short-term measurement uses a small charcoal canister. Charcoal in the device adsorbs airborne radon and then later provides the decay daughters for measurement using the daughter's gamma emissions. Since the charcoal continuously adsorbs and desorbs radon, it is not a true integrating device. Instead it provides a snapshot of the radon concentration. The device's accuracy is estimated at about +/- 20% (New York, Quest. 3). Alpha-track detectors are commonly used for long-term monitoring. These devices use a film or plastic that interacts with the radon or decay daughter alpha particles (EPA Radon). After exposure, the film or plastic is "developed" to enhance the tracks of the alpha particles. The density of the alpha tracks is used to determine concentration values. This type of device effectively integrates exposure to radon and, therefore, can be used for practically any length of time.

Radon daughters can also be collected by active air sampling using an air pump and a collection filter. Since this method only collects the non-gaseous, radon decay daughters, a specific relationship between radon and its decay daughters must be assumed. This relationship is not always consistent; therefore, the assumption may or may not be accurate. In addition, radon decay daughters decay relatively quickly so the filter has to be analyzed soon after the collection period ceases; normally within a few hours.

If radon measurements are high, the building can be modified so that it is effectively sealed from soil gas. Ventilation can be used to capture and remove radon as it enters the structure or to dilute its concentration in occupied spaces. Air cleaning methods to collect radon daughters can also be used.

7.5.3 VOCs

New carpet, curtains, equipment, and furniture, especially of the pressed-wood variety, are likely to be contributing VOCs to the breathing air of a building. This is especially true when renovations are ongoing or recently completed. Pesticides and cleaners often contribute to IAQ problems. Copy machines, computers, printing inks, cooking emissions, adhesives, cleaners, disinfectants, and air fresheners can all be sources of indoor air quality problems. Personal care products like nail polish, hair spray, and perfume also emit VOCs.

There are several methods available to quantify airborne concentrations of most VOCs. These substances can be assessed using a passive diffusion sampler, an impinger, or a sorbent tube. For example, sorbent tubes can be used for aldehydes. For this class of analyte, sorbent tubes normally contain silica that is coated with acidified 2,4 dinitrophenylhydrazine (DNPH). Formaldehyde, acetaldehyde, and MIBK reacted with the DNPH to form derivatives that can later be eluted and measured using high-performance liquid chromatography (HPLC) (Cal. ARB "SOP"). Sorbent tubes, however, can introduce significant sources of error (EMSL "TO" 2). During thermal desorption, analytes can decompose. Using solvent desorption, analytes can be diluted. Both types of errors affect the overall process accuracy and sensitivity.

Another sample methodology is to bring the suspect air to the laboratory. This method makes use of a thoroughly cleaned and evacuated stainless steel canister (e.g., Summa) to draw and contain an air sample. The canister is then sent to a qualified laboratory, which will then analyze the sample. Using this method, a broad spectrum of VOC analytes can be evaluated qualitatively and quantitatively.

EPA Method TO-15 is a popular test for broad spectrum VOCs that uses the evacuated canister (EPA "Deter."). TO-15 can be used to determine the concentrations of all of the top-tier, high-risk substances identified in the Section 6.3. In addition, besides the pesticides, it covers the full list of VOCs identified in the Johnston Study (Table 5.2). After sampling, the canister's contents are concentrated by cooling and then subjective to gas chromatography/mass spectrometry. The detection limit is about 1 ppb for each analyte, which is more than sufficient to identify contaminants below the RELs identified in Table 5.2.

Consideration should be given to taking wide-spectrum VOC measurements as a matter of routine because of the following reasons:

- The upper portion of nominal concentration ranges for many VOCs exceed the REL. As noted for formaldehyde in Table 5.2, typical concentrations exceed the REL by a factor of more than 5.
- At nominal concentrations, long-term health risks from carcinogens may be unacceptable, especially for VOCs like formaldehyde, 1,4 dichlorobenzene, and naphthalene. Although the combined effects of typical, multiple-VOC exposures are not well understood, knowledgeable individuals can make health risk assessments based on known toxicity and target organ data.
- Aside from the obvious acute toxic effects and potential carcinogenic effects of VOCs, they may also be causing sub-clinical, chronic effects such as low-grade headaches, mucous membrane and eye irritation, and general malaise, all of which can affect occupant comfort and productivity.

If there is evidence of increased potential for VOC exposure such as ongoing renovations or building activities that use VOCs (e.g., graphic arts), measurements become even more important. Elevated VOC readings help identify specific contaminants that can be linked to potential sources. Depending on the VOC source, removal, remediation, or isolation may be in order. If this is not practical, increasing dilution air may be considered.

7.5.4 Bioaerosols

Moisture can amplify the quantities of mold and bacterial aerosols. Moisture reduction and general cleanliness can control bioaerosol concentrations by limiting insect, mite and rodent populations. These can all be sources of allergens to building occupants. Individuals' skin, hair and clothing also introduce quantities of bioaerosols into a building. These include dust mites, pollens, and animal dander. If internal sources are kept in check, commonly used air filtration systems should reduce airborne levels of biological materials to acceptable levels for all but the most sensitive occupants.

For more definitive information, some laboratories do provide bioaerosol analyses. EMSL, for example, provides an analytical service for common allergens including dog (Can f1), cat (Fel d1), dust mites (Der fl and Der Pl), and cockroaches (Bla g1) ("Indoor"). The results of such measurements may or may not help identify the cause of specific problems because there are no designated thresholds for "acceptable" and "unacceptable" levels. Sensitization thresholds, however, have been identified for many allergens. For example, the feline sensitization threshold for humans is estimated to be 8 micrograms per gram (ug/g) of dust (Macher 359). For dust mites, the value is 2 ug/g (Macher 359).

Bioaerosol analytical methods for mold can identify both viable and non-viable quantities; both of which can have negative health effects. Collection methods can be

passive, such as an open Petri dish with agar, or active such as area or personnel air monitors. For active monitoring, inertial impactors are generally used.

Measurements of bioaerosols are normally not necessary unless there are indications, such as musty odors or areas of excessive moisture, that the concentrations of bioaerosols might be excessive. According to Tsai, however, "investigators have observed differences in air concentrations of culturable microorganisms over time and space of three to four orders of magnitude; even greater than what was observed in the BASE buildings" (356). With this high variability, the usefulness of such evaluations becomes questionable. Still, IAQ investigators often measure bioaerosol concentrations inside and outside of buildings to help identify potential health threats. Measurements are also useful if particular occupants are known to have allergies to specific substances. If elevated levels of bioaerosols are identified, the sources should be sought and controlled.

7.6 Response Summary

In summary, key actions for IAQ practitioners in response to IAQ concerns should generally include the following:

- Collect basic information about concern, complaints, or identified health effects.
- Evaluate the efficacy of the HVAC system including the introduction of dilution air.
- Determine if any moisture problems exist.
- Evaluate potential IAQ problems that originate from outside the structure.
- Evaluate smoking patterns.
- Measure radon.

- Evaluate sources and measure VOCs.
- Evaluate bioaerosols.

These actions are further detailed in the following IAQ Response Checklist (Table 7.1).

TABLE 7.1 - IAQ RESPONSE CHECK LIST

General Conditions	**Inquire**	Are there reports of illness or symptoms? Are they widespread?	Does the illness or symptoms suggest a specific cause?	Do those affected have known allergies?	Is there any pattern to the symptoms (location, time of day, etc.)?
	Inquire	Is the work space thermally comfortable? What is the relative humidity?	Are there any odors present?	What is the general level of cleanliness?	Are there potential pathways for vehicle exhaust or other sources of CO?
	Measure	Measure temperature and humidity.	Summer 73 to 79°F Winter 68 to 74.5°F (AHSRAE "55")	Relative humidity 30% to 65% (AHSRAE "55")	Measure CO - ≤9 ppm peak (AHSRAE "55")
	Act	Improve comfort level. Discomfort increases likelihood of IAQ concern. High humidity promotes mold and other bioaerosols.	Specific medical diagnosis may help direct investigation.	Initiate clean up. The lack of general cleanliness can elevate levels of bioaerosol allergens.	
HVAC System	**Inquire**	Is sufficient fresh air introduced into work spaces? Is the work space adequately ventilated or are there pockets of stagnant air?	Does condensate properly drain from unit? Is a biocide use in the drip pan?	Can the fresh air intake be drawing in contaminants? See next column. Is the intake filtered or should it be?	Vehicle exhaust; plumbing stack vent; nearby industrial emissions; facility power plant exhaust; cigarette smoke.
	Measure	Measure fresh air intake volume (ASHRAE-62). 15-60 CFM/person	Measure CO_2 as indication of fresh air. (ASHRAE 62) <700 ppm	Use velocity meter, air capture hood, or smoke test to check building air flow. (TSI) >0.8 ft/sec	Evaluate quality of intake air, if suspect.
	Act	Ensure sufficient levels of fresh, dilution air. Rebalance HVAC system, if necessary.	Ensure condensate from HVAC flows freely out of unit.		

TABLE 7.1 - IAQ RESPONSE CHECK LIST (continued)

Moisture	**Inquire**	Check locations where water is used such as ceilings, basements, mechanical rooms, bathrooms and kitchens.	Are there signs of unconfined moisture? See next column.	Standing water or mold; high humidity; musty smell; water stains; peeling paint or loose tiles; condensate on windows.	
	Measure	Use moisture meter on suspect surfaces.	May use infrared camera to detect temp. variations.		
	Act	Stop moisture infiltration.	Remove damp materials.		
Tobacco Smoke	**Inquire**	Are non-smokers exposed to ETS?	Does the facility or employer have a smoking policy?	If there is a smoking room, to non-smokers need to enter? Is there sufficient ventilation and effected barriers to shield non-smokers?	If smoking area outside, do non-smokers have to walk through it; can smoke still enter building?
	Act	Through an established and enforced smoking policy, ensure non-smokers are not exposed to ETS.			
Radon	**Inquire**	Are there portions of the facility that are below grade?	Are work areas within the first 2 floors well ventilated?	Has radon been measured? (IAEA 11) <14 pCi/l.	
	Measure	Measure radon at lowest facility levels.	If high, measure other areas.		
	Act	High levels of radon can be mitigated.	Structural sealing	Enhanced ventilation.	

TABLE 7.1 - IAQ RESPONSE CHECK LIST (continued)

Volatile Organic Compounds	**Inquire**	Are there any VOC odors?	Is there now or has there been any recent remodeling?	Are there sources of VOC emission such as graphic arts supplies, paints, fuels, pesticides, excessive perfume odors, nail polish, hair spray, etc.?	Are there any new carpets, draperies, furniture, partitions, etc.?
	Measure	EPA Method TO-15 for broad spectrum VOC	Sorbent tubes are available for many VOCs.	Photo Ionization Detector can be used to locate sources.	
	Act		Remodeling efforts should be isolated from building ventilation.	If sources of VOCs are identified, consider local exhaust ventilation, source removal or isolation, or use of an alternative substance.	Dilution ventilation may need to be increased for peak off-gassing periods.
Bioaerosols	**Inquire**	Do symptomatic occupants have animal allergies?	Has there been a history of rodent or insect infestation?	Are rodents (or their droppings) or insects present? Are the levels of dust excessive?	Are there indications of mold or recent remediation of mold?
	Measure	Samples can be taken for dog and cat allergens. No dogs or cats have to be present for the allergens to be present. (Macher) ≤8 ug/g for cats	Samples can be taken for cockroach allergens.	Dust mite allergens may be measured. (Macher) ≤2 ug/g.	If there presence of mold is confirmed, measurements can be taken but don't lend themselves well to interpretation.
	Act	Increase air filtration, ventilation, and or dilution air.		Adapt an integrated pest management system that minimizes the use of pesticides.	Modify facility cleaning protocols.

8.0 RESULTS – AGENCY-RECOMMENDED RESPONSES

Based on the discussion in the previous section, efforts to improve the overall health of building occupants should include elements to measure radon, eliminate exposure to tobacco smoke, keep airborne chemical exposures in check, minimize the concentrations of allergens, and eliminate moisture problem areas. It should be noted, however, that typical responses to IAQ concerns focus of "fixing" the immediate problems (unpleasant odors, sore throat, irritated eyes, etc.), not long-term health impacts such as cancer. This dichotomy is identified in the typical response protocols developed by the AIHA, OSHA and the EPA, which are discussed below.

8.1 AIHA Recommendations

According to the AIHA, "it is very difficult to use the findings of air testing to draw conclusions about the degree of health risk to which occupants are exposed" (par.19). Instead, AIHA recommends that systematic measures be taken to attempt to identify and control the source of the IAQ problem, specifically citing ETS control. Carbon dioxide measurements are also identified as being helpful in determining if sufficient fresh air is being brought into a structure (AIHA, par. 16).

The AIHA promotes source control as the most cost-effective solution to IAQ problems. AIHA also notes the effectiveness of ventilation system modifications to introduce more fresh air and also identifies air cleaning as a potentially effective measure especially when the source of the contaminant is outdoor air.

AIHA does not address radon but does discuss ETS. Although AIHA does not support chemical sampling unless there is good reason to do so, it does promote the identification and mitigation of potential sources of chemical contaminants such as poor locations for

fresh-air intake, recent indoor construction activities, or the operation of large photocopiers. For bioaerosols, it supports sampling and analysis only if a clinical diagnosis suggests such exposure. Besides carbon dioxide measurements, the AIHA recommends no routine sampling and analysis.

8.2 OSHA Recommendations

The OSHA Technical Manual for IAQ Investigations recommends that initial screening be done for formaldehyde, carbon dioxide, carbon monoxide, and VOCs. It further recommends additional screening, based on professional judgment for acetic acid, nitrogen oxides, ozone, radon, airborne particulates, and a broad, pre-assessment of airborne microorganisms.

Since NIOSH reported that 52% of IAQ problems were found to be rooted in poor ventilation characteristics, OSHA promotes the early evaluation of ventilation systems as part of their IAQ investigation. For OSHA, IAQ problem resolution centers on ventilation. The Technical Manual notes that "the most effective engineering control for the prevention of IAQ problems is assuring an adequate supply of fresh outdoor air..." (OSHA "IAQ" sec. V.A.1 (a)). The manual also suggests the use of air treatment and source control to help alleviate IAQ problems (OSHA "IAQ" sec. V.A). Specific source control measures noted are "substitution, removal, encapsulation, local exhaust ventilation, and the use of physical barriers" (OSHA "IAQ" sec. V.A.4).

OSHA does acknowledge the carcinogenic effects of radon and the broad health effects of ETS. As noted, it supports early sampling of formaldehyde and VOCs. For bioaerosols, as with the AIHA, it supports sampling and analysis only if a clinical diagnosis suggests such exposure.

8.3 EPA Recommendations

The EPA has developed a computer program that helps building owners and managers address IAQ issues. This software is called the "Indoor Air Quality Building Education and Assessment Model" (I-BEAM). I-BEAM recommends against routine sampling and analysis of airborne contaminants. It further contends that most IAQ problems can be diagnosed through the following actions:

- Educated observations
- An awareness of odors
- A sense of temperature and relative humidity
- A smoke pencil to observe the existence and direction of air flow

I-BEAM also notes that occasionally it is beneficial to measure the quantity of outdoor air being supplied to a building. To measure airflow, the program recommends the use of a flow hood. It also notes that airflow can be calculated through the use of a velocity meter or with carbon dioxide measurements, noting the latter as a "last resort" (sec. - Basic Measurement Techniques). To solve IAQ problems, I-BEAM reports that specific contaminant measurements are normally unnecessary but can be helpful in the following situations (sec. - Measuring Contaminants):

- To assess known sources of target contaminants
- To measure contaminants, like radon, that have no acute effects but could cause serious illness
- To assess the effectiveness of source control measures
- For comparison with other, non-complaint buildings
- To provide documented results for liability reasons

The EPA clearly focuses on source control. I-BEAM suggests the following mitigation techniques (Table 1.2 and 1.4):

- Control the types and quantities of substances used for housekeeping
- Establish a smoking policy
- Use local exhaust ventilation or pressure control in high emission areas
- Use low-emitting building-related products (carpet, plywood, furniture)
- Monitor and perform regular preventative maintenance on HVAC system
- Control moisture to minimize the growth potential of mold
- Keep vehicle exhaust out of occupied spaces
- Isolate construction and painting activities
- Establish an integrated pest management program to minimize the use and effects of pesticides

I-BEAM also notes that it is important to use dilution ventilation in accordance with established standards. Although the EPA is a strong supporter of radon measurements in the home and notes that radon *may* be sampled in the workplace, it does not promote the routine measurement of radon in the workplace. Routine VOC monitoring is also not recommended. EPA strongly supports ETS elimination or control.

8.4 Response Recommendations Summary

Table 8.1 summarizes the suggested response to IAQ concerns from the three agencies reviewed. Although it does not directly promote radon sampling, the OSHA approach provides the best correlation to the risk-based response identified in Section 7.0.

Table 8.1 – Recommended Routine IAQ Responses

Action	AIHA	OSHA	EPA
Collect basic information	Yes	Yes	Yes
Check HVAC Operation	Yes	Yes	Yes
Evaluate Moisture	Only noted as potential source	Yes	Yes
Evaluate Outside Sources	Only noted as potential source	Yes	Yes
Evaluate ETS	Yes	Yes	Yes
Measure Radon	No	No	No
Measure VOCs	No	Yes	No
Measure Bioaerosols	No	No	No

8.5 Evaluation of IAQ Professionals

In August 2005, 40 Questionnaires were sent to IAQ professionals to evaluate their response methods to IAQ concerns. The contacts were selected from individuals who had noted their availability has "Indoor Environmental Quality" consultants within the AIHA website. Fourteen responses, a 35% response rate, were received from 11 states including Minnesota, New York (2), Kentucky, Arizona, Louisiana (2), Indiana, Texas, Florida, South Carolina, New Jersey and Pennsylvania (2). Aside from additional communications to the fourteen individuals noted for clarification of their responses, no other responses were solicited.

Although the questionnaire could have covered a wide variety of topics about IAQ, the primary purpose was to determine the sampling practices of IAQ professionals. Responding individuals were asked to identify their sampling practices by filling out a table similar to the one shown in Table 8.2. An "other" category was also included in the questionnaire to ensure that all prevalent types of sampling were not inadvertently excluded. This category did not show a trend for any other target sampling. About 77% of

Respondents measured temperature and humidity at the outset of an IAQ investigation.

The results of the poll on sampling practices are summarized in Table 8.2.

Table 8.2 - Sampling Questionnaire Response
(Number of responses)

Analyte	Never	Rarely	Occasionally	Often	Almost Always
Radon	9	2	2		
Pesticides	7	6			
Aldehydes					
Acetaldehyde	2	5	5		
Formaldehyde		2	9	3	
Chlorinated Solvents					
Carbon tetrachloride	6	8			
Methylene chloride	4	8	1	1	
Tetrachloroethylene	4	7	3		
Trichloroethylene	5	7	2		
Other VOCs					
Benzene	3	8	3		
Chloroform	4	6	4		
Chloromethane	3	8	3		
1,4-dichlorobenzene	3	7	4		
N-hexane	3	6	5		
MIBK	3	6	5		
Naphthalene	3	7	4		
Toluene	2	7	5		
Methyl chloroform	4	7	3		
Mixed xylenes	2	8	5		
TVOC		4	8	2	
Chlorofluorocarbons					
Freon 11, 12	8	4	2		
Bioaerosols					
Animal-Related Allergens	2	7	4	1	
Mold			1	9	3
Bacteria and Viruses	2	4	5	2	1
Other					
Particulate Matter		6	5	3	
Carbon Monoxide		1	5	3	5
Carbon Dioxide		1		4	9

Besides the sampling habits, IAQ professionals were also asked other specific questions. Regarding ETS, the poll's respondents noted that ETS was not a significant IAQ problem. Although there are still many states that allow smoking in public areas, it is not common to find typical workplaces that still allow uncontrolled smoking. On average, respondents noted that a specific causative agent was identified about half of the time in their IAQ investigations. Most of the time, this agent was identified as mold. Of the survey respondents, 91% agreed with NIOSH's assessment that about half of IAQ problems are related to inadequate ventilation. Some respondents noted that the source of IAQ complaints was often the simultaneous presence of numerous indoor air contaminants. In such cases, the problem could normally be resolved by removing sources and or increasing dilution airflow.

9.0 DISCUSSION

AIHA, OSHA, and EPA all suggest that an air exchange assessment, using carbon dioxide or airflow measurements, is useful. The fresh air assessment is important because this action helps ensure that all contaminant sources are diluted. Concentration reductions translate directly into health risk reduction. All three agencies also agree that ETS is harmful and exposure to non-smokers should be controlled and minimized or eliminated.

Both AIHA and EPA question the usefulness of direct contaminant measurements for typical IAQ investigations. They only support measurements when there is an underlying reason, such as a medical diagnosis of an IAQ-related illness. Conversely, OSHA recommends initial screening work for formaldehyde, carbon dioxide, CO, and VOCs. EPA specifically notes that it may be useful to sample for contaminants like radon that have no acute effects but could cause serious illness but, like the other agencies, does not recommend routine sampling of radon.

IAQ practitioners generally appear to be following the collective recommendations of these three standard-setting organizations. The questionnaire showed that carbon dioxide is measured often to evaluate the sufficiency of fresh air exchange. In addition, many measured CO. Bacteria and particulate matter were occasionally sampled. Most respondents seldom measured VOCs except for formaldehyde and total VOCs, which were measured occasionally.

Despite AIHA, EPA, and OSHA recommendations, mold was often measured. This could be due, at least in part, to the fact that sampling was often driven by client demands. On average, about half of the sampling was believed to be driven by client demands while

the other half was driven by the IAQ professional's own judgment, although most respondents leaned heavily towards one driver or the other. As noted earlier, IAQ professionals also believe that mold is often the root cause of the IAQ problems they are asked to help resolve.

Most respondents noted that they agreed with the NIOSH assessment that the majority of IAQ problems were related to inadequate ventilation characteristics and many agreed that IAQ issues could often be solved by increasing the amount of fresh air. One respondent noted that increasing fresh air exchange rates reduced the number of complaints but did not "solve" the underlying cause of the problem that was initially reported.

Radon appeared to have the weakest association in terms of nominal risk and sampling recommendation and implementation. Although AIHA, EPA, and OSHA all discuss radon, sampling is not promoted as a matter of routine. This was mirrored in the IAQ professional questionnaire that suggests radon is seldom measured.

10.0 CONCLUSION

The following section summarizes the results of the research findings and specifically addresses the identified research questions.

10.1 Research Question, Part 1

Does scientific research substantiate a causal link between IAQ contaminants and human health? Which indoor air contaminants appear to present the greatest health risks?

The results of this research effort have demonstrated that common IAQ contaminants *can* be a health hazard at typical concentrations found in the workplace. ETS and radon top the list in terms of potential health risks. ETS, however, only presents a risk if smoking is allowed in the workplace. This is becoming more uncommon.

Radon has been shown to present a substantial risk to occupants of some buildings. In one large study, over 20% of buildings showed radon levels in excess of the EPA criterion for homes (IAEA 7). In addition, the level of cancer risk associated with the criterion is unusually high.

Bioaerosols were the most difficult airborne substances to evaluate in terms of risk. This research effort showed the lack of health risk indexes for bioaerosols. Although there is an established connection between airborne biological material and allergic reactions, a quantitative risk comparison to other indoor air contaminants was not possible. Popular media has suggested that exposure to mold, specifically Stachybotrys, can be very harmful. Scientific organizations, however, refute this claim. In addition, Stachybotrys remained undetected in an 86-building subset of the BASE study. In general, however, bioaerosols

are known to be responsible for allergic responses in building occupants. These responses can be a slight nuisance or life-threatening and, as such, cannot be ignored.

If smoking is eliminated and radon concentrations are low, VOCs typically present a large fraction of the health risk in indoor air. Although there is a good deal of uncertainty surrounding published RELs for VOCs and other indoor air contaminants, these values have been developed through a careful review of exposure-related scientific studies. As such, they represent the best available benchmark to determine the relative safety of indoor air.

An evaluation of air quality RELs for VOCs and typical ranges of indoor air concentrations showed that concentrations do routinely exceed RELs for many indoor air contaminants. Formaldehyde topped the ranking for acute effects while 1,4-dichlorobenzene was shown to present the highest cancer risk. Other substances also showed risk levels that are sufficient to raise concern.

Besides the lack of bioaerosol health indexes, this research effort also highlighted the fact that there is a marked void in exposure science regarding exposure to multiple indoor air contaminants. Published matter on the subject of IAQ often alludes to the combined effects of many sources of indoor air contamination noting that a specific causative agent is never identified as being responsible for reported acute effects. Even though mixtures causing acute effects are not well understood, they are often effectively addressed through higher volumes of dilution air.

10.2 Research Question, Part 2

Collectively, through the development of suggested response protocols, and individually, through actual response methods, are IAQ professionals focusing on conditions that present the greatest health risks?

Organizations such as the OSHA, EPA, and AIHA, which provide focal points for IAQ response standards, have developed documents that describe IAQ and provide advice on how to address IAQ concerns. Given specific building conditions, nearly any variety of IAQ contaminant could pose very serious health threats; however, the most prevalent, top-tier health threats identified by this thesis effort include ETS, VOCs, and radon. Of the three organizations; all promote the protection of non-smokers against ETS; only OSHA promotes the routine sampling of VOCs; and none promote the routine sampling of radon.

As shown in the text of this work, VOCs routinely exceed RELs in workplace air. Nominal concentrations of formaldehyde exceed its REL by a factor of five. Typical workplace concentrations of 1,4-dichlorobenzene and other VOCs exceed the EPA's traditional level of acceptable cancer risk. In addition, although processes used to establish RELs for individual contaminants is generally conservative, it can be argued that the application of available standards is not conservative. This is because the standards address only single-contaminant exposure. This approach does not represent typical exposure conditions which involve the simultaneous exposure to numerous indoor air contaminants that often share the same target organs.

In summary, VOC measurements in the workplace should be taken routinely. The cost of the TO-15, broad-spectrum VOC measurement method identified in Section 7 is less than $200 (EMSL "2005"). Although the RELs do not draw a definitive line between that

which is safe and that which is harmful, IAQ professionals can judge the level of air quality based on measurements. This can be done first by comparing individual air contaminants to RELs and risk factors and then, through an evaluation of individual VOC health impacts, the potential collective health effects can be estimated.

OSHA, EPA, and AIHA do not routinely target radon in their respective methodologies. In addition, IAQ professionals rarely conduct a radon evaluation. Despite this limited concern, radon is both prevalent and presents a high degree of risk in the workplace. The European Union has agreed with this assessment and has established a directive, which among other things, addresses workplace radon exposure (Ireland 2). This directive, 96/29/EURATOM, notes that radon in the workplace is a "potentially significant source of occupational exposure." Based on the directive, Ireland, for example, now requires all employers to conduct a radon risk assessment (Ireland 3). Measurements are required in regions that are known to have elevated radon levels or in sub-grade structures. The implementing Irish document notes that all employers "are urged to take a pro-active approach and consider having radon measurements made" (Ireland 3).

The low priority given to radon is likely due to the fact that concerns linked to IAQ usually hinge on acute effects instead of stochastic effects. Unless a cancer "cluster" is being evaluated, IAQ professionals often attempt to determine the cause of bad odors or a rash of sore throats or irritated eyes. Radon's effect is more insidious. It's only known detrimental effect is lung cancer, which normally appears many years after exposure.

This effect is reminiscent of another carcinogen, which is now effectively being controlled but not before it caused untold suffering and loss of life. Asbestos health effects have caused over 2.5 million cases of mesothelioma and will result in an estimated $275

billion in damages (Ridenour). The American legal system has harshly punished companies that did not react quickly and appropriately to known health threats presented by asbestos. Industrial giants like W.R. Grace, Owens Corning and almost 50 other companies were sent into bankruptcy (Ridenour) because of asbestos claims. Radon test kits, which start at about $15, can help identify radon-related health threats and limit employer liability.

OSHA, EPA, and AIHA often focus on dilution air. This includes the evaluation of a building's air exchange rate either through the direct measurement of air flow or through carbon dioxide measurements. The questionnaire showed that IAQ professionals also focus on the amount of dilution air. This is beneficial since indoor air dilution reduces concentrations of nearly all IAQ contaminants, including those that result in acute and stochastic health effects. This translates into overall risk reduction for building occupants.

10.3 Summary

For acute health effects, more attention could be focused on VOCs, especially the higher-risk VOCs listed in Section 7.1.3. These substances are often found above established RELs and may present an unchecked health risk. The effects of simultaneous exposure to multiple VOCs is not well understood; however, a precautionary approach appears to be prudent based on comparable health effects.

For stochastic effects, the risk from radon stands out. Radon is present is many workplaces at concentrations that exceed the criteria at which EPA recommends mitigation action for the home. In addition, the cancer risk level associated with the EPA radon criteria is quite high; well above the 10^{-4} risk normally noted as the upper limit of cancer risk used by the EPA. Although one could argue that household exposure results in more

risk than the workplace because of occupancy times, this is not sufficient to justify apathy for radon health concerns at work.

Along with radon, 1,4-dichlorobenzene also stood out as a relatively high carcinogenic risk. Because of their small or non-existent acute effects, neither 1,4-dichlorobenzene or radon receive much attention from IAQ organizations or professionals. Although IAQ professionals rarely measure concentrations of VOCs or radon, their efforts to ensure proper amounts of dilution air have a direct, positive effect on reducing unhealthy VOC concentrations.

Organizations like OSHA, EPA, and AIHA, which provide guidance on IAQ matters, and IAQ professionals that response to IAQ concerns, may be a bit off target if their focus is indeed overall occupant health. Although it is easier to focus on the "here and now" effects of poor IAQ, the longer-term effects, including cancer, are at least as serious and may be more prevalent than what is currently perceived. Furthermore, these latent health effects can be kept in check using relatively easy and inexpensive measurement methods.

10.4 Responsibility

The results of this research has shown that substances including radon, specific VOCs and the combined effects of VOCs may present an unchecked and unacceptable level of health risk in the non-industrial workplace. Arguably, OSHA has not been very effective in developing and updating workplace criteria for industrial operations. As a result, to better ensure worker health and safety, EHS professionals often use more modern and appropriate standards (TLVs) developed by the ACGIH. OSHA has not tried to develop IAQ standards and, in fact, after unsuccessfully trying to develop a rule on ETS, found that

the General Duty Clause does not pertain to ETS despite the extensive research that has demonstrated significant health risks from exposure to ETS.

The EPA seems to be the logical choice for the eventual development of IAQ standards. Title V of the Superfund Amendments and Reauthorization Act (SARA) in 1986 directed the EPA to establish an IAQ research program and to disseminate information about their findings (EPA "Indoor No. 6"). The EPA has examined the level of risk associated with radon exposure in the home and, as a logical extension, should also address the level of risk presented in the work place. The CalEPA has put significant work into the development of CRELs and the EPA should and, in fact, is referring to these values in their Technology Transfer Network, Air Toxics Website. Substantial scientific research has formed the basis of the CRELs and they could be adopted as national standards.

Perhaps society would be better served if a non-governmental agency, such as the ACGIH, would tackle the issue of IAQ standard setting. The ACGIH has successfully done this for industrial exposures and already has garnered respect from the EHS professional, regulatory agencies, and regulated entities. The current TLV publication (REF) could be modified to include a column for non-industrial workplace exposure. The EHS professional who responds to IAQ concerns would then be obligated to refer to the ACGIH IAQ standard under the OSHA General Duty Clause.

10.5 Next Steps

The results of this research effort has shown that, based on available scientific research, there should be cause for concern about IAQ. As noted, there are three classes of IAQ contaminants that warrant increased diligence. They include radon, specific VOCs, and the cumulative effects of VOCs in indoor air. Similar to the European Union, the United States

should consider rulemaking to make workplace radon assessments mandatory. Also in step with the European Union, the United States should consider the cumulative concentrations of VOCs. There are issues that must be addressed in order to effectively implement a TVOC-based standard. TVOC is a broad term that doesn't have any inherent clarity on what is included and what is not. In addition, high TVOC values may or may not indicate high values of toxicity. The concept of TVOC may be compatible with a comprehensive approach that includes broad initial testing for VOCs followed by species-specific testing (TO-15) if a certain threshold is exceeded. Then actual workplace concentrations could be evaluated against IAQ-TLVs in the same manner EHS professionals currently evaluated multiple contaminants in an industrial workplace. Contaminants that share target organs for acute effects would be summed. Carcinogens would also have their IAQ-TLV fractions summed and maintained at values less than unity.

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