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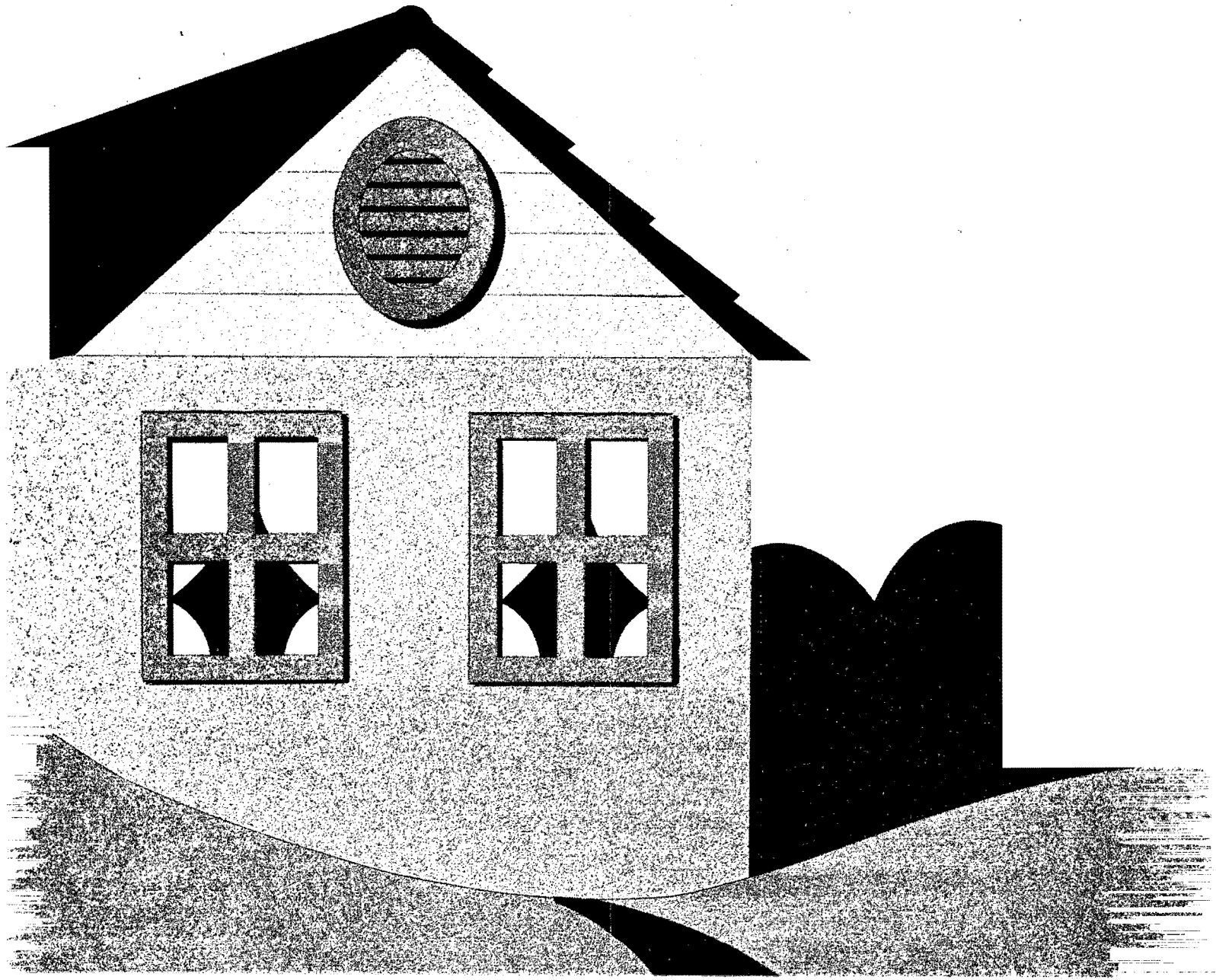
July 1991

Office of Air and Radiation (6607J)



# Introduction to Indoor Air Quality

## A Reference Manual



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# **Introduction to Indoor Air Quality**

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## SECTION 1.

### OVERVIEW OF THE REFERENCE MANUAL

The *Indoor Air Quality Reference Manual* is the companion document to the *Indoor Air Quality Learning Module*. The purpose of the *Reference Manual* is to provide an opportunity for continuing education plus useful reference material on selected indoor air quality topics.

The *Reference Manual* is divided into 8 sections corresponding to the first eight lessons of the *Learning Module*. Section 1 provides an overview of the *Reference Manual* and suggests ways that the *Reference Manual* can best be used as an adjunct to the *Learning Module*. Sections 2-8 contain information that supplements the corresponding lessons in the *Learning Module*. For example, Lesson 2 of the *Learning Module* describes the factors that affect indoor air quality, while Section 2 of the *Reference Manual* shows how those factors are combined in indoor air quality modeling to simulate indoor

environments; Section 2 also provides specific information and data on individual factors. Sections 3 and 4 of the *Reference Manual* correspond to Lessons 3 and 4 of the *Learning Module* and contain information on the nature of human responses as well as health effects from specific contaminants. Section 5 contains information about air cleaning devices and residential heating and air mover systems.

The *Reference Manual* also contains information and exhibits which can be directly used in field investigations. For example, Section 4 contains tables which relate symptoms, contaminants, and sources in a way that could assist in diagnosing indoor air quality problems; Section 6 provides information on specific measurement techniques and equipment, including availability of equipment from various manufacturers; Section 7 provides a listing of public health and occupational standards which can be useful in interpreting measured data; and Section 8 includes specific forms and questionnaires which can be used to collect data during field investigations.

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## **SECTION 2.**

### **FACTORS AFFECTING INDOOR AIR QUALITY**

Section 2.1 discusses the general mass balance equation and its use in indoor air quality modeling. Exhibits 2-1 through 2-6 provide some examples of empirical data for parameters which are used in the model. Section 2.2 contains Exhibit 2-7 which is a detailed listing of sources and contaminants potentially released by those sources.

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## 2.1. INDOOR AIR QUALITY MODELING

Indoor air quality models describe the transport and dispersion of air contaminants throughout a structure and the variation of indoor air contaminant concentrations as a function of source strengths, air-exchange rates, removal mechanisms, and other parameters.

Most models are based on either the principles of conservation of energy or the conservation of mass in a compartment or zone. Some models are based on empirical methods in which test data are evaluated statistically and fitted using regression analysis. These empirical models may better reflect the specific circumstances for which they are calibrated, but they do not have the wide applicability of the models which are based on first principles.

In a mass or energy balance model, the term compartment or zone refers to a region in which spatial variations in contaminant concentration can be ignored over the time period of interest. A single room, a floor, or a house that is well-mixed is usually treated as a single zone. Houses with central forced-air heating systems can be considered to be well-mixed when the circulation fan is operating. Houses with other types of heating systems can also be considered to be well-mixed providing interior doors remain open and a sufficiently long time period is allowed for mixing. For steady-state conditions (when generation of contaminants equals removal), these models reduce to simple algebraic equations. The basic mass balance equation for a single zone model is presented below.

The accuracy of the single zone model depends on the degree of mixing, the time period of concern, and the extent to which the parameters have been characterized. Model performance can be measured by comparing predicted data with actual measured values. After the model has been calibrated, it should be evaluated against other data. It is important to note that the data set which is used for calibrating the model should not be used to evaluate the model's general predictive capability.

Single zone models may not be adequate when sources and sinks are not uniformly distributed throughout the area or when stratification of contaminants occurs, and in these cases multi-zone models may be needed. These models may be adequate, for example, to describe contaminant concentrations when a kerosene heater is operating in one room of a house (zone 1) that is separated from the remainder of the house (zone 2) by closed doors.

Multi-zone models might also be used when predicting contaminant concentrations in a building with multiple floors. These models include separate mass balance equations for each zone, and they are more complex than single zone models.

In general, indoor air quality models are useful tools that can be used: 1) to understand how the factors that affect indoor air quality relate to one another, 2) to predict concentrations of contaminants for places and conditions that cannot be measured, and 3) to determine required accuracy and precision for monitoring studies.

### Available Indoor Air Quality Models

Numerous models have been developed to estimate concentrations of contaminants in indoor air, and some of these also estimate inhalation exposures. The Air and Energy Engineering Research Laboratory (AEERL) at EPA has developed a multi-zone indoor air quality model (Sparks, 1988) which can be used on an IBM-PC or compatible computer.

The AEERL model treats each room as a well-mixed chamber that can contain both sources and sinks. Source terms which can be included are random on/off sources (for example, cigarettes), sources that are on for specific periods of time (for example, kerosene heaters), steady-state sources (for example, moth crystals), and sources with high initial emission rates followed by a low steady-state rate of emission (for example, floor wax). The model also allows the impact of heating, ventilating, and air-conditioning (HVAC) systems, air cleaners, and interroom air

flows on indoor air quality to be evaluated. The model has been verified to a limited extent with experimental data from EPA's indoor air quality test house.

The AEERL model is user friendly and has a menu-driven user interface. Output from the model can be displayed if a graphics adapter and monitor are available. Additional information on the model and user's manual can be obtained by contacting the Air and Energy Engineering Research Laboratory, U.S. EPA, Research Triangle Park, NC 27711.

Further discussion on single zone, multi-zone, and exposure models can be found in NAS (1981); Wadden and Scheff (1983); Nagda, Rector, and Koontz (1987); McNall *et al.* (1985); Sexton and Ryan (1988); Sexton and Hayward (1987); Axley (1987); and Repace (1987).

## Mass Balance Equation

The primary source for the following discussion is Nagda *et al.* 1987; other useful sources include NRC (1981) and Wadden and Scheff (1983).

The generation and removal of contaminants in indoor environments can be described mathematically based on the conservation of mass:

$$\begin{aligned} \text{rate of accumulation} = \\ \text{rate of [input + generation - output - sinks]}, \end{aligned} \quad (1)$$

or

$$\begin{aligned} \frac{VdC_i}{dt} = \text{rate of change} & \left[ \left( \begin{array}{c} \text{infiltration} \\ \text{of outdoor air} \end{array} \right) + \left( \begin{array}{c} \text{generation} \\ \text{indoors} \end{array} \right) \right. \\ & \left. - \left( \begin{array}{c} \text{exfiltration} \\ \text{of indoor air} \end{array} \right) - \left( \begin{array}{c} \text{indoor removal} \\ \text{of contaminants} \end{array} \right) \right] \end{aligned} \quad (2)$$

where,

V = the indoor volume,  
C<sub>i</sub> = the indoor concentration, and  
t = time

Parameters in the mass balance equation must be evaluated independently. Some parameters, such as volumes and surface areas, can be measured directly or can be easily obtained from blueprints. Others such as ventilation rates and source emission/removal rates are more difficult to obtain.

## Infiltration and exfiltration

The infiltration of contaminants from the outdoors depends on the product of the outdoor contaminant concentrations (C<sub>o</sub>) and the volume rate of air exchange (νV), where ν is the air exchange rate in air changes per hour (ach).

Not all outdoor air contaminants that move into a structure reach the inside; some fraction of contaminants, F<sub>b</sub>, is intercepted by the cracks and crevices in the building envelope which decreases the amount that actually reaches the indoor air. The overall relationship for the change in indoor contaminant concentrations due to infiltration from outdoor air is, therefore, given by:

$$VdC_{i(\text{infil})} = (1 - F_b)\nu VC_o dt.$$

Removal of contaminants due to the exfiltration of indoor air is the product of the volume rate of air exchange (νV) and the concentration of air leaving the structure, C<sub>e</sub>. In cases of good mixing, C<sub>e</sub> is the same as C<sub>i</sub> and the exfiltration term over a period of time is given by:

$$VdC_{i(\text{exfil})} = -\nu VC_i dt.$$

## Generation and removal of contaminants

The generation of contaminants indoors (source term) over a period of time can be expressed as Sdt, where S is the contaminant emission rate,

$$VdC_{i(\text{gen})} = Sdt.$$

The removal of indoor contaminants is due to chemical reactions, adsorption of contaminants on

indoor surfaces, and removal by mechanical means through air cleaning devices. The rate of decay due to chemical reactions and/or adsorption over a period of time is given by  $\lambda dt$ , where  $\lambda$  is the overall decay rate of the contaminant.

Removal by air cleaning devices depends on the volume flowrate of air handled by the device,  $q$ , and on the efficiency of the device,  $F$  (that is, the proportion of contaminants removed). Removal by air cleaning devices can be expressed as  $qFC_i dt$ .

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The expression for total removal over a period of time is then given by:

$$VdC_{i(\text{rem})} = -\lambda dt - qFC_i dt.$$

#### Effective Volume

The concentration of contaminants indoors also depends on the indoor volume. The actual volume that is available for contaminant dispersal depends on the degree of air circulation, and it is known as the effective volume ( $kV$ ), where  $k$  is a dimensionless factor. The value of  $k$  becomes 1 when the entire indoor air volume is available for contaminant dispersal. The value of  $k$  is less than 1 when there is no forced mixing and the degree of circulation depends on thermal gradients indoors.

#### Generalized Mass Balance Equation

Equation 2 can be written as a generalized mass balance equation for predicting indoor concentrations. Assuming uniformly mixed conditions and an effective volume,  $kV$ , rather than the total indoor volume,  $V$ , equation 2 becomes:

$$kVdC_i = (1 - F_b)\nu kVC_o dt + Sdt - \nu kVC_i dt - \lambda dt - qFC_i dt \quad (3)$$

$$\lambda dt - qFC_i dt \quad ,$$

or

$$\frac{dC_i}{dt} = (1 - F_b)\nu C_o + \frac{S}{kV} - \nu C_i - \frac{\lambda}{kV} - \frac{qFC_i}{kV} \quad (4)$$

where,

$C_i$  = indoor concentration (mass/volume);

$F_b$  = fraction of outdoor concentration intercepted by the building envelope (dimensionless fraction);

$\nu$  = air exchange rate (1/time);

$C_o$  = outdoor concentration (mass/volume)

$S$  = indoor source generation rate (mass/time);

$kV$  = effective indoor volume where  $k$  is a dimensionless fraction;

$\lambda$  = decay rate (mass/time);

$q$  = flow rate through air cleaning device (volume/time); and

$F$  = efficiency of the air cleaning device (dimensionless fraction).

**Mixing factor:** Because the extent of air mixing in the interior varies, a mixing factor,  $m$ , may be introduced which modifies the air exchange to yield an effective air exchange rate for exfiltration of a contaminant. The mixing factor is the ratio of the concentration of the exiting air to the concentration of the indoor air. When the two concentrations are the same, the air is said to be completely mixed, and  $m$  equals one. When contaminants are exhausted directly from their source,  $m$  will be  $>1$ . However, the more usual case is for  $m$  to be  $<1$  because mixing is not complete.

The value of  $m$  has been estimated to be in the range of 0.33 - 1.0 (Wadden and Scheff, 1983). In general, mixing between rooms in residential structures is usually complete in less than 1 hour; therefore, the complete mixing assumption is often

used to estimate average concentrations over time periods greater than 1 hour.

The effective air exfiltration rate for a given contaminant is the product of the mixing factor,  $m$ , and the air exchange rate,  $\nu$ , and it is given by  $m\nu$ . Therefore, equation 4 becomes:

$$\frac{dC_i}{dt} = (1 - F_b)\nu C_o + \frac{S}{kV} - m\nu C_i - \frac{\lambda}{kV} - \frac{qFC_i}{kV} \quad (5)$$

### Use of the Mass Balance Equation

The basic mass balance equation can be used for many applications, and the solutions to the equation will vary depending on initial assumptions. Some examples of applications include using the equation to predict the buildup of contaminants as a result of the infiltration of contaminated outdoor air or from using an indoor source for varying time periods; to evaluate the effectiveness of mechanical ventilation; or to determine the effect of air exchange rates and other variables on indoor contaminant concentrations.

#### Equilibrium Concentrations

One application of the model is to compute the equilibrium (steady-state) concentrations that would be achieved under a variety of conditions. The simplest case assumes a nonreactive contaminant, no indoor sources ( $S = 0$ ), no cleaning devices ( $F = 0$ ), no capture of outdoor contaminants by the indoor air ( $F_b = 0$ ), and uniform mixing ( $m = 1$ ). Under these conditions, equation 5 reduces to:

$$\frac{dC_i}{dt} = \nu(C_o - C_i) \quad (6)$$

Thus, in this simple case, when equilibrium is reached (that is, when the indoor air concentration is constant),  $dC_i/dt = 0$ , and the indoor concentration equals the outdoor concentration.

**Effect of Indoor Sources:** If we now introduce an indoor source of contaminants, equation 6 becomes:

$$\frac{dC_i}{dt} = \nu(C_o - C_i) + \frac{S}{kV},$$

and the equilibrium concentration (when  $dC_i/dt = 0$ ) would be given by:

$$C_i = C_o + \frac{S}{k\nu V}.$$

Other terms can be introduced in a similar way.

**Effect of Time:** Another application is to determine under a given set of conditions how much time is required to reach equilibrium or what concentration will result after a given period of time. Using the simple case in equation 6 where we assume an initial indoor concentration,  $C_{i0}$ , and a final indoor concentration equal to a constant outdoor concentration,  $C_o$ , then the indoor concentration at any time,  $t$ , is given by:

$$C_{i,t} = C_o + (C_{i0} - C_o) e^{-\nu(t-t_0)} \quad (7)$$

For example, we can calculate the indoor concentration of carbon monoxide (CO) after 2 hours in a 100 m<sup>3</sup> space assuming that the outdoor concentration is 9 ppm; the initial CO indoors is 3 ppm; there are no indoor sources or cleaning devices; the air exchange rate is 0.3 ach; and uniform mixing of the indoor air occurs. The solution is:

$$\begin{aligned} C_{2hr} &= 9 \text{ ppm} + (3 \text{ ppm} - 9 \text{ ppm}) (0.55) \\ &= 5.7 \text{ ppm.} \end{aligned}$$

After 2 hours the indoor concentration under the stated conditions equals 5.7 ppm or about 60% of outdoor concentration.

### Quantifying Parameters

Values for the input parameters which are needed either to make simple computations or to use available indoor air quality models are derived by direct measurements or by combining special knowledge of specific conditions with values derived from the literature or specific research. The following discussion provides some basis for assisting the user in defining values for specific applications.

## 8

**Infiltration and exfiltration:** The infiltration rate of a given building can vary considerably depending on the weather conditions, occupant activities, and the operation of appliances and HVAC equipment.

Weatherization studies on houses in the United States have shown that major sources of air leakage are walls and floors, ceilings, heating systems, windows and doors, and fireplaces. Air leaks through vents and diffusion through walls are minor sources. The importance of these individual sources will vary depending on the region of the country and construction techniques. Exhibit 2-1 identifies specific sources of air leakage and ranges of infiltration that have been measured for each.

**Air exchange rates:** Air exchange rates for input into models can be obtained in one of three ways. The type of air exchange rate data which are needed will depend on the particular situation which is being investigated.

One approach is to use an average number of air exchanges per hour that have been developed for different types of structures and conditions. This method provides only ballpark estimates, since air exchange rates cannot be reliably estimated from a visual inspection of the building, its age, or construction. Air exchange rates can also be determined using empirical models which are statistical fits to measurements over a long period of time at specific sites. These models incorporate temperature differentials between indoors and outdoors and wind speed with empirically derived regression constants to obtain air exchange rates. The accuracy

of empirical models is about 40%, but individual predictions can vary by 100% (ASHRAE, 1989). The best way to obtain air exchange rates is to measure them directly using tracer gas methods. If direct measurements are not possible, air exchange rates can also be determined indirectly by measuring or calculating air leakage rates and converting these rates to air exchange rates.

A model developed by the Lawrence Berkeley Laboratory (Sherman and Grimsrud, 1989) has been widely used as the basis for indirect calculations and it is summarized below. The accuracy of these calculations will depend on the accuracy of the required inputs. The method of calculating the air exchange rates from leakage rate data in residences is as follows (ASHRAE, 1989):

- 1) Use Exhibit 2-2 to determine the effective air leakage area from each possible source. For example, the leakage area of 100 ft of uncaulked sills is:  $100 \text{ ft} \times 0.19 \text{ in}^2/\text{ft} = 27.0 \text{ in}^2$ .
- 2) Add the individual leakage areas to obtain a total effective leakage area. The total effective leakage area can also be measured using fan pressurization.
- 3) Using the effective leakage area, calculate the airflow rate due to infiltration:

$$Q = L(A\Delta t + B\mu^2)^{0.5}$$

where,

$Q$  = airflow rate, cfm;

$L$  = effective leakage area,  $\text{in}^2$ ;

$\Delta t$  = average indoor-outdoor temperature difference for the time interval of the calculation,  $^{\circ}\text{F}$ ;

$A$  = stack coefficient,  $\text{cfm}^2 \text{ in}^{-4} ^{\circ}\text{F}^{-1}$ ;



The stack coefficient for residences is a function of the number of stories:

- A = 0.0156 for one story;
- A = 0.0313 for two stories;
- A = 0.0471 for three stories.

B = wind coefficient,  $\text{cfm}^2 \text{ in}^{-4} \text{ mph}^{-2}$ ;

The wind coefficient depends on the number of stories and the degree of shielding around the house, and it can be obtained from Exhibit 2-3.

$\mu$  = average wind speed measured for the time interval of interest, mph.

- 4) Calculate the infiltration rate by dividing Q by the building volume.

#### Example Calculation:

Estimate the infiltration over the heating season in a one-story house with a volume of  $10,000 \text{ ft}^3$  and a leakage area of  $50 \text{ in}^2$ . The average indoor temperature during the heating season is  $75^\circ\text{F}$  and the average outdoor temperature is  $32^\circ\text{F}$ . The house is located on a lot that has a thick hedge on one side and single story houses on the other sides (heavy shielding). The average wind speed during the heating season is 5 mph.

First, calculate the airflow rate due to infiltration:

$$\begin{aligned} Q &= 50 [(0.0156 \times 43) + (0.0039 \times 5^2)]^{0.5} \\ &= 43.8 \text{ cfm} \\ &= 2630 \text{ ft}^3/\text{hr}. \end{aligned}$$

Next, calculate the ach:

$$\begin{aligned} &= (2630 \text{ ft}^3/\text{hr})/10,000 \text{ ft}^3 \\ &= 0.26 \text{ ach}. \end{aligned}$$

**Source and removal terms:** A wide range of sources and source combinations are possible in indoor environments. Some sources may start and stop in a random fashion (tobacco products), some emit for limited and specified periods of time (gas heaters), some emit at rates that are high initially but reduced over short or long periods of time (waxes, formaldehyde), and others may emit at a more uniform rate over a period of time (moth balls). Different types of sources and source combinations can be modeled, but the equations may become more complex. Also, a given source can have different emissions at different times depending on the conditions of the measurements. For example, the rate of emissions from a kerosene heater that uses a wick will depend on the burner setting, age of the wick, type of fuel used, age of the heater, and other factors. In addition, it should be noted that different methodologies for the measurement of the emission rate can yield different results. Exhibit 2-4 gives examples of some emission rates for selected sources and contaminants.

The removal term, R, is often unknown, and for some contaminants it may depend on the physical and chemical characteristics of the interior space. The removal term may be incorporated into the source term to give a net source term, or it can be evaluated as a function of the decay rate ( $\lambda$ ) or deposition velocity ( $v_{\text{dep}}$ ); Exhibits 2-5 and 2-6 provide examples of decay rates and deposition velocities for selected contaminants. The caveats for the source term also apply to the removal term. Removal expressed as a function of the decay rate and the contaminant mass ( $VC_i$ ) is given by:

$$R = \lambda VC_i$$

Removal expressed as deposition is given by:

$$R = v_{\text{dep}} a C_i$$

where,

(continued next page)

$v_{\text{dep}}$  = deposition velocity, length time<sup>-1</sup> and

$a$  = area of contact, length<sup>2</sup>.

The relationship between  $\lambda$  and  $v_{\text{dep}}$  is then:

$$v_{\text{dep}} = \frac{\lambda V}{a}.$$

## 10

### Exhibit 2-1. Major sources of infiltration measured during weatherization studies.

SOURCE	RELATIVE AMOUNT OF LEAKAGE	
	RANGE (%)	AVERAGE (%)
walls	18-50	35
ceiling details	3-30	18
heating system	3-28	15
windows and doors	6-22	15
fireplaces	0-30	12
vents in conditioned spaces	2-12	5
diffusion through walls		<1

SOURCE: ASHRAE (1985)

**Exhibit 2-2. Effective leakage area of building components (0.016 inches water).**

COMPONENT	BEST EST.	MAX	MIN	COMPONENT	BEST EST.	MAX	MIN
<b>SILL FOUNDATION-WALL</b>				<b>DOMESTIC HOT WATER SYSTEMS</b>			
Caulked, in <sup>2</sup> /ft of perimeter	0.04	0.06	0.02	Gas Water Heater (only if in conditioned space), in <sup>2</sup> per unit	3.1	3.9	2.325
Not caulked, in <sup>2</sup> /ft of perimeter	0.19	0.19	0.05	<b>ELECTRIC OUTLETS AND LIGHT FIXTURES</b>			
<b>JOINTS BETWEEN CEILING AND WALLS</b>				Electric Outlets and Switches			
Joints, in <sup>2</sup> /ft of wall	0.07	0.12	0.02	Gasketed, in <sup>2</sup> per outlet and switch	0	0	0
(only if not taped or plastered and no vapor barrier)				Not gasketed, in <sup>2</sup> per outlet and switch	0.076	0.16	0
<b>WINDOWS</b>				Recessed Light Fixtures, in <sup>2</sup> per fixture	1.6	3.10	1.6
Casement				<b>PIPE AND DUCT PENETRATIONS THROUGH ENVELOPE</b>			
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.011	0.017	0.006	Pipes			
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.023	0.034	0.011	Caulked or sealed, in <sup>2</sup> per pipe	0.155	0.31	0
<b>Awning</b>				Not caulked or sealed, in <sup>2</sup> per pipe	9.30	1.55	0.31
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.011	0.017	0.006	Ducts			
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.023	0.034	0.011	Sealed or with continuous vapor barrier, in <sup>2</sup> per duct	0.25	0.25	0
<b>Single Hung</b>				Unsealed and without vapor barrier, in <sup>2</sup> per duct	3.7	3.7	2.2
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.032	0.042	0.026	<b>FIREPLACE</b>			
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.063	0.083	0.052	Without Insert			
<b>Double Hung</b>				Damper closed, in <sup>2</sup> per unit	10.7	13.0	8.4
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.043	0.063	0.023	Damper open, in <sup>2</sup> per unit	54.0	59.0	50.0
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.086	0.126	0.046	<b>With Insert</b>			
<b>Single Slider</b>				Damper closed, in <sup>2</sup> per unit	5.6	7.1	4.03
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.026	0.039	0.013	Damper open or absent, in <sup>2</sup> per unit	10.0	14.0	6.2
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.052	0.077	0.026	<b>EXHAUST FANS</b>			
<b>Double Slider</b>				Kitchen Fan			
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.037	0.054	0.02	Damper closed, in <sup>2</sup> per fan	0.775	1.1	0.47
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of window	0.074	0.11	0.04	Damper open, in <sup>2</sup> per fan	6.0	6.5	5.6
<b>DOORS</b>				<b>Barbroom Fan</b>			
Single Door				Damper closed, in <sup>2</sup> per fan	1.7	1.9	1.6
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of door	0.114	0.215	0.043	Damper open, in <sup>2</sup> per fan	3.1	3.4	2.8
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of door	0.157	0.243	0.086	<b>Dryer Vent</b>			
<b>Double Door</b>				Damper closed, in <sup>2</sup> per fan	0.47	0.9	0
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of door	0.114	0.215	0.043	<b>HEATING DUCTWORK—FORCED AIR SYSTEMS</b>			
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> of door	0.16	0.32	0.1	(only in unconditioned space)			
<b>Access to Attic or Crawl space</b>				Joints taped or caulked, in <sup>2</sup> per house	11	11	5
Weatherstripped, in <sup>2</sup> /ft <sup>2</sup> per access	2.8	2.8	1.2	Joints not taped/caulked, in <sup>2</sup> per house	22	22	11
Not weatherstripped, in <sup>2</sup> /ft <sup>2</sup> per access	4.6	4.6	1.6	<b>FURNACE—FORCED AIR SYSTEMS</b>			
<b>WALL-WINDOW FRAME</b>				(only if in conditioned space)			
Wood Frame Wall				Sealed combustion furnace, per unit	0	0	0
Caulked, in <sup>2</sup> /ft <sup>2</sup> of window	0.004	0.007	0.004	Retention head burner furnace, in <sup>2</sup> per unit	5	6.2	3.1
No caulking, in <sup>2</sup> /ft <sup>2</sup> of window	0.024	0.039	0.022	Retention head plus stack damper, in <sup>2</sup> per unit	3.7	4.6	2.8
<b>Masonry Wall</b>				Furnace with stack damper, in <sup>2</sup> per unit	4.6	6.2	3.1
Caulked, in <sup>2</sup> /ft <sup>2</sup> of window	0.019	0.03	0.016	<b>AIR CONDITIONER</b>			
No caulking, in <sup>2</sup> /ft <sup>2</sup> of window	0.093	0.15	0.082	Wall or window unit, in <sup>2</sup> per unit	3.7	5.6	0
<b>WALL-DOOR FRAME</b>							
Wood Frame Wall							
Caulked, in <sup>2</sup> /ft <sup>2</sup> of window	0.004	0.004	0.001				
No caulking, in <sup>2</sup> /ft <sup>2</sup> of window	0.024	0.024	0.009				
<b>Masonry Wall</b>							
Caulked, in <sup>2</sup> /ft <sup>2</sup> of window	0.0143	0.0143	0.004				
No caulking, in <sup>2</sup> /ft <sup>2</sup> of window	0.072	0.072	0.024				

SOURCE: Reprinted with permission from the 1985 ASHRAE Handbook—Fundamentals published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

**Exhibit 2-3. Values for wind coefficient.**

SHIELDING CLASS	HOUSE HEIGHT (STORIES)		
	ONE	TWO	THREE
1— no obstructions or local shielding	0.0119	0.0157	0.0184
2— light local shielding; few obstructions, a few trees or small shed	0.0092	0.0121	0.0143
3— moderate local shielding; some obstructions within two house heights, thick hedge, solid fence, or one neighboring house	0.0065	0.0086	0.0101
4— heavy shielding; obstructions around most of the perimeter, buildings of trees within 30ft in most directions; typical suburban shielding	0.0039	0.0051	0.0060
5— very heavy shielding; large obstructions surrounding perimeter within two house heights; typical downtown shielding	0.0012	0.0016	0.0018

**Exhibit 2-4. Source emission rates for selected contaminants.**

CONTAMINANT AND MATERIAL	SOURCE EMISSION RATE	REFERENCE
<i>Formaldehyde</i>		
medium density fiberboard <sup>a</sup> particle board	1.5 mg/m <sup>2</sup> /hr 0.560 mg/m <sup>2</sup> /hr initially 0.1 - 0.2 mg/m <sup>2</sup> /hr after 6 to 27 months	CPSC, 1985
textiles, resilient flooring carpeting, ceiling tiles, carpet pad	≤0.01 mg/m <sup>2</sup> /hr 0.01 mg/m <sup>2</sup> /hr	Matthews <i>et al.</i> 1984
fibrous glass insulation, softwood plywood	0.02 mg/m <sup>2</sup> /hr	
hardwood paneling	0.11-0.28 mg/m <sup>2</sup> /hr	
particleboard underlayment	0.30 mg/m <sup>2</sup> /hr	
industrial particleboard	0.31 mg/m <sup>2</sup> /hr	
medium density fiberboard	1.5 mg/m <sup>2</sup> /hr	
UFFI simulated wall panel	0.23 mg/m <sup>2</sup> /hr	
gas burner, gas oven	0.67 mg/hr	
kerosene heater, convective	0.33 mg/hr	
kerosene heater, radiant	1.3 mg/hr	
cigarettes	0.5 mg/hr	
oven <sup>b</sup> top burner <sup>c</sup>	11.4 (9.9-14.2) µg/kcal (n=5) 5.2 (2.0-12.0) µg/kcal (n=5)	Traynor <i>et al.</i> , 1979
<i>Perchloroethylene<sup>d</sup></i>		
50% polyester, 50% rayon rayon	220 µg/m <sup>2</sup> /hr 55 µg/m <sup>2</sup> /hr	Tichenor and Sparks, 1988 <sup>d</sup>
polyester knit acetate	430 µg/m <sup>2</sup> /hr 6700 µg/m <sup>2</sup> /hr	
acrylic knit	56 µg/m <sup>2</sup> /hr	
wool blend	990 µg/m <sup>2</sup> /hr; 1200 µg/m <sup>2</sup> /yr	
cotton	440 µg/m <sup>2</sup> /hr	
linen	570 µg/m <sup>2</sup> /hr	
65% polyester, 35% cotton	350 µg/m <sup>2</sup> /hr	
80% rayon, 15% flax	180 µg/m <sup>2</sup> /hr	

(continued next page)

**Exhibit 2-4. Source emission rates for selected contaminants (continued).**

CONTAMINANT AND MATERIAL	SOURCE EMISSION RATE	REFERENCE
<i>Para-dichlorobenzene</i>	1.44 mg/cm <sup>2</sup> /hr	Clayton and Stephenson, 1988
<i>Carbon Monoxide</i>		
gas stove <sup>e</sup>	61.7 ± 3.58 µg/kJ (n=192)	Borrazzo <i>et al.</i> , 1987
oven	950 (650-1600) µg/kcal (n=6)	Traynor <i>et al.</i> , 1979
stove, top burner	890 (720-1090) µg/kcal (n=4)	
kerosene heater, blue flame	125.9 µg/kJ	Porter, 1984
reduced fuel consumption <sup>f</sup>	1.40 µg/kJ	
kerosene heater, white flame	23.9 µg/kJ	
reduced fuel consumption <sup>f</sup>	3.00 µg/kJ	
kerosene heater, convective	1.26 ± 0.49 10 <sup>-6</sup> ft <sup>3</sup> /Btu/hr	Ritchie and Arnold, 1984
kerosene heater, radiant	1.16 ± 0.48 10 <sup>-6</sup> ft <sup>3</sup> /Btu/hr	
wood stove, airtight	10-140 cm <sup>3</sup> /hr (n=7)	Traynor <i>et al.</i> , 1987
wood stove, not airtight	220-1800 cm <sup>3</sup> /hr (n=4)	
<i>Carbon Dioxide</i>		
oven	200,000 µg/kcal (195,000-250,000) µg/kcal (n=6)	Traynor <i>et al.</i> , 1979
stove, top burner	205,000 µg/kcal (196,000-217,000) µg/kcal (n=3)	
kerosene heater, convective	1376 ± 200 10 <sup>-6</sup> ft <sup>3</sup> /Btu/hr	Ritchie and Arnold, 1984
kerosene heater, radiant	1379 ± 240 10 <sup>-6</sup> ft <sup>3</sup> /Btu/hr	
<i>Nitrogen Dioxide</i>		
gas stoves	10.5 ± 1.43 µg/kJ (n=192)	Borrazzo <i>et al.</i> , 1987
oven	62 (44-74) µg/kcal (n=11)	Traynor <i>et al.</i> , 1979
stove, top burner	85 (69-100) µg/kcal (n=4)	
kerosene heater, blue flame	4.7 µg/kJ	Porter, 1984
reduced fuel consumption <sup>f</sup>	1.15 µg/kJ	

**Exhibit 2-4. Source emission rates for selected contaminants (continued).**

CONTAMINANT MATERIAL	SOURCE EMISSION RATE	REFERENCE
<i>Nitrogen Dioxide (continued)</i>		
kerosene heater, white flame	7.2 µg/kJ	
reduced fuel consumption <sup>f</sup>	1.61 µg/kJ	
kerosene heater, convective	$0.211 \pm 0.042 \times 10^{-6} \text{ ft}^3/\text{Btu/hr}$	Ritchie and Arnold, 1984
kerosene heater, radiant	$0.025 \pm 0.008 \times 10^{-6} \text{ ft}^3/\text{Btu/hr}$	
<i>Nitric Oxide</i>		
gas stoves	$16.8 \pm 1.37 \text{ µg/kJ (n=192)}$	Borrazzo <i>et al.</i> , 1987
oven	$29 (14-50) \text{ µg/kcal (n=11)}$	Traynor <i>et al.</i> , 1979
stove, top burner	$31 (21-47) \text{ µg/kcal (n=4)}$	
kerosene heater, blue flame	0.1 µg/kJ	Porter, 1984
reduced fuel consumption <sup>f</sup>	--	
kerosene heater, white flame	14.4 µg/kJ	
reduced fuel consumption <sup>f</sup>	0.52 µg/kJ	
kerosene heater, convective	$0.411 \pm 0.105 \times 10^{-6} \text{ ft}^3/\text{Btu/hr}$	Ritchie and Arnold, 1984
kerosene heater, radiant	$0.014 \pm 0.008 \times 10^{-6} \text{ ft}^3/\text{Btu/hr}$	
<i>Sulfur Dioxide</i>		
oven	$0.8 (0.5-1.0) \text{ µg/kcal (n=11)}$	Traynor <i>et al.</i> , 1979
stove, top burner	$0.8 (0.6-0.9) \text{ µg/kcal (n=4)}$	
kerosene heater, convective	$0.078 \pm 0.010 \times 10^{-6} \text{ ft}^3/\text{Btu/hr}$	Ritchie and Arnold, 1984
kerosene heater, radiant	$0.079 \pm 0.017 \times 10^{-6} \text{ ft}^3/\text{Btu/hr}$	
<i>Hydrogen Cyanide</i>		
oven	$1.8 (1.6-2.3) \text{ µg/kcal (n=3)}$	Traynor <i>et al.</i> , 1979
stove, top burner	0.07 µg/kcal	

(continued next page)

**Exhibit 2-4. Source emission rates for selected contaminants (continued).**

CONTAMINANT AND MATERIAL	SOURCE EMISSION RATE	REFERENCE
<i>Total Suspended Particulates</i>		
wood stove, airtight	2.5-8.7 mg/hr (n=7)	Traynor <i>et al.</i> , 1985
wood stove, not airtight	16-230 mg/hr (n=4)	
no stove, background	1.1, 1.6 mg/hr (n=2)	
<i>Benzo(a)pyrene<sup>b</sup></i>		
wood stove, airtight	0.02-0.76 µg/hr (n=7)	Traynor <i>et al.</i> , 1985
wood stove, airtight	2.2-57 µg/hr (n=4)	
no stove, background	<0.01µg/hr (n=2)	

<sup>a</sup> based on CPSC analysis of existing data

<sup>b</sup> Oven operated at 1 hr at 180°C (350°F).

<sup>c</sup> Operated with water-filled cooking pots.

<sup>d</sup> Emissions from dry cleaned fabrics. The reader is cautioned by Tichenor *et al.* to use the results in a qualitative way, not for emissions calculations.

<sup>e</sup> Emission factors are based on a statistical analysis of existing data by various investigators.

<sup>f</sup> 75% of normal fuel consumption.

<sup>g</sup> Outdoor penetration factor of 0.48

<sup>h</sup> Outdoor penetration factor of 0.30



**Exhibit 2-5. Decay rates for selected contaminants.**

CONTAMINANT AND MATERIAL	DECAY RATE	REFERENCE
<i>Nitrogen Dioxide</i>		
based on steel chamber studies		
• highest removal		Billick and Nagda, 1987
unpainted plaster board	> 8.4/hr	
cement block	8.4/hr	
wool carpet	6.0/hr	
• high removal		
used bricks	4.2/hr	
masonite	4.1/hr	
polyurethane foam	3.7/hr	
• moderate removal		
cotton/polyester bedspread	2.7/hr	
painted plasterboard	2.6/hr	
plywood (1/4 in)	2.6/hr	
acrylic fiber or nylon		
carpet	1.9 - 2.0/hr	
ceiling tile (wood fiber)	1.9/hr	
all vinyl wallcovering		
with proper backing	1.9/hr	
• low removal		
particleboard	0.7/hr	
ceramic tile	0.7/hr	
cotton terrycloth	0.3/hr	
wool (80%)/polyester (20%) fabric	0.3/hr	
window glass	<0.1/hr	
galvanized metal duct	0	
formica countertop	0	
vinyl or asphalt tile	0	
<i>Formaldehyde</i>		
based on concentration measurements	-0.0182 to -0.0231/mo (ave = -0.0195)	Versar, 1985
based on "fast" chamber studies		U.S. CPSC, 1985
particleboard underlayment	-0.078/mo (ave)	
paneling	-0.093/mo (ave)	
medium density fiberboard	-0.053/mo (ave)	
based on concentration data for Houston	-0.0013 to -0.0028/mo (ave)	Stock and Sixto,
<i>Particles &lt;1 micron diameter</i>	0.05/hr	Dockery and
<i>Radon</i>	$1.258 \times 10^{-4}/\text{min}$	Kusuda <i>et al.</i> , 1980

**Exhibit 2-6. Deposition velocities for selected contaminants on various surfaces and indoor areas.**

CONTAMINANT AND MATERIAL		DEPOSITION VELOCITY	REFERENCES
<i>Sulfur Dioxide</i>			
carpet			Walsh <i>et al.</i> , 1977
pink tufted	(pH = 4.1)		
pile		0.031 cm/sec	
backing		0.006 cm/sec	
orange	(pH = 3.5)		
pile		0.053 cm/sec	
backing		0.014 cm/sec	
green	(pH = 6.7)		
pile		0.074 cm/sec	
backing		0.016 cm/sec	
white	(pH = 9.2)		
pile		0.072 cm/sec	
backing		0.012 cm/sec	
mustard	(pH = 4.8)		
pile		0.022 cm/sec	
backing		0.017 cm/sec	
dark green (unused)	(pH = 4.3)		
pile		0.020 cm/sec	
backing		0.011 cm/sec	
dark green (used)	(pH = 4.5)		
pile		0.029 cm/sec	
backing		0.014 cm/sec	
embossed vinyl		0.096 cm/sec	Walsh <i>et al.</i> , 1977
wallpaper		0.007 cm/sec	
paint			Walsh <i>et al.</i> , 1977
gloss		0.033 cm/sec	
emulsion		0.128 cm/sec	
<i>Nitrogen Dioxide</i>			
flooring materials			
carpet		0.55 to 3.46 m/hr (n = 5)	Miyasaki, 1984

**Exhibit 2-6. Deposition velocities for selected contaminants on various surfaces and indoor areas (continued).**

CONTAMINANT AND MATERIAL	DEPOSITION VELOCITY	REFERENCES
<i>Nitrogen Dioxide (continued)</i>		
tatami facing	0.46 m/hr	
floor sheet	0.04 to 0.09 m/hr (n = 3)	
plastic tile	0.12 m/hr	
ceramic tile	0.15 m/hr	
bath mat	1.97 m/hr	
needle punch	0.47 m/hr	
wall materials <sup>a</sup>		
wall paper	0.06, 0.08 m/hr (n=2)	
printed plywood	0.05 m/hr.	
ceiling materials <sup>a</sup>		Miyazaki, 1984
insulation board	4.31 m/hr	
painted insulation board	2.13 m/hr	
plaster board	0.66 m/hr	
wooden cement board	1.17 m/hr	
asbestos cement board	1.47 m/hr	
<i>Nitric Oxide</i>		
flooring materials <sup>a</sup>		Miyazaki, 1984
carpet 1	0.01 m/hr	
tatami facing	0.01 m/hr	
floor sheet 1	0.00 m/hr	
needle punch	0.03 m/hr.	
ceiling materials		Miyazaki, 1984
insulation board	0.00 m/hr	
painted insulation board	0.04 m/hr	
plaster board	0.11 m/hr	
wooden cement board	0.12 m/hr	
<i>Ozone</i>		
fabrics		Sabersky <i>et al.</i> , 1973
cotton muslin	0.88 - 6.52 cm/min	
lamb's wool	0.24 - 6.34 cm/min	
nylon	0.03 - 1.92 cm/min	
linen	0.33 - 0.56 cm/min	(continued next page)

**Exhibit 2-6. Deposition velocities for selected contaminants on various surfaces and indoor areas (continued).**

CONTAMINANT AND MATERIAL	DEPOSITION VELOCITY	REFERENCES
<i>Ozone (continued)</i>		
building materials		Sabersky <i>et al.</i> , 1973
neoprene	0.91 - 5.79 cm/min	
plywood (1 side varnished)	0.30 - 1.83 cm/min	
polyethylene sheet	0.61 - 1.46 cm/min	
lucite	0.03 - 0.37 cm/min	
aluminum	0.03 - 0.06 cm/min	
plate glass	0.03 - 0.06 cm/min	

\* average values from the results of experiments at 20-26°C, 40-60% RH

## 2.2. SOURCES OF INDOOR AIR CONTAMINANTS

Exhibit 2-7 provides a more detailed tabulation of sources and contaminants. Product categories and examples of products are identified for major source categories including consumer and commercial sources, building sources, personal sources, and outdoor sources. Examples of contaminants which have been identified for the product categories are also given.

Specific compounds are grouped according to general categories of contaminants (for example, vinyl chloride is a VOC which has been measured from building materials). Examples of building materials are included (pressed wood products, construction adhesive, insulating materials, plastic piping, and vinyl or plastic wall coverings). *The reader should not attempt to match specific contaminants with specific products.*

**Exhibit 2-7. Sources of indoor air contaminants.****SOURCES****CONTAMINANTS****CONSUMER AND COMMERCIAL PRODUCTS****Cleaners and waxes**

aerosol bathroom cleaner  
 unpressurized aerosol window cleaner  
 liquid all purpose cleaner  
 powdered abrasive cleaner  
 dishwashing detergent  
 concentrated spot remover  
 liquid floor wax  
 aerosol furniture wax  
 aerosol and solid room deodorants  
 paste furniture wax  
 oven cleaners

**Particulates**

- nonmetals (phosphates, other inert powders)

**VOCs**

- aromatic hydrocarbons (toluene, p-dichlorobenzene)
- halogenated hydrocarbons (perchloroethylene; methylene chloride; 1,1,1-trichloroethane)
- alcohols
- ketones (acetone, methyl ethyl ketone)
- aldehydes (formaldehyde)
- esters (alkyl ethoxylate)
- ethers

**Paints and Associated Supplies**

paints (oil, urethane, acrylic)  
 varnishes and shellac  
 wood stains  
 paint thinners  
 paint brush cleaners  
 paint removers

**Particulates**

- metals (lead, mercury, chromium)

**VOCs**

- aromatic hydrocarbons (toluene)
- aliphatic hydrocarbons (n-hexane, heptane)
- halogenated hydrocarbons (methylene chloride, propylene dichloride)
- alcohols
- ketones (methyl ethyl ketone, methyl isobutyl ketone)
- ester (ethylacetate)
- ethers (methyl ether, ethyl ether, butyl ether)

**Pesticides**

termite treatment of homes  
 aerosol all-purpose household pesticides  
 roach killer (powder, liquid, spray)  
 flea killer (powder, liquid dip, aerosol)  
 mold and mildew inhibitors  
 houseplant insecticides  
 moth repellents  
 rodenticides (rat or mouse killer)

**Particulates**

- nonmetals (sulfur, lime)

**VOCs**

- aliphatic hydrocarbons (kerosene)
- aromatic hydrocarbons (xylene)
- halogenated hydrocarbons (chlordane, p-dichlorobenzene, heptachlor, chlorpyrifos, diazinon)

*(continued next page)*

**Exhibit 2-7. Sources of indoor air contaminants (continued).**

SOURCES	CONTAMINANTS
<b>CONSUMER AND COMMERCIAL PRODUCTS (continued)</b>	
<b>Pesticides (continued)</b>	<b>VOCs (continued)</b>
fungicides (household disinfectants)	<ul style="list-style-type: none"> <li>ketones (methyl isobutyl ketone)</li> <li>organic sulfur/phosphorous compounds (malathion)</li> </ul>
<b>Adhesives</b>	<b>VOCs</b>
rubber cement	<ul style="list-style-type: none"> <li>aliphatic hydrocarbons (hexane, heptane)</li> <li>aromatic hydrocarbons</li> <li>halogenated hydrocarbons</li> <li>alcohols</li> <li>organic nitrogen compounds (amines)</li> <li>ketones (acetone, methyl ethyl ketone)</li> <li>esters (vinyl acetate)</li> <li>ethers</li> </ul>
plastic model glue	
floor tile adhesive	
ceramic adhesive	
carpet adhesive	
all-purpose adhesives	
<b>Cosmetic/Personal Care Products</b>	<b>VOCs</b>
perfume	<ul style="list-style-type: none"> <li>alcohols (propylene glycol, ethyl alcohol, isopropyl alcohol)</li> <li>ketones (acetone)</li> <li>aldehydes (formaldehyde, acetaldehyde)</li> <li>esters</li> <li>ethers (methyl ether, ethyl ether, butyl ether)</li> </ul>
personal deodorants (aerosols, solids)	
body powder (talc)	
shampoo and body soaps	
rubbing alcohol	
hair sprays	
<b>Automotive Products</b>	<b>VOCs</b>
hydraulic fluids	<ul style="list-style-type: none"> <li>aliphatic hydrocarbons (kerosene, mineral spirits)</li> <li>aromatic hydrocarbons (benzene, toluene, xylene)</li> <li>halogenated hydrocarbons (perchloroethylene)</li> <li>alcohols (ethylene glycol, isopropyl alcohol)</li> <li>ketones (methyl ethyl ketone)</li> <li>amines (triethanolamine, isopropanolamine)</li> </ul>
motor oils	
gasoline	
automotive cleaners	
automotive waxes	
<b>Hobby Supplies</b>	<b>Particulates</b>
photographic chemicals	<ul style="list-style-type: none"> <li>nonmetals (fibers, smoke)</li> </ul>
specialty adhesives	
clay dust	

**Exhibit 2-7. Sources of indoor air contaminants (continued).****SOURCES****CONTAMINANTS****CONSUMER AND COMMERCIAL PRODUCTS (continued)****Hobby Supplies (continued)**

wood fillers

**VOCs**

- aliphatic hydrocarbons (kerosene, hexane, heptane)
- aromatic hydrocarbons (toluene, xylene, benzene)
- halogenated hydrocarbons (methylene chloride, ethylene chloride)
- alcohols (benzyl alcohol, ethanol, methanol, isopropyl alcohol)
- aldehydes (formaldehyde, acetaldehyde)
- ketones (methyl isobutyl ketone, acetone)
- esters [di-(2-ethylhexyl) phthalate] (DEHP)
- ethers (ethylene glycol ether)
- amines (ethylene diamine)

**Furnishings and Clothing**

carpets

upholstered furniture

plastic furniture

shower curtains

draperies

blankets

mattresses

**VOCs**

- aromatic hydrocarbons (styrene, brominated aromatics)
- halogenated hydrocarbons (vinyl chloride)
- aldehydes (formaldehyde)
- ethers
- esters (DEHP)

**BUILDING SOURCES****Building Materials**

pressed wood products

construction adhesive

insulating materials

plastic piping

vinyl or plastic wall coverings

**Particulates**

- fibers (fiberglass, asbestos)

**VOCs**

- aliphatic hydrocarbons (n-decane, n-dodecane)
- aromatic hydrocarbons (toluene, styrene, ethylbenzene)
- halogenated hydrocarbons (vinyl chloride)
- aldehydes (formaldehyde)
- ketones (2-propanone, 2-butanone)
- ethers
- esters (urethane, ethylacetate, DEHP)

*(continued next page)*

**Exhibit 2-7. Sources of indoor air contaminants (continued).**

SOURCES	CONTAMINANTS
<b>BUILDING SOURCES (continued)</b>	
<b>Building Materials (continued)</b>	<b>Radioactive Contaminants</b> <ul style="list-style-type: none"> <li>• radon gas</li> </ul>
<b>Heating, Ventilating, and Air-Conditioning Systems</b> furnaces (carbon-based fuels) air conditioner reservoirs	<b>Inorganic Gases</b> <ul style="list-style-type: none"> <li>• sulfur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide</li> </ul> <b>Particulates</b> <ul style="list-style-type: none"> <li>• nonmetals (fiberglass, molds, smoke)</li> </ul> <b>VOCs</b> <ul style="list-style-type: none"> <li>• aliphatic hydrocarbons (methane)</li> </ul> <b>Polynuclear Aromatic Hydrocarbons</b> <ul style="list-style-type: none"> <li>• benzo(a)pyrene</li> </ul>
<b>Garages</b> vehicular exhaust stored chemicals (pesticides, paints, solvents, gasoline)	<b>Inorganic Gases</b> <ul style="list-style-type: none"> <li>• sulfur dioxide, nitrogen oxides, carbon monoxide</li> </ul> <b>Particulates</b> <ul style="list-style-type: none"> <li>• metals (lead, nickel, platinum, palladium)</li> </ul> <b>VOCs</b> <ul style="list-style-type: none"> <li>• aromatic hydrocarbons (benzene)</li> <li>• chlorinated hydrocarbons, other substituted hydrocarbons</li> </ul> <b>Polynuclear Aromatic Hydrocarbons</b> <ul style="list-style-type: none"> <li>• benzo(a)pyrene</li> </ul>
<b>Combustion Appliances</b> unvented heaters (kerosene, gas) gas cooking stoves woodburning stoves and fireplaces	<b>Inorganic Gases</b> <ul style="list-style-type: none"> <li>• sulfur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide</li> </ul>



**Exhibit 2-7. Sources of indoor air contaminants (continued).****SOURCES****CONTAMINANTS****BUILDING SOURCES (continued)****Combustion Appliances (continued)****VOCs**

- aliphatic hydrocarbons (propane, butane, isobutane)

**Polynuclear Aromatic Hydrocarbons**

- benzo(a)pyrene

**Radioactive Contaminants**

- radon

**Aldehydes**

- acetaldehyde, acrolein

**PERSONAL SOURCES****Tobacco Smoke****Over 3800 Compounds Including:**

- Inorganic Gases
- Metals
- Particulates
- Radioactive Contaminants
- VOCs
- Organic Nitrogen Compounds
- Ketones
- Polynuclear Aromatic Hydrocarbons

**Human and Biological Origin**

- animal feces
- pets
- indoor plants (spores, pollen)
- metabolic products
- pathogens

**Inorganic Gases**

- ammonia

**Particulates**

- nonmetals (dander, feces)

**VOCs**

- aliphatic hydrocarbons (methane)
- aromatic hydrocarbons (toluene)
- aldehydes (acetaldehyde)

(continued next page)

**Exhibit 2-7. Sources of indoor air contaminants (continued).**

SOURCES	CONTAMINANTS
<b>OUTDOOR SOURCES</b>	
Soils and Rocks	<b>Radioactive Contaminants</b> <ul style="list-style-type: none"> <li>• radon gas</li> </ul>
<b>Outdoor Air</b> <ul style="list-style-type: none"> <li>• industrial emissions</li> <li>• contaminated groundwater</li> <li>• vehicular exhaust</li> </ul>	<b>Inorganic gases</b> <ul style="list-style-type: none"> <li>• carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone</li> </ul> <b>Particulates</b> <ul style="list-style-type: none"> <li>• metals (lead, other metals of respirable size range)</li> <li>• nonmetals (fibers)</li> </ul> <b>VOCs</b> <ul style="list-style-type: none"> <li>• aliphatic hydrocarbons</li> <li>• aromatic hydrocarbons</li> <li>• halogenated hydrocarbons</li> <li>• aldehydes and ketones</li> <li>• alcohols</li> <li>• esters</li> <li>• ethers</li> <li>• organic nitrogen compounds</li> <li>• organic sulfur/phosphorous compounds</li> </ul>
<b>Potable Water</b> <ul style="list-style-type: none"> <li>• volatilization of VOCs during showering, bathing, other uses of potable water</li> </ul>	<b>Radioactive Contaminants</b> <ul style="list-style-type: none"> <li>• radon gas</li> </ul> <b>VOCs</b> <ul style="list-style-type: none"> <li>• halogenated hydrocarbons (1,1,1-trichloroethane, chloroform, trichloroethylene, tetrachloroethylene)</li> </ul>
<b>Humidifiers</b>	<b>Particulates</b> <ul style="list-style-type: none"> <li>• aerosolized asbestos and minerals, biological contaminants</li> </ul>
<b>Contaminated Groundwater</b> <ul style="list-style-type: none"> <li>• seepage into basements</li> </ul>	<b>Radioactive contaminants</b> <b>VOCs</b>

SOURCE: Adapted from U.S. EPA. (1987)

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## **SECTION 3.**

### **DEFINING HEALTH EFFECTS AND RISK ASSESSMENT**

Section 3.1 contains a discussion of what constitutes an adverse health effect from the perspective of different public health organizations; Section 3.2 provides an overview of the structure and function of the respiratory tract and its defense mechanisms; Section 3.3 provides an overview of the process of risk assessment; and Section 3.4 provides a summary of EPA cancer risk assessments for specific indoor air contaminants.

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#### **List of Exhibits**

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### 3.1. DEFINING ADVERSE HEALTH EFFECTS

There is a range of effects that can occur from exposure to indoor air contaminants. Some exposures result in body burdens which do not produce physiologic changes or morbidity. Others can produce mild discomfort at one extreme, and mortality at the other. Because of these broad ranges of effects and variability in susceptibility, it is useful to review different approaches to the question of whether or not an exposure has resulted or can result in adverse health effects.

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The American Thoracic Society (Andrews, *et al.*, 1985) has developed guidelines which define adverse respiratory effects. These guidelines were developed within the context of the Clean Air Act as it applies to protection of the public against adverse health effects from outdoor air contaminants. In this context, the Society's Scientific Assembly on Environmental and Occupational Health defines adverse effects as "medically significant physiologic or pathologic changes" that interfere with normal activity, cause episodic respiratory illness, incapacitating illness, permanent respiratory injury, and/or progressive respiratory dysfunction.

Recognizing that the determination of adverse health effects is not entirely medical, but also a subjective societal decision, the Assembly listed potential health effects in a hierarchy of severity and did not demarcate between adverse and nonadverse effects. Thus, the definition of "medically significant" is broadly interpreted and includes:

- asthmatic attacks;
- reports of chronic respiratory symptoms;
- the need to take pulmonary medication;
- decreased pulmonary function;
- increased prevalence of wheezing;
- chest tightness;
- cough/phlegm;
- acute upper respiratory infections;
- eye, nose, and throat irritation; and
- odors.

This listing provides guidance that recognizes that irritation and odor effects can be interpreted as adverse health effects.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), in ASHRAE Standard 62-1989, defines acceptable air quality as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction." ASHRAE also explicitly identifies discomfort effects as unacceptable.

ASHRAE Standard 62-1989 reflects a concern for the growing number of sick building syndrome complaints by building occupants. This definition also reflects the Society's traditional interest in occupant satisfaction with the building's thermal environment. Thus, the ASHRAE definition and the background information to the procedures section of the Standard provide considerable latitude in determining whether or not adverse effects occur.

The American Public Health Association's Model Housing Code (Mood, 1986) also provides latitude in addressing adverse health effects. The term "cognizant authority" used by ASHRAE is also used in APHA's Model Housing Code. In APHA's model code, the term usually refers to the local health officer who has the responsibility of determining whether or not the presence of a contaminant is harmful.

The World Health Organization's Working Group on Indoor Air Quality (WHO, 1983) did not explicitly define adverse health effects, but identified the following effects as adverse: odor, irritation, airway effects, carcinogenic effects, systemic effects, and respiratory disease.

Based on these sources, an adverse health effect could be interpreted broadly to include effects which are medically significant, physiologic or pathologic changes which do not result in the

expression of symptoms and/or frank disease, and discomfort effects, including odors. Decreases in productivity should also be added to this list.

This interpretation reflects an emerging international consensus of individuals and organizations involved with indoor air quality. Woods (1986) aptly distills the criteria for judging building performance based on presentations and discussions from Indoor Air 84, the Third International Conference on Indoor Air Quality and Climate. As summarized by Woods, these criteria include the ability of the building to provide for the health, safety, comfort, acceptability, well-being, and productivity of occupants.

### 3.2. THE RESPIRATORY TRACT

Every person breathes in 10,000 to 20,000 liters of air each day that contain several million particles and gas molecules. It is one of nature's wonders that the respiratory tract is able to cleanse much of this contaminated air by the time the air reaches the region of the lungs where gas exchange takes place.

The respiratory tract is protected from injury by many interrelated defense mechanisms including mechanical defenses, fluids that line the airways, airway reflexes, and antimicrobial, inflammatory and immune defenses. If one or more of these is impaired, respiratory damage and disease can result.

An understanding of the structure and defense mechanisms of the respiratory tract is a useful first step toward understanding many of the respiratory related health effects associated with indoor air contaminants.

#### Structure of the Respiratory Tract

The respiratory tract can be divided into three regions: the nasopharyngeal region, the tracheobronchial region, and the pulmonary region (Exhibit 3-1).

#### Nasopharyngeal Region

The nasopharyngeal region is the upper portion of the respiratory tract, and it consists of the nose, mouth, pharynx, and larynx. A primary function of this region is to condition the temperature and humidity of the air in the nose.

As air enters the nose, nasal hairs trap some of the larger particles. Another important defense mechanism is the turbulent flow of air in this region. The airflow is turbulent because of turbinates and the small cross-sectional area in the nasopharynx. Larger particles (>8-10  $\mu\text{m}$ ) are removed by inertial impaction, and there is a rapid drop in the deposition rate of particles having a mass median diameter of less than 1 micron.

Other defense mechanisms include the presence of nasal secretions and mucociliary clearance. Highly soluble or reactive gases such as sulfur dioxide and formaldehyde are effectively absorbed by or interact with nasal secretions, which decreases the concentration of these contaminants that reach the lower airways.

#### Tracheobronchial Region

The tracheobronchial region includes the trachea and bronchi. The trachea, a tube about 4.5 inches long and 1 inch in diameter, extends from the bottom of the larynx through the neck and into the chest. At the lower end, it divides into two tubes, the right and left bronchi. These conducting airways are lined with ciliated epithelium and coated with a thin layer of mucus which is secreted by goblet cells and mucus-secreting cells. The airway secretions are about 95% water, and the remainder consists of carbohydrates, proteins, inorganic materials, and small amounts of antimicrobial substances.

The nasopharyngeal and tracheobronchial regions also have "irritant" receptors which are located in the epithelium. Inhaled gases or particles can

activate the irritant receptors and initiate bronchoconstriction, mucus hypersecretion, and rapid breathing. Bronchoconstriction is a reaction in which the smooth muscles of the airways constrict, causing the airways to narrow.

Contaminants in this region are removed by impaction onto the airway secretions and removal by the action of the cilia. The cilia are hairlike filaments that wave back and forth at about 12 times per second. They are abundant in the respiratory tract from the nose to the terminal bronchioles. Their role is to propel mucus that contains contaminants from the airways to the upper respiratory tract (called mucociliary transport mechanism or mucociliary escalator) where the mucus may be swallowed or expelled by sneezing or coughing.

If the cilia become damaged (for example, by tobacco smoke), they cannot propel the mucus. It remains in the airways until it is coughed up and expectorated or swallowed. (Heavy smokers typically have to cough up mucus in the mornings when they arise because of a buildup of mucus during the night—as a result of cilia which are not able to remove mucus efficiently.)

Within each lung, the bronchi divide and subdivide, becoming smaller and smaller. The branches at the farthest reaches of the lung (pulmonary region) are very small and are called bronchioles. This division or bifurcation can be visualized by thinking of the trachea as the trunk of an upside down tree, and the bronchi and bronchioles as the branches which become smaller and smaller.

The bronchioles do not contain as many ciliated cells as the larger airways; they have almost no mucus producing cells and a very thin layer of airway secretions that line airways. The bronchioles appear to be particularly susceptible to injury from contaminants, particularly cigarette smoke and ozone.

### Pulmonary Region

The pulmonary region is the area where gas exchange occurs. The bronchioles lead into several ducts (alveolar ducts), each of which ends in a cluster of air sacs. Each cluster (alveolar sac) resembles a tiny bunch of grapes and ends in tiny air sacs called alveoli. The walls of the alveoli are thin membranes only one to two cells thick through which oxygen and other gases can pass freely.

From top to bottom, the respiratory tract branches from the trachea into 25 to 100 million branches, and these branches end in about 300 million alveoli. These alveoli have a combined cross sectional area of about 8.6 ft<sup>2</sup> (an amazingly large area considering that the cross sectional area of the trachea is only about .31 in<sup>2</sup>) [Olishifski and Benjamin, 1988].

Gas exchange in the alveolar region is based on the principle that gases diffuse rapidly from areas of higher concentration to areas of lower concentration. In the body, the concentration of oxygen (and any contaminants) is higher in the alveolar air than it is in the blood coming from the body's tissues. At the same time the pulmonary artery brings oxygen deficient blood from the body tissues back to the capillaries which are in contact with the alveoli.

Oxygen from the lungs diffuses from the alveoli to the body via the pulmonary vein, which carries the blood to the heart. Some of the oxygen is carried in solution in the plasma, and the remaining is combined with hemoglobin in the red blood cells to form oxyhemoglobin. The oxygen is then released by the hemoglobin whenever the oxygen tension of the plasma decreases. As the oxygen diffuses from the plasma into the tissue capillaries, it is continually replenished by more oxygen from the oxyhemoglobin.

The diffusion of carbon dioxide follows the same principle, but the concentration of carbon dioxide is higher in the body tissues than in the incoming air.



Contaminants that reach the air-exchange surfaces of the terminal alveoli are intercepted, ingested, and processed by alveolar macrophages or polymorphonuclear leucocytes. Once these cells have completed their work, they exit the lung via the mucociliary escalator or via the lymphatic system.

Those contaminants (such as carbon monoxide) that are not removed by the lung's defense mechanisms can enter the blood and lymph systems, resulting in the transport of contaminants to the organs where adverse effects can occur.

The bronchioles and the alveoli appear to be particularly susceptible to injury from inhaled toxicants. This may occur because under normal conditions the bronchioles contain fewer ciliated cells than larger airways, almost no mucus-producing cells, and the clearance mechanism of this region is relatively slow.

### **Modes of Action (Gases, Particles)**

The mode of action of contaminants in the respiratory system depends on the characteristics of the gases and particles and on the individual's rate and type of breathing (oral, nasal, or combination).

Particles and gases that reach the conducting airways first interact with liquids that line the respiratory tract. Reactions with these liquids can potentially increase the susceptibility of the underlying airway epithelium to injury. Acute effects include inflammation and pulmonary edema; chronic effects include bronchitis, bronchiolitis, fibrosis, emphysema, alveolitis, and cancer.

#### **Gases**

Important characteristics of gases which determine how they behave in the respiratory tract include solubility, reactivity, and concentration. Soluble gases are absorbed in the upper airways, where they may be buffered, detoxified, diffuse into the systemic circulation, or exert a pathologic effect.

Extremely water soluble gases such as ammonia and sulfur dioxide most often cause upper airway irritation and injury. Sulfur dioxide is highly soluble, and about 90% of all sulfur dioxide that is inhaled is absorbed in the upper respiratory passages with only slight penetration to the lower respiratory tract.

Ozone is several hundredfold less soluble than sulfur dioxide, and less of it will be absorbed in the upper respiratory tract. If the breathing rate is increased or if breathing switches from nose to mouth, less of each contaminant is removed in the upper respiratory tract and more will reach the middle and lower portion of the lungs. Nitrogen dioxide is less soluble and less reactive than ozone. Therefore, it could penetrate more deeply into the lungs.

Insoluble gases such as carbon monoxide, which are not reactive with airway secretions or cells, can reach the lower lung and diffuse into the bloodstream in the same concentrations as they were inspired.

#### **Particulates**

The action of particulates depends on size, shape, density, and reactivity of the particulates. Particles will be deposited in one of the three regions of the lung depending on the velocity of the airstream and the size of the particles (Task Group on Lung Dynamics, 1966).

Larger particles are deposited primarily in the nasopharyngeal region. As particles are inhaled, some are deposited as the airstream passes through the nose and pharynx. In this region, the changing path of the airstream causes larger particles to be removed by impaction on the airway walls because they cannot negotiate the turbinates. Particles greater than about 10 microns in diameter are effectively trapped by the nasopharyngeal defense mechanisms. About 60-80% of particles in the size range 5 to 10 microns in diameter are trapped in this zone. Small particles (less than 5 microns in

diameter) are not effectively trapped in this zone—only 5% are trapped and the remainder can travel to the lower regions of the lung (Task Group on Lung Dynamics, 1966).

In the tracheobronchial region, airflow is slower and particles are deposited by sedimentation and impaction. This region has minimal deposition of particles except for very small particles which are deposited by diffusion. About 10% of the particles in the size range 1 to 10 microns in diameter and 30% of particles 2 to 5 microns in diameter are deposited in this zone (Task Group on Lung Dynamics, 1966).

In the pulmonary region, particles are deposited by diffusion, and one method of removal occurs by macrophages. In this region there is a maximum efficiency of deposition at a size around 0.1 microns in diameter or less and between about 1 and 2 microns in diameter (about 30% deposition), and there is a minimum efficiency for particles about 0.5 microns in diameter (Task Group on Lung Dynamics, 1966).

The air sac linings are coated with a fluid film that serves the same cleansing function as the fluid in the breathing tubes. Deposited particles or dissolved particles and gases may be removed by the fluid which flows upward in the air sacs. The macrophages, in turn, can migrate to the small bronchioles where they are removed by the mucociliary escalator, or they may pass through the alveolar membrane into the lymph system. Macrophages can also be destroyed and release particles into the alveolar sac. If particles are not removed by these means, they may form a deposit in the air sac which may or may not result in health effects.

The rate of clearance of particles is important in determining the responses to contaminants, especially slow acting toxicants such as carcinogens. The residence time of particles ranges from minutes to hours in the upper respiratory tract, hours to days in the tracheobronchial region, and days to months in the pulmonary region.

### Pattern of Breathing

The type and rate of breathing also affect the deposition of particles and gases. During mouth breathing, larger particles will get deeper into the lung if the breathing is slow, deep, and with large lung volumes. Mouth breathing bypasses the defense mechanisms in the nasopharyngeal region.

### Pulmonary Function Tests

In many scientific studies pulmonary function tests are performed to determine if contaminants can adversely affect the respiratory tract, and physicians also use pulmonary function tests to determine if lung function has been impaired. Large decreases in pulmonary function provide evidence of an adverse respiratory effect, but small changes may or may not be significant.

The American Thoracic Society's Scientific Assembly on Environmental and Occupational Health views pulmonary function tests which *seem* to reflect inflammatory changes of the small airways equivocally. The Assembly observes that preliminary results indicate that these tests may predict susceptibility to respiratory disease or increased responsiveness, but concludes the results should not be used as indicators of adverse health effects in individuals. The Assembly's ambiguity reflects the current scientific data base in this area.

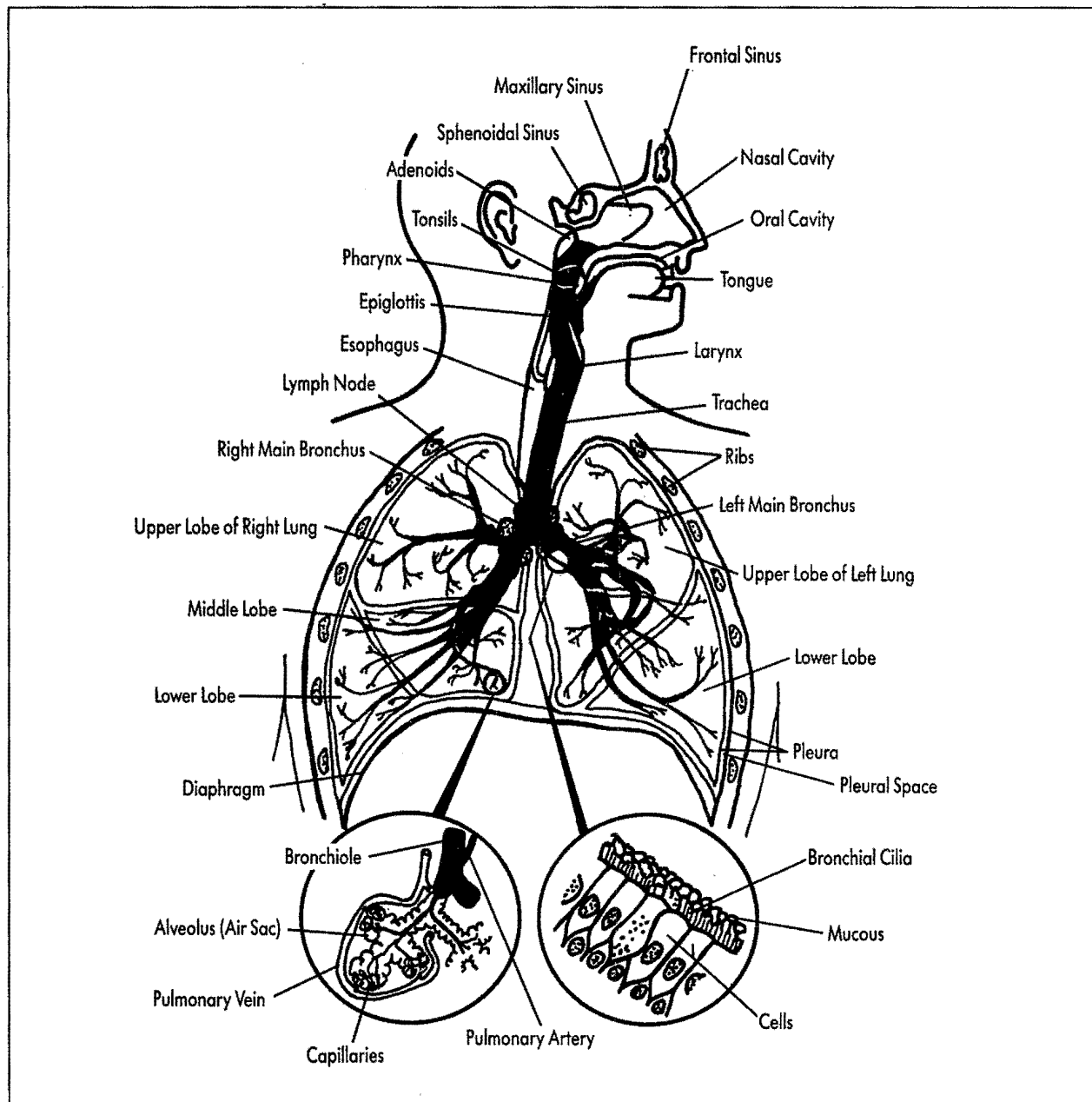
The ventilatory capacity of the lungs can be measured by a spirometer. The spirometer is an instrument which measures volumes of air and relates them to time (Exhibit 3-2 summarizes some of the commonly used terms of pulmonary function tests). Small, portable spirometers which can be used in field work can be purchased. These instruments can provide basic ventilatory measurements. More sophisticated tests require laboratory spirometry equipment.

Lung function testing is probably most useful in the evaluation of lung function after occupational exposures or as a component of research, but there

may be some instances when it may be an appropriate component of an indoor air quality investigation. The investigator should know that lung function tests have limitations. The results of these tests vary considerably among normal people of the

same sex, age, and height. Whenever these tests are conducted as part of an indoor air quality assessment, a physician or other knowledgeable person should conduct and interpret results.

### Exhibit 3-1. Structure of the respiratory tract.



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SOURCE: Reprinted with permission of the American Lung Association.

**Exhibit 3-2. Commonly used ventilatory measurements.**

TERM	SYMBOL	DESCRIPTION
vital capacity	VC	The largest exhaled volume of air measured after a maximal inspiration followed by a maximal expiration without forced or rapid effort.
forced vital capacity	FVC	The vital capacity performed with expiration as forceful and rapid as possible.
one-second forced expiratory volume	FEV <sub>1</sub>	Volume of air exhaled during the first second of a forced vital capacity; normally, the FEV <sub>1</sub> is about 80% of the FVC.
one-second forced expiratory volume expressed as a percentage of FVC	$\frac{\text{FEV}_1}{\text{FVC}} \times 100$	The observed FEV <sub>1</sub> expressed as a percentage of the observed FVC. The ratio is typically normal or increased in restrictive diseases and reduced in obstructive diseases.
maximal voluntary ventilation	MVV	Volume of air which a subject can breathe with voluntary maximal effort for a given time (10-15 sec., if possible, equated to 1 min.).

SOURCE: West (1980), Olishifski and Benjamin (1988)

**3.3. RISK ASSESSMENT**

Risk assessment is a tool that has been used increasingly in the fields of environmental science and health to identify the probability of injury, disease, or death from exposure to agents (chemical, physical or biological) under specific circumstances. Risk assessments attempt to answer, either qualitatively or quantitatively, basic questions such as: Is the water, food, or air safe? Will acute or chronic effects result? If there is an effect, will it occur in months, years, or decades? How many people are likely to be affected by exposure to the agent?

Risk assessment can also be used to evaluate the net risk and costs associated with a particular policy. For example, before water was chlorinated, many deaths occurred from infectious disease outbreaks

such as typhoid and cholera. More recently, the use of chlorine to disinfect water is known to increase the rate of formation of halogenated hydrocarbons. Risk analysis can be used to compare the risk (and therefore cost) of illness associated with not chlorinating water to the increased risk of cancer from chlorination byproducts.

The process of risk assessment is not infallible. Caution must be used in making assumptions and selecting input data for the assessments. When risk assessments are used, the uncertainty associated with them must always be acknowledged.

Useful references for additional information on risk assessment include several articles on cancer risk assessment (Calabrese, 1987; Menzel, 1987; Sielken, 1987; Severn, 1987; Wilkinson, 1987) and guidelines published by EPA for conducting exposure

assessments and assessing risks from carcinogens, mutagens, teratogens and chemical mixtures (U.S. EPA, 1986 a-e). EPA's risk assessment methodologies are currently under review and revised guidelines are anticipated.

### Assessment vs Management of Risk

Once the risk associated with exposure to an agent has been defined, a policy can be developed to manage that risk. In the environmental and health fields, risk assessments are generally performed by scientists and engineers, and the management of risk is usually a decision made by a governmental agency.

Risk management is a socio-political decision on whether or how much to control future exposure to the contaminant or activity under consideration. The risk assessment portion of the decision-making process should be carried out independently from considerations of the consequences of risk management. The risk management decision depends in part on the risk assessment, but also on the consideration of social, economic, and political factors.

### Measures of Risk

Risk assessments are used to measure the likelihood of a specific effect, such as death from acute hazards (in early deaths/year), cancer (in early deaths/year), and various types of chronic conditions (in cases/year).

Risk can be measured for a population or an individual. A population risk is the number of occurrences of a hazard per year within a given population. For example, assume there were 15 million automobile accidents in the U.S. in 1988; of these, assume that about 1 in 300 resulted in the death of an individual. The population risk is  $1/300 \times 15$  million, or 50,000 deaths/year.

The individual risk is the probability of a single occurrence affecting an individual during a year. For the automobile accident example, the individual

risk of dying as a result of an automobile accident is about 50,000 deaths/year/250 million people. This means that an individual has a 2 in 10,000 chance (or 1 in 5000) chance of dying as a result of an automobile accident.

The above examples are quantitative estimates of risk, but risk can also be expressed in qualitative terms using categories such as "low," "medium," or "high."

### Perception of Risk

There is a difference between the measure of risk and the perception of risk. The measurement of risk is based upon an estimated likelihood or frequency of an effect. The perception of risk is based upon a societal-political or personal interpretation and acceptance of the hazard posed by a situation or chemical exposure. For example, people who drive cars, but do not wear seatbelts, may perceive their risk to be less than the actual risk of driving without wearing seatbelts. On the other hand, the perceived risk of flying may be considerably higher than the actual risk for those people who are afraid to fly.

Risks can be voluntary or involuntary and may result from natural or synthetic substances. In general, people are willing to accept higher risks from voluntary exposure to agents (for example, smoking) than from involuntary exposure (for example, pesticide residues in food). Also, people might be willing to accept a cancer risk of 1/10,000 or 1/100,000 as a result of eating peanut butter containing low levels of naturally occurring aflatoxin, but they might reject having a synthetic chemical with a cancer risk of 1/100,000 in their water supply.

### The Risk Assessment Process

EPA has published guidelines for performing risk assessments of carcinogens, mutagens, chemical mixtures, and developmental toxicants (U.S. EPA 1986 a-e). The basic elements of risk assessment

which are identified in the guidelines include one or more of the following: hazard identification, dose-effect evaluation, exposure assessment, and risk characterization. Examples used in the discussion of these elements below are taken predominantly from carcinogenic risk assessment, not because it is more important, but because this area is the most developed.

### Hazard Identification

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Hazard identification is the process of determining whether or not exposure to an agent can cause an increase in the incidence of a health condition. This involves a review and analysis of available scientific information to determine whether or not an agent poses a particular risk.

Information which is used to identify hazards is obtained from cellular and tissue studies, animal studies, controlled human exposure studies, case studies of humans exposed in accidents or in the workplace, and epidemiologic studies.

**Carcinogen risk assessment:** A hazard identification to determine whether or not a contaminant poses a carcinogenic risk should include information on the nature of contaminants, degradation products, and metabolites. The available scientific literature should be reviewed for the following key elements:

- physical and chemical properties which affect the distribution and decay of the chemical in the body;
- routes and patterns of exposure;
- structural or activity properties of the chemical or its metabolites that support or argue against the prediction of potential carcinogenicity;
- metabolic and pharmacokinetic properties of the chemical which determine how the

chemical is distributed, metabolized, and excreted in the animal or human;

- toxicologic effects other than carcinogenicity, interactions with other chemicals or agents and with lifestyle factors, and other factors relating to toxicologic effects;
- short-term predictive tests which detect chemical interactions with DNA and assess mutagenic activity;
- long-term animal studies which identify the tumorigenic or carcinogenic potential of the chemical; and
- human epidemiologic studies which examine the association between the chemical and the incidence of cancer.

Of these elements, animal and human epidemiologic studies have been the most widely used sources of data to evaluate hazards, but they do have limitations.

**Animal studies** are used because it is assumed that effects in humans can be inferred from effects in animals. This assumption is generally accepted because all the chemicals that have been demonstrated to be carcinogenic in humans (except possibly arsenic) have been shown to be carcinogenic in some, but not all, animal species. Even so, caution must be used when animal studies are interpreted because there are potential differences in the way different species metabolize, distribute, and excrete chemicals.

The overall confidence that an agent which is carcinogenic in animals will be carcinogenic in humans increases with the following types of evidence:

- an increase in the number of animal species and strains showing an effect, and with both sexes showing an effect;

- an increase in the number of tissue sites affected by the agent;
- the presence of a clear-cut dose-effect relationship;
- a high level of statistical significance of the increased tumor incidence in treated compared to control groups;
- a dose-related shortening of the time for tumors to form or death to occur as a result of tumors; and
- a dose-related increase in the proportion of tumors which become malignant.

Human epidemiologic studies which are properly designed and conducted provide the most direct information about the toxicity of a particular contaminant. These studies, however, are not available for most chemicals because of the complexity and cost associated with gathering these data. Epidemiologic studies require large sample sizes for statistical reasons, and long time periods are needed to observe effects such as cancer. It is also difficult to quantify exposures because confounding variables such as socioeconomic effects, personal habits such as smoking and drinking, and other risk factors may not be known or cannot be adjusted for in the calculations.

Because of the problems associated with epidemiologic studies, animal studies and the other types of evidence listed above are usually used to derive estimates of cancer risk in humans.

The weight of evidence is reviewed carefully for technical adequacy and then given an overall classification for human carcinogenicity. The EPA classification system includes 5 groups in descending order of overall weight of the evidence:

**Group A (Carcinogenic to Humans):** Used when there is sufficient evidence from *epidemiologic* studies

to support a finding that a causal relationship exists between exposure to the agent and cancer;

**Group B (Probably Carcinogenic to Humans):**

Used when there is enough evidence of carcinogenicity based on animal studies and limited epidemiological evidence (Group B1) or inadequate or no human data (Group B2);

**Group C (Possibly Carcinogenic to Humans):**

Used when there is limited evidence for carcinogenicity in animals and inadequate or no human data;

**Group D (Not Classifiable as to Human Carcinogenicity):**

Used when there is inadequate animal evidence of carcinogenicity and inadequate or no human data; and

**Group E (Evidence of Noncarcinogenicity in Humans):**

Used when there is no evidence for carcinogenicity in at least two adequate animal tests in different species or in both adequate epidemiologic and animal studies.

### Dose-Effect Assessment

Dose-effect assessment is a critical part of the overall risk assessment process. It attempts to quantify the relationship between the dose and adverse effects expected in humans. Ideally, human epidemiologic data should be used to develop the dose-effect relationship for carcinogenic and noncarcinogenic effects. In practice, however, these data are usually not available, and data from animal studies are used.

There are three problems associated with the use of animal data which must be considered in the dose-effect assessment. First, animals are usually exposed at high doses, which means that effects at low doses must be extrapolated. Second, animals and humans differ in susceptibility. Third, there are some individuals in the population who may be more susceptible to effects than the average person.

The extrapolation of effects at high doses to those at low doses usually involves one of two assumptions:

1) biological effects occur after a threshold dose has been reached, or 2) there is a linear relationship between the dose and the effect. Effects which involve the alteration of genetic material (genotoxic effects), including the initiation of cancer, are assumed to be nonthreshold effects; that is, the effect is proportional to the dose, and there will always be an effect unless the dose is zero. A threshold dose is assumed for effects which are not genotoxic.

These assumptions, however, may need to be revised for some substances as new methods of assessing dose-effect relationships are developed. One of these new methods is the use of physiological pharmacokinetic modeling, which compares the sensitivity of animal and human cells and then relates these via dosimetry models to human and animal species sensitivity (Menzel, 1987). Whenever these new models appropriately simulate real effects, they may be preferable to the traditional threshold versus nonthreshold models.

Regardless of the assessment methodology, numerical estimates of the dose-effect relationship should not stand alone—assumptions and uncertainties should be included. The risk characterization should include a discussion and interpretation of the numerical estimates that provide the risk manager some insight into the degree to which the estimates are likely to reflect the true magnitude of the risk to humans.

**Noncarcinogen dose-effect assessment:** For noncarcinogens, the threshold dose in animal studies is approximated by the no-observed-adverse-effect level, NOAEL (expressed in mg/kg/day). The NOAEL is selected in the context of the entire data set. Uncertainties in the NOAEL are compensated by dividing the NOAEL by an uncertainty factor (previously called the safety factor) which may be 10 (or less), 100, 1000, or 10,000. The uncertainty factor dates to the early days of food additive legislation when it became clear that there was no universally accepted quantitative method of ex-

trapolating from animal data to humans. The selection of the uncertainty factor is a professional judgment that depends on the nature and quality of the data, the seriousness of the effect, the type of effect, and the population to be protected.

The NOAEL can be used to derive the reference dose (RfD) for humans. The reference dose, which was formerly called the acceptable daily intake (ADI), can be expressed as an oral reference dose (mg/kg/day) or inhalation reference concentration (mg/m<sup>3</sup>). The RfD is a dose (from contaminants in food, water, and air) that is *anticipated* to be without risk to humans over a lifetime of exposure. The RfD is derived by dividing the NOAEL for the toxic effect appearing at the lowest dose by the uncertainty factor. An additional modifying factor which comments on the quality of the data may also be included. The RfD is an estimate of risk (with uncertainty that spans perhaps an order of magnitude). It is not a guarantee of absolute safety, and it may overestimate the risk in some instances.

In those instances when the NOAEL cannot be identified, the RfD might be calculated with the lowest observed-adverse-effect level (LOAEL).

The assessment should be accompanied by a confidence statement that comments on the quality of the study that drives the assessment, the underlying data base and the degree to which the selected study agrees with the data base, and the overall adequacy of the assessment.

**Carcinogen dose-effect assessment:** There are three main components to the dose-effect assessment for carcinogens:

- 1) the appropriate data base is selected based on the quality of the data, its relevance to human modes of exposure, and other factors;
- 2) mathematical models are used to extrapolate from high to low doses of exposure; and



- 3) appropriate scaling factors are used to extrapolate from animal studies to human exposure.

In the absence of human data, data are typically used from a species that responds most like humans or has in the long-term studies shown the greatest sensitivity.

Several mathematical models (linearized multistage model, one-hit model, gamma multi-hit model, log-probit model, and other time-to-response models such as the Weibull model) have been used to extrapolate the risks from high doses to those at low doses. No single model is recognized as most appropriate for all carcinogens (U.S. EPA, 1986a). The selection of a specific model depends on the underlying mechanism that results in the development of cancer, and if such data are available, the selected model should be consistent with these data. Unfortunately, the way in which cancer develops is not understood for most carcinogens. In the absence of these data, EPA recommends the use of the multistage model, which assumes that cancer originates in a single cell as a result of an irreversible and self-replicating process that involves a number of different random biological events.

EPA uses a linearized modification of the multistage model which assumes that the time rate of occurrence of each event is in strict linear proportion to the dose. This model, the linearized multistage model, is considered to be the strongest of the available models (U.S. EPA, 1988). The selection of the model for extrapolation is important because at low doses the predicted values from the models diverge significantly. For example, for a given dose there may be a factor of  $10^5$  or  $10^8$  difference in the estimation of lifetime cancer risk at a given concentration by the most conservative and least conservative models. This is an uncertainty equivalent to not knowing if one has enough money to buy a cup of coffee or pay off the national debt (Cothorn, *et al.* 1986). Even so, it is highly likely that the projections of the more protective models will not under-

estimate risk and they may strongly overestimate it (U.S. EPA, 1988).

The risk estimates at low doses derived from animal studies must also be adjusted for the differences between the human and the animal test species. Some of these differences include body size, genetic variability, population homogeneity, health status, life span, pharmacokinetic effects such as metabolism and excretion patterns, and the exposure regimen.

The most common approach for making these adjustments is to use standardized scaling factors which are related to the type of exposure pathway and sensitivity of the target organs. Scaling factors include mg per kg body weight per day, ppm in the diet or water, mg per m<sup>2</sup> body surface per day, and mg per kg body weight per lifetime. Because detailed toxicological, physiological, metabolic, and pharmacokinetic data may be limited for a specific agent, EPA considers a scaling factor based on surface area (mg per m<sup>2</sup> body surface area per day) to be appropriate because certain pharmacological effects scale according to surface area (U.S. EPA, 1986a).

Carcinogenic risk assessments must be accompanied by a weight-of-evidence statement that is a professional judgment of the quality of the assessment. The system for classifying the evidence is given under the **Hazard Identification** section.

### Exposure Assessment

The exposure assessment estimates the exposures to which the population of interest is likely to be subjected. It must be combined with the dose-effect assessment in order to obtain a quantitative estimate of the risk.

At the present time there is no single approach to exposure assessment that applies to every case. Rather, the method that is used must match the individual case based on the available data. As in all

phases of the risk assessment process, the assumptions, approximations, and assertions made for the exposure assessment should be stated.

The major elements of the exposure assessment which are outlined by EPA include identification and characterization of the following areas:

- **Sources.** The production, distribution, uses, disposal, and environmental releases of the chemical should be assessed.
- **Exposure pathways and environmental fate.** The transport, transformation, principle pathways of exposure, and predicted environmental distribution should be evaluated.
- **Measured or estimated concentrations.** The concentrations available for exposure should be evaluated using measurement, mathematical models, or a combination of the two.
- **Exposed populations.** Populations and subpopulations at potentially high exposure should be identified, and subpopulations of high sensitivity may be studied separately.
- **Integrated exposure analysis.** An exposure profile is developed from the estimation of environmental concentrations and the description of the exposed population. This profile should include the size of the exposed population; duration, frequency, and intensity of exposure; and routes of exposure.

EPA currently assumes that receiving a high dose of a carcinogen over a short time period is equivalent to receiving a low dose over a lifetime. This assumption is used to calculate a lifetime average daily exposure (LADE) that is incorporated into the risk characterization.

### Risk Characterization

The final step in the risk assessment process is the characterization of risk. In this step, numerical estimates of risk are presented along with a framework for evaluating those risks. The risk characterization section should summarize the hazard identification, exposure assessment, and the dose-effect assessment, and the public health risk estimates. Major assumptions, scientific judgments, and to the extent possible, uncertainties should be included.

**Noncarcinogen Risk Characterization:** The risk for noncarcinogens may be characterized by a margin of safety (MOS) approach that is estimated by dividing the reference dose (oral or inhalation) by the estimated daily human dose (U.S. EPA, 1988). The MOS quantifies the ratio between potential exposures and a presumed safe level; it is not an absolute statement of risk, but a surrogate for risk. The larger the MOS, the smaller the risk. The MOS that is needed to protect human health will vary depending on the agent, and its selection is similar to the process used to select the uncertainty factors for the reference dose calculation.

**Carcinogen Risk Characterization:** The numerical estimates for carcinogenic risks can be calculated in one of three ways. The unit cancer risk, under an assumption of low-dose linearity, is the excess lifetime risk due to a continuous constant lifetime exposure of one unit of carcinogen concentration. Typical exposure units include ppm or ppb in food or water, or ppm or  $\mu\text{g}/\text{m}^3$  in air. When the dose, expressed as  $\text{mg}/\text{kg}/\text{day}$  is used rather than the concentration, the term slope factor is used and represents the risk per unit dose. One can convert a slope factor to unit risk by multiplying the slope factor by the inhalation rate ( $20 \text{ m}^3/\text{day}$ ) and dividing by body weight ( $70 \text{ kg}$ ). The dose corresponding to a given level of risk can be used in some instances—for example, when using nonlinear extrapolation models where the unit risk would

differ at different dose levels. Finally, risks can be characterized either in terms of individual risks, population risks, or both.

Individual risks provide an estimate of the additional lifetime risk for individuals exposed to average and maximum levels of an agent. Individual risks can be obtained by multiplying the incremental unit risk (from the dose effect assessment) by the lifetime average daily exposure of that person (U.S. EPA, 1989).

Population risk estimates provide a measure of the possible total expected excess number of cancers in a population during a lifetime of exposure to a given agent. The population risk is derived by multiplying the individual risk by the total exposed population over some selected time period (U.S. EPA, 1989).

The usefulness of these estimates must be balanced with the likelihood that the agent is a human carcinogen. The likelihood is reflected by the letters A, B<sub>2</sub>, B<sub>1</sub>, C where "A" is the most certain risk and "C" is only a possible human carcinogen. The availability of a unit risk estimate does not modify the uncertainty associated with "B" or "C" designations nor are risks for A carcinogens necessarily more accurate than risks for "B" and "C" agents.

### **3.4. EPA CANCER RISK ASSESSMENTS FOR INDOOR AIR CONTAMINANTS**

EPA maintains an online data base, Integrated Risk Information System (IRIS), that is a primary source of EPA health hazard assessments and related information on chemicals of environmental concern. IRIS is intended for users with

some knowledge of health sciences, but extensive training in toxicology is not needed. IRIS is maintained by the Environmental Criteria and Assessment Office, U.S. EPA, Cincinnati, OH. This data base, which includes over 400 chemicals, can be accessed by groups outside of EPA through diskettes which are updated quarterly or through online sources which are updated monthly. The user fees are about \$130 per quarter for the diskettes, and the online service has a \$25 per month fee which is applied to a user fee of \$25 per hour plus an additional charge for each computer screen accessed.

The online data base includes the following information: oral reference dose assessments, inhalation reference dose assessments, carcinogenicity assessments (slope factors/unit risk factors), drinking water health advisories, EPA regulatory actions, and supplementary data.

Exhibit 3-3 provides a summary of cancer risk estimates for selected indoor air contaminants. All of the estimates, except radon, are unit risk estimates which provide an upper bound estimate of risk that may occur from continuous lifetime exposure per unit of air concentration of the contaminant (U.S. EPA, 1989). These numbers can be used to compare or prioritize hazards in a relative sense, and in some special circumstances may be useful for evaluating the highest likely cancer impact on an exposed population.

The risk estimate for radon includes an estimate of the annual population cancer risk resulting from exposure to radon indoors. Estimates of the annual population cancer risk resulting from exposure to other contaminants are not available at this time.

**Exhibit 3-3. EPA cancer risk assessments.<sup>1</sup>**

CONTAMINANT	UNIT RISK <sup>2,3</sup> (CLASSIFICATION)	ESTIMATED ANNUAL EXCESS CANCER CASES
Radon	$3.6 \times 10^{-4}/\text{WLM}^{(4)}(\text{A})$	20,000 <sup>(9)</sup>
VOCs		
Benzene	$8.3 \times 10^{-6}/\mu\text{g}/\text{m}^3 (\text{A})$	
Methylene chloride	$4.7 \times 10^{-7}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Chloroform	$2.3 \times 10^{-5}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Carbon tetrachloride	$1.5 \times 10^{-5}/\mu\text{g}/\text{m}^3 (\text{B2})$	
1,2-Dichloroethane	$2.6 \times 10^{-5}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Trichloroethylene	$1.7 \times 10^{-6}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Tetrachloroethylene	$5.8 \times 10^{-7}/\mu\text{g}/\text{m}^3 (\text{B2/C})$	
Formaldehyde	$1.3 \times 10^{-5}/\mu\text{g}/\text{m}^3 (\text{B1})$	
PAHs		
Benz(a)-anthracene	$8.9 \times 10^{-4}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Benzo(a)-pyrene (BaP)	$1.7 \times 10^{-3}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Dibenzo(a,h)-anthracene	$1.4 \times 10^{-2}/\mu\text{g}/\text{m}^3 (\text{B2})$	
3-Methylchol-anthrene	$2.7 \times 10^{-3}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Pesticides		
Aldrin	$4.9 \times 10^{-3}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Chlordane	$3.7 \times 10^{-4}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Dieldrin	$4.6 \times 10^{-3}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Heptachlor	$1.3 \times 10^{-3}/\mu\text{g}/\text{m}^3 (\text{B2})$	
Lindane	$3.8 \times 10^{-4}/\mu\text{g}/\text{m}^3 (\text{C})$	

**Exhibit 3-3. EPA cancer risk assessments<sup>1</sup>(continued).**

CONTAMINANT	UNIT RISK <sup>2,3</sup> (CLASSIFICATION)	ESTIMATED ANNUAL EXCESS CANCER CASES
Asbestos	1.6 x 10 <sup>-4</sup> to 2.3 x 10 <sup>-3</sup> / 0.01 fibers/ml <sup>(5,6,7)</sup> (A)	
	1.8 x 10 <sup>-3</sup> to 2.7 x 10 <sup>-3</sup> / 0.01 fibers/ml <sup>(7,8)</sup> (A)	

<sup>1</sup>SOURCE: U.S. EPA (1989a)

<sup>2</sup>Unit risk of the contaminant is an upper bound estimate of the lifetime risk of contracting cancer per unit exposure. Upper bound means that the true risk which can't be defined is not likely to be higher than the upper bound value and may be lower.

<sup>3</sup>The risk estimates for radon, asbestos, and benzene are based on epidemiological data. The risk estimates for the organic contaminants, except benzene, are based on animal bioassay data and represent the "upper-bound" estimate of the risk. The alpha designation i.e A, B<sub>2</sub>, B<sub>1</sub>, C, is the weight-of-evidence classification which indicates the certainty that the agent is a human carcinogen.

<sup>4</sup>U.S. Environmental Protection Agency (EPA). 1986. *Risk Assessment Methodology Environmental Impact Statement: NESHAPs for Radionuclides. Background Information Document. Vol. I.* U.S. EPA, Office of Radiation Programs: Washington, DC.

<sup>5</sup>Fibers as measured by phase contrast microscopy.

<sup>6</sup>Lung cancer in male and female smokers and nonsmokers.

<sup>7</sup>U.S. Environmental Protection Agency (EPA). 1985. *Airborne Asbestos Health Update.* EPA-600/8-84-003F. U.S. EPA Office of Health and Environmental Assessment: Research Triangle Park, NC.

<sup>8</sup>Mesothelioma in male and female smokers and nonsmokers.

<sup>9</sup>Future downward revision to approximately 16,000 annual excess cancer cases is likely.

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## SECTION 4.

### SOURCES AND HEALTH EFFECTS OF SELECTED CONTAMINANTS

Section 4 provides a discussion of the sources and health effects of combustion contaminants, pesticides, microbiological contaminants, formaldehyde, and other volatile organic compounds. Each of the sections contains exhibits which summarize health effects data. In addition, Section 4.2 also discusses the regulatory framework for pesticides.

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## 4.1. COMBUSTION CONTAMINANTS

There are many possible sources of combustion contaminants in residential and commercial buildings. These sources can release contaminants which can result in health effects ranging from headaches and respiratory tract irritation to death. This section provides an overview of health effects that have been related to contaminants from combustion sources.

### Sources of Combustion Contaminants

#### Residential Buildings

An important concern associated with the use of vented and unvented combustion sources is safety hazards including fires, burns from contact with hot metal surfaces, and poisonings from the accidental ingestion of fuel. Fires are also a concern with the use of tobacco products, hobby, and craft activities. A second concern is the release of indoor air contaminants from all fuel-burning unvented appliances and from vented appliances which are improperly installed, poorly maintained, or improperly operated. Safety hazards will not be discussed further in this section, but potential health effects from specific combustion contaminants are summarized below.

The primary fuel sources for vented and unvented household appliances include natural gas, fuel oil, wood, coal, kerosene, and LP gas. Charcoal, newsprint, and other potentially hazardous fuels should not be burned indoors.

Large combustion appliances such as gas, wood, or oil-fired central heating systems are used mainly in those areas where winter temperatures fall below 68°F. Smaller appliances such as gas water heaters, ranges, and clothes dryers are used all year. Under normal conditions the byproducts of these appliances are exhausted outside of the dwelling through a flue or chimney. Contaminants can be released indoors if there is a blockage in the flue or chimney or if the appliance is not vented properly.

When a combustible fuel burns, heat and light are given off along with a broad range of contaminants including asphyxiants, irritants, carcinogens, teratogens, and mutagens. Carbon monoxide, carbon dioxide, water vapor, and the nitrogen oxides are the primary contaminants from the combustion of natural gas. The combustion of kerosene adds sulfur dioxide and inhalable particulates, including polycyclic aromatic hydrocarbons to the inventory. Tobacco combustion and improperly vented wood and coal combustion sources increase the list of potential contaminants, and they can release aldehydes, a variety of polycyclic aromatic compounds, and other contaminants to the indoor air.

Tobacco smoke, combustion-related hobby and craft activities, and unvented kerosene and gas space heaters pose special problems because they release contaminants directly into the living space. Tobacco smoke is of particular concern because of the many carcinogenic, teratogenic, and mutagenic chemicals in the smoke.

Another potential problem is the release of moisture from the combustion of fuel by unvented sources. It is possible for water vapor from combustion to condense onto window frames and sills and to wet surfaces such as wood and insulation which are not directly visible. In addition to structural damage which can be caused by excessive moisture, these wetted materials can provide an excellent substrate for microbial growth which can produce a variety of effects in sensitive individuals (Section 4.4).

#### Commercial Buildings

In commercial buildings, important sources of combustion contaminants include tobacco smoking, garages which are attached to working spaces, and improperly located air intake vents. Air intake vents which are located at ground level or adjacent to vehicles or other combustion sources can significantly elevate indoor contaminant levels by transporting contaminants to all areas served by the air handling system.

## Health Effects of Combustion Contaminants

Symptoms of exposure to combustion contaminants can include headaches, decreased alertness, flu-like symptoms, nausea, fatigue, rapid breathing, chest pain, confusion, impaired judgment, and others. Concentrations at which these symptoms will occur depend on health status and individual variations in sensitivity, so that specific responses at a given concentration of a contaminant will vary among individuals.

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Each year there are unnecessary deaths due to carbon monoxide poisoning from faulty furnaces and other combustion sources. When an investigator receives a call and the client reports headaches, drowsiness, and nausea, especially during the heating season, the inspector should be aware of potential problems with furnaces or unvented combustion appliances.

### Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless, and tasteless gas which is produced from the incomplete combustion of any carbon-containing fuel. It is a chemical asphyxiant that prevents oxygen from reaching the body's tissues. Normally, oxygen is carried to the body's tissues by hemoglobin in the form of oxyhemoglobin (OHb). When CO is present, it also combines with hemoglobin to form carboxyhemoglobin (COHb). In fact, CO is about 200 times as effective as oxygen (O<sub>2</sub>) in combining with hemoglobin. This means that when both O<sub>2</sub> and CO are present, hemoglobin will not be available to carry O<sub>2</sub> to the tissues. Once inside the body, CO has a half-life of about 5 hrs.

The health effects of CO exposure are generally discussed in terms of the % COHb in the blood (Exhibit 4-1a,b). The level of COHb is directly related to the CO concentration in the air, the duration of the exposure, and the activity level of the individual. For a given CO dose, the COHb level will reach an equilibrium over some period of time. As the CO concentration increases or decreases from this point, the COHb level will follow.

Normally, metabolic processes in the body will result in a COHb level of 0.5% to 1.0%. Average COHb levels among nonsmokers are 1.2% - 1.5%. In cigarette smokers this level is about 3% - 4% on average, but it may be as high as 10% in heavy smokers (WHO, 1987).

Continuous exposure to 30 ppm CO leads to an equilibrium COHb level of 5%; about 80% of this value occurs in 4 hours and the remaining 20% over the next 8 hours. Continuous exposure to 20 ppm CO leads to COHb levels of 3.7% and exposure to 10 ppm leads to COHb levels of 2%. The time for equilibrium to be established is usually 8 hours, but this time can be shorter if a person is physically active (Doull *et al.*, 1980).

Carbon monoxide can have detrimental effects on the heart, lungs, and nervous system. At COHb levels of 10% or less, the major effects are cardiovascular and neurobehavioral. Levels of 2.5% have been shown to aggravate symptoms in angina pectoris patients. No adverse health effects have been reported below 2.0% COHb; and findings in the range of 2.0 to 2.9% are inconclusive (WHO, 1987). A level of 2.5% COHb can result from exposure to air with 50 ppm CO for 90 minutes or 15 ppm for 10 hours (Turiel, 1985).

### Nitrogen Oxides

There are many chemical species of the oxides of nitrogen (NO<sub>x</sub>), but nitrogen dioxide (NO<sub>2</sub>) and nitric oxide (NO) are of greatest concern as indoor air contaminants. Nitrogen oxides are produced when fossil fuels are burned, and most of the emissions occur as NO which can be converted to NO<sub>2</sub>.

*Nitric oxide* is a colorless, odorless, and tasteless gas that is only slightly soluble in water. The toxicological and health effects data base for NO is somewhat limited. There is some evidence of inflammatory changes at the cellular level at 2 ppm (U.S. EPA, 1982). The formation of methemoglobin (met-Hb), which interferes with the transport

of oxygen, has been attributed to the action of nitrite ion generated by either NO or NO<sub>2</sub> in solution. Background levels of met-Hb in the blood are in the range of 0.2 and 0.7% in the absence of high NO<sub>x</sub> levels. Case *et al.* (1979) provide evidence to show that met-Hb in whole blood can result from the direct uptake of NO by hemoglobin in the blood. Case *et al.* suggest that exposure to NO at 3 ppm may be physiologically comparable to exposure to CO concentrations of 10 ppm to 15 ppm.

**Nitrogen dioxide** is a corrosive and highly oxidizing gas with a characteristic pungent odor which has been described as stinging, suffocating, and irritating. The odor threshold has been placed between 0.11 ppm and 0.22 ppm by different investigators (WHO, 1987). NO<sub>2</sub> has a pungent odor that is described as stinging, suffocating, and irritating. The odor threshold has been placed between 0.11 ppm and 0.22 ppm by different investigators (WHO, 1987).

NO<sub>2</sub> is a deep lung irritant which has been shown to result in biochemical alterations and histologically demonstrable lung damage in laboratory animals as a result of both acute and chronic exposures. In laboratory animals, biochemical changes occur at concentrations as low as 0.2 ppm for 30 minutes (WHO, 1987). Long-term animal studies have resulted in emphysema-like structural changes and increased susceptibility to bacterial lung infections (WHO, 1987). Changes at the cellular level occur at the time of exposure, but biological effects are delayed, which complicates the understanding of long term effects.

In humans, 80% to 90% of NO<sub>2</sub> can be absorbed upon inhalation. Controlled clinical studies have been conducted on susceptible subjects at concentrations in the range of 0.1 ppm to 5.0 ppm. Most studies show that substantial changes in pulmonary function can be demonstrated in normal, healthy adults at or above concentrations of 2 ppm (WHO, 1987). The evidence at lower concentrations is not as clear. Asthmatics appear to be responsive at

about 0.5 ppm, and subjective complaints have been reported at that level (WHO, 1987). Below 0.5 ppm, small but statistically significant, decrements in pulmonary function have been reported in asthmatics (WHO, 1987). Kagawa and Tsuru (1979) reported decrements in the lung function of asthmatics at concentrations as low as 0.15 ppm, but others have not substantiated these findings. Exhibit 4-2 summarizes some of the human exposure studies that have been conducted.

Epidemiologic studies suggest that children who are exposed to combustion contaminants from gas stoves have higher rates of respiratory symptoms and illness than other children. Nitrogen dioxide concentrations in these studies ranged from a low of 0.005 ppm to about 0.3 ppm (U.S. EPA, 1982; WHO, 1987). In general, these results have not been supported in studies of adults. Exhibit 4-3 summarizes some of the studies which have been conducted.

### Carbon Dioxide

Carbon dioxide is a colorless, odorless gas. It is a simple asphyxiant, but it can also act as a respiratory stimulant. At concentrations above 1.5% respiration is affected, and breathing becomes faster and more difficult. Concentrations above 3% can cause headaches, dizziness, and nausea. Above concentrations of 6% - 8% stupor and death can result (NRC, 1981).

The lowest level at which effects have been observed in both human and animal studies is about 1% (U.S. CPSC, 1983). Structural changes in the lungs of guinea pigs have been observed along with calcification of the kidneys. In humans, effects include increases in respiration, changes in blood pH and pCO<sub>2</sub>, and decreases in the ability to perform strenuous exercise. The significance of these effects is not clear, but a potential increase in respiratory and gastrointestinal illness has been postulated because these effects were observed in submarine crews at concentrations of 0.5% - 1%

(NRC, 1981). Exhibit 4-4 summarizes the results of some studies which have been conducted.

### Sulfur Dioxide

Sulfur dioxide (SO<sub>2</sub>) is a colorless gas with a strong, pungent odor which can be detected at about 0.5 ppm (NRC, 1981). SO<sub>2</sub> is very soluble in water and exerts its irritant effects primarily on the upper respiratory tract, but its site of action depends on the presence of particulates, and the rate, depth, and type of breathing.

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There is considerable variability in the response to SO<sub>2</sub> among both normal, healthy subjects and asthmatics, and this makes it difficult to define a no-adverse-effect level. It has been estimated that about 5% of the population may be sensitive to SO<sub>2</sub> (WHO, 1987).

There is good agreement that healthy adults experience adverse effects at concentrations of 0.75 ppm to 1.0 ppm, and that asthmatics experience increased airway resistance at exposures of about 0.4 ppm for 10 minutes, both during exercise and at rest (WHO, 1987). Discernable effects have been reported below that level, but WHO concludes that the consequences of those effects are not clear.

Increased airway resistance has been reported at concentrations of 0.1 ppm among mild asthmatics who were exercising (Sheppard, 1981a). There is also some evidence that sulfur dioxide at levels of 0.15 ppm appears to act synergistically with ozone at levels of 0.15 ppm (Kagawa and Tsuru, 1979a). Exhibit 4-5 summarizes some of the human exposure studies which have been conducted on asthmatic subjects.

### Particulates

In addition to the compounds listed above, other gases and particulates can be released from indoor combustion sources. In homes where wood is burned, respirable particulates which include

polynuclear (or polycyclic) aromatic hydrocarbons (PAH) compounds, trace metals, nitrates, and sulfates have been measured. PAH compounds and chromium (Tu and Hinchliffe, 1983) have also been measured from kerosene heaters.

PAHs are of particular concern because of their carcinogenic potential. PAH compounds include a large number of organic compounds which contain two or more benzene rings in their structure. These compounds are produced as the result of incomplete combustion. They are only very slightly soluble in water, but they are very soluble in fat. Although fat soluble, these compounds are metabolized rapidly in the body and do not tend to bioaccumulate in the fatty tissues. It is thought that the metabolites of PAH compounds in the body (diol-epoxides) are ultimately the carcinogens (WHO, 1987).

Once PAH compounds enter the air, they can be adsorbed onto respirable-sized particles and inhaled into the lungs. PAH compounds are also present in foods (smoked, broiled, refined) and water; in fact, the oral intake of PAH compounds may be much higher than the inhaled amount in the general population (WHO, 1987).

PAH compounds have been shown to be carcinogenic in animal tests and mutagenic in short-term laboratory tests. Evidence for carcinogenicity is supported by epidemiological studies of coke-oven workers, coal-gas workers, and workers in aluminum production plants (WHO, 1987).

### Environmental Tobacco Smoke

Environmental tobacco smoke (ETS) is a term which describes the contaminants released into the air when tobacco products burn or when smokers exhale. The hazards of inhaling mainstream smoke (inhaled by the smoker) and sidestream smoke (produced at the burning end of the tobacco product) are well documented. The inhalation of ETS is known as "involuntary smoking" or "passive smoking."

Studies have shown that cigarette smoke contains over 3800 chemical compounds (NRC, 1981); some of these compounds are shown in Exhibit 4-6. Many of these gaseous and particulate contaminants are irritants, and others are carcinogens (43 identified compounds), mutagens, and teratogens. Particles in tobacco smoke are especially hazardous because they are inhalable (0.1  $\mu\text{m}$  to 1.0  $\mu\text{m}$ ), remain airborne for hours after smoking stops, and attract radon decay products. Exhibit 4-6 shows that concentrations of contaminants in sidestream smoke can be several times higher than those in mainstream smoke.

In 1986 two major reports reached similar conclusions about the hazards of passive smoking; these were *Environmental Tobacco Smoke. Measuring Exposures and Assessing Health Effects*, which was prepared by the National Academy of Sciences (NRC, 1986) for the Environmental Protection Agency and the Department of Health and Human Services, and *The Health Consequences of Involuntary Smoking*, which was prepared for the Office of the Surgeon General (U.S. DHHS, 1986).

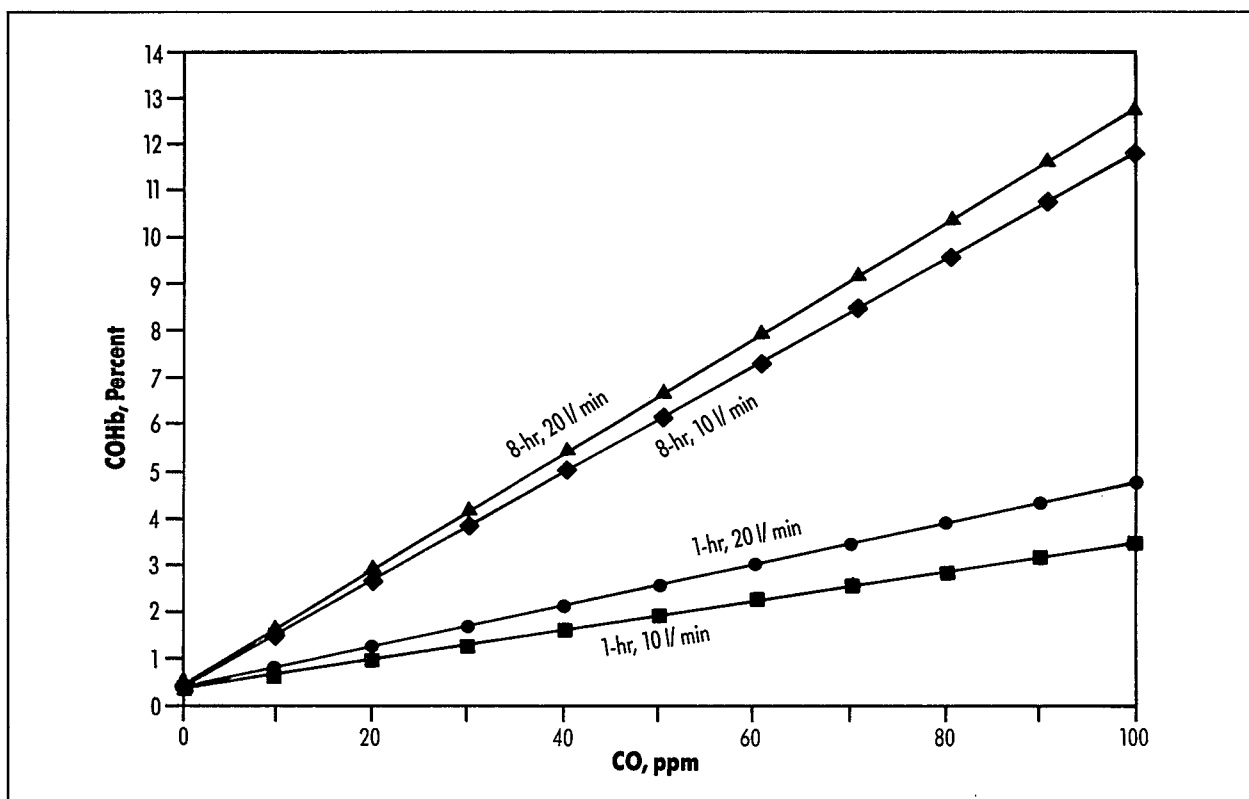
Both reports concluded that passive smoking significantly increases the risk of lung cancer in adults. The NAS Report (NRC, 1986) estimates that the risk of lung cancer is about 30% higher for nonsmoking spouses of smokers than for nonsmok-

ing spouses of nonsmokers, and that as many as 20% of lung cancers in nonsmokers may stem from exposure to tobacco smoke. The Surgeon General's Report (U.S. DHHS, 1986) concludes that simply separating nonsmokers from smokers in work environments is not sufficient to protect nonsmokers. Although the available studies did not specifically include workplace environments, tobacco smoke poses similar risks, regardless of the environment.

There was also agreement that passive smoking substantially increases respiratory illness in children. Children who live in households where there are smokers are more likely to have respiratory infections (including bronchitis and pneumonia) than children in nonsmoking households. Additional effects in children include increases in coughing, wheezing, sputum production, slower lung function growth, and low birthweight babies in mothers who are nonsmokers but are exposed to ETS. The prevalence of these effects has been found to increase with the number of smokers in the home.

The evidence for these effects was so strong that the National Research Council's Committee on Passive Smoking voted to recommend eliminating tobacco smoke from any area where there are small children or infants.

**Exhibit 4-1a. Relationship between carbon monoxide (CO) concentrations and carboxyhemoglobin (COHb) levels in blood.**



Predicted COHb levels resulting from 1- and 8-hr exposures to carbon monoxide at rest (10 l/min) and with light exercise (20 l/min) are based on the Coburn-Forster-Kane equation using the following assumed parameters for nonsmoking adults: altitude = 0 ft; initial COHb level = 0.5%; Haldane constant = 218; blood volume = 5.5 l; hemoglobin level = 15 g/100 ml; lung diffusivity = 30 ml/torr/min; endogenous rate = 0.007 ml/min.

**SOURCE:** Raub, J. A. and L. D. Grant. 1989. "Critical health issues associated with review of the scientific criteria for carbon monoxide." Presented at the 82nd Annual Meeting of the Air Waste Management Association. June 25-30. Anaheim, CA. Paper No. 89.54.1. Used with permission.

**Exhibit 4-1b. Carboxyhemoglobin levels and related health effects.**

% COHb IN BLOOD	EFFECTS ASSOCIATED WITH THIS COHb LEVEL
80	Death <sup>a</sup>
60	Loss of consciousness; death if exposure continues <sup>a</sup>
40	Confusion; collapse on exercise <sup>a</sup>
30	Headache; fatigue; impaired judgement <sup>a</sup>
7-20	Statistically significant decreased maximal oxygen consumption during strenuous exercise in healthy young men <sup>b</sup>
5-17	Statistically significant diminution of visual perception, manual dexterity, ability to learn, or performance in complex sensorimotor tasks (such as driving) <sup>b</sup>
5-5.5	Statistically significant decreased maximal oxygen consumption and exercise time during strenuous exercise in young healthy men <sup>b</sup>
Below 5	No statistically significant vigilance decrements after exposure to CO <sup>b</sup>
2.9-4.5	Statistically significant decreased exercise capacity (i.e., shortened duration of exercise before onset of pain) in patients with angina pectoris and increased duration of angina attacks <sup>b</sup>
2.3-4.3	Statistically significant decreased (about 3-7%) work time to exhaustion in exercising healthy men <sup>b</sup>

SOURCE: <sup>a</sup>U.S. EPA (1979); <sup>b</sup>U.S. EPA (1985)

# Exhibit 4-2. Controlled studies of the effects of human exposure to nitrogen dioxide.<sup>a</sup>

POLLUTANT CONCENTRATION		DURATION OF EXPOSURE AND ACTIVITY	NUMBER & TYPE OF SUBJECTS	PULMONARY EFFECTS	SYMPTOMS	REFERENCE
$\mu\text{g}/\text{m}^3$	ppm					
9400	5	14 hours	8, normal	Increase of <i>Raw</i> during the first 30 minutes of exposure, with decrease during the following 4 hours. Increase of <i>Raw</i> after 6.8 and 14 hours of exposure. Reactivity to acetylcholine increased.	Not described	Beil & Ulmer (1976)
9400	5	2 hours + intermittent light exercise	11, normal	Increase of <i>Raw</i> and decrease in <i>AaDO</i> <sub>2</sub> ; no further increase when combined with 200 $\mu\text{g O}_3$ per $\text{m}^3$ and 13.0 mg $\text{SO}_2$ per $\text{m}^3$	Not described	Von Nieding <i>et al.</i> (1977)
7520	4	75 minutes including light and heavy exercise	25, normal 23, asthmatic	No effect on <i>SRaw</i> , heart rate or skin conductance	Systolic blood pressure different. No Symptoms	Linn <i>et al.</i> (1985)
4700	2.5	2 hours	8, normal	Increase of <i>Raw</i> , no change in <i>PaO</i> <sub>2</sub> or <i>PaCO</i> <sub>2</sub>	Not described	Beil & Ulmer (1976)
1880	1	2 hours	16, normal	Small changes in <i>FVC</i>	5 subjects complained of chest tightness	Hackney <i>et al.</i> (1978)
1880	1	2 hours	8, normal	No increase in <i>Raw</i>	Not described	Beil & Ulmer (1976)
940-9400	0.5-5	3-60 minutes	63, chronic bronchitic	Increase of <i>Raw</i> at 3.0 $\text{mg}/\text{m}^3$	Not described	Von Nieding <i>et al.</i> (1971)
			25, chronic bronchitic	Decrease of <i>PaO</i> <sub>2</sub> at 7.5 $\text{mg}/\text{m}^3$ ; no change at 3.8 $\text{mg}/\text{m}^3$	Not described	Von Nieding <i>et al.</i> (1973)
940	0.5	2 hours	10, normal 7, chronic bronchitic 13, asthmatic	None	7 out of 13 asthmatic subjects suffered from symptoms such as chest tightness	Kerr <i>et al.</i> (1979)



# Exhibit 4-2. Controlled studies of the effects of human exposure to nitrogen dioxide<sup>a</sup> (continued).

POLLUTANT CONCENTRATION		DURATION OF EXPOSURE AND ACTIVITY	NUMBER & TYPE OF SUBJECTS	PULMONARY EFFECTS	SYMPTOMS	REFERENCE
µg/m <sup>3</sup>	ppm					
560	0.3	20 minutes at rest, followed by 10 minutes of moderate exercise (oral exposure, mouthpiece)	10, asthmatic	NO <sub>2</sub> plus exercise decrease in FEV <sub>1</sub> and partial expiratory flow rates at 60% TLC. After exposure at rest, no significant change in function	None	Bauer <i>et al.</i> (1984)
560	0.3	20 minutes at rest, followed by three 10 minute cycles of moderate exercise (chamber exposure)	13, asthmatic	11% decrease in FEV <sub>1</sub> ; statically significant		Roger <i>et al.</i> (1990)
560 2000	0.3 1.06	1 hour	8, normal	Small increase in mean SRaw at 560 µg/m <sup>3</sup> ; no change at 2000 µg/m <sup>3</sup>		Rehn <i>et al.</i> (1982)
380	0.2	2 hours intermittent light exercise	31, asthmatic	No effect on forced expiratory function or total respiratory resistance observed with NO <sub>2</sub> alone. Small exacerbation by NO <sub>2</sub> of metacholine-induced bronchoconstriction in 17 of 21 subjects tested	Fewer symptoms during NO <sub>2</sub> exposure compared to air	Kleinman <i>et al.</i> (1983)
280 290	0.15 NO <sub>2</sub> 0.15 O <sub>3</sub> 0.15 NO <sub>2</sub> + O <sub>3</sub>	2 hours intermittent light exercise	6, normal	Decrease in SGaw/Vig with O <sub>3</sub> for 5 of 6 subjects, and all 6 for combined O <sub>3</sub> + NO <sub>2</sub> ; very small (<5%) decrease in SGaw/Vig with NO <sub>2</sub> alone in 3 of 6 subjects	Cough with O <sub>3</sub> and O <sub>3</sub> + NO <sub>2</sub> , but not NO <sub>2</sub> alone	Kagawa & Tsuru (1979)
230 460 910	0.12 0.24 0.48	20 minutes at rest	8, normal 8, asthmatic	Normal: small increase in SRaw at 460 µg/m <sup>3</sup> ; decrease in SRaw at 910 µg/m <sup>3</sup> ; no change in reactivity to histamine. Asthmatic: no effects in SRaw; increase in reactivity to histamine at 910 µg/m <sup>3</sup>		Bylin <i>et al.</i> (1985)

(continued next page)

**Exhibit 4-2. Controlled studies of the effects of human exposure to nitrogen dioxide<sup>a</sup> (continued).**

POLLUTANT CONCENTRATION		DURATION OF EXPOSURE AND ACTIVITY	NUMBER & TYPE OF SUBJECTS	PULMONARY EFFECTS	SYMPTOMS	REFERENCE
$\mu\text{g}/\text{m}^3$	ppm					
190	0.1	1 hour at rest	20, asthmatic 20, normal	No effect on baseline $SGaw$ , $FEV_1$ or $V_{\text{low}}$ ; increased reactivity to carbachol in normal subjects and in asthmatics	None	Ahmed <i>et al.</i> (1982)
190	0.1	1 hour at rest	9, asthmatic, hypersensitive to ragweed	No effect on baseline $SGaw$ , $FEV_1$ and $V_{\text{low}}$ or reactivity to ragweed	None	Ahmed <i>et al.</i> (1983)
190	0.1	1 hour at rest	15, normal 15, asthmatic (atopics)	No change in $SRaw$ for either group; no change in sensitivity to methacholine	None	Hazucha <i>et al.</i> (1983)
190	0.1	1 hour at rest	7, asthmatic	No change in response to grass pollen after exposure to $\text{NO}_2$		Orehek <i>et al.</i> (1981)
190	0.1	1 hour at rest	20, asthmatic	No effect on $SRaw$ ; increased sensitivity to carbachol in some subjects		Orehek <i>et al.</i> (1976)

<sup>a</sup> Indication of change only described if statistically significant. Abbreviations are as follow:  $SRaw$ , specific airway resistance;  $Raw$ , airway resistance;  $SGaw$ , specific airway conductance, the reciprocal of  $SRaw$ ;  $FEV_1$ , forced expiratory volume at 1 second;  $TLC$ , total lung capacity;  $V_{\text{ig}}$ , total gas volume;  $V_{\text{low}}$ , flow volume;  $PaO_2$  and  $PaCO_2$ , arterial partial pressure of oxygen and carbon dioxide;  $AaDO_2$ , difference in partial pressure of oxygen in the alveoli as against the arterial blood;  $FVC$ , forced vital capacity.

SOURCE: *Air Quality Guidelines for Europe*. Copenhagen, WHO Regional Office for Europe, 1987 (WHO Regional Publications, European Series, No. 23). Used with permission.

### Exhibit 4-3. Effects of exposure to nitrogen dioxide plus other gas stove combustion products in the home on the incidence of acute respiratory disease in epidemiology studies involving gas stoves.

NO <sub>2</sub> CONCENTRATION µg/m <sup>3</sup> (ppm)	STUDY POPULATION	EFFECTS	REFERENCE
<i>Studies of Children</i>			
NO <sub>2</sub> concentration not measured at time of study	2554 children from homes using gas to cook compared to 3204 children from homes using electricity; ages 6-11	Bronchitis, day or night cough, morning cough, cold going to chest, wheeze, and asthma increased in children in homes with gas stoves	Melia <i>et al.</i> (1977)
NO <sub>2</sub> concentration not measured in same homes studied	4827 children, ages 5-10	Higher incidence of respiratory symptoms and disease associated with gas stoves after controlling for confounding factors	Melia <i>et al.</i> (1979)
Kitchens: 9-596 (gas) (0.005-0.317) 11-353 (electric) (0.006-0.188) Bedrooms: 7.5-318 (gas) (0.004-0.169) 6-70 (electric) (0.003-0.037) (by triethanolamine diffusion samplers)	808 6-and-7-year-olds	Higher incidence of respiratory illness in gas-stove homes. No apparent statistical relationship between lung function tests and exposure to NO <sub>2</sub> levels in kitchen or bedroom	Florey <i>et al.</i> (1979) Companion paper to Melia <i>et al.</i> (1979); Goldstein <i>et al.</i> (1979)
Sample of households 24 hr average: gas (0.005-0.11); electric (0-0.06); outdoors (0.015-0.05); monitoring location not reported; 24 hr averages by modified sodium arsenite; peaks by chemiluminescence	128 children, ages 0-5 346 children, ages 6-10 421 children, ages 11-15	No significant difference in reported respiratory illness between homes with gas and electric stoves in children from birth to 12 years	Mitchell <i>et al.</i> (1974); See also Keller <i>et al.</i> (1979 a,b)
Sample of same households as reported above but no new monitoring reporting	174 children under 12	No evidence that cooking mode is associated with the incidence of acute respiratory illness	Keller <i>et al.</i> (1979b)

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**Exhibit 4-3. Effects of exposure to nitrogen dioxide plus other gas stove combustion products in the home on the incidence of acute respiratory disease in epidemiology studies involving gas stoves (continued).**

NO <sub>2</sub> CONCENTRATION μg/m <sup>3</sup> (ppm)	STUDY POPULATION	EFFECTS	REFERENCE
95 percentile of 24 hr indoor average; 39-116 μg/m <sup>3</sup> (0.02-0.06) (gas) vs 17.6-95.2 μg/m <sup>3</sup> (0.01-0.05) (electric); frequent peaks (gas) > 1100 μg/m <sup>3</sup> (0.6 ppm); 24 hr by modified sodium arsenite; peaks by chemiluminescence	8120 children ages 6-10 in 6 different communities; data collected on lung function and on history of illness before the age of 2	Significant association between history of serious respiratory illness before age 2 and use of gas stoves. Small but statistically significant decrements in lung function tests between lower FVC <sub>1</sub> , FVC levels from gas stove homes compared with children from homes with electric stoves	Speizer <i>et al.</i> (1980) Spengler, <i>et al.</i> (1979)
<i>Studies of Adults</i>			
Preliminary measurements peak hourly 470-940 μg/m <sup>3</sup> ; max 1880 μg/m <sup>3</sup> (1ppm)	Adults cooking with gas stoves, compared to those cooking with electric stoves	No consistent statistically significant increases in respiratory illness associated with gas stove usage	U.S. EPA (1976)
See Mitchell <i>et al.</i> (1974) for monitoring	Adults cooking with gas stoves, compared to those cooking with electric stoves, 146 households	No evidence that cooking with gas is associated with an increase in respiratory disease	Keller <i>et al.</i> (1979a, b)
See Mitchell <i>et al.</i> (1974) for monitoring	Members of 441 households	No significant difference in reported respiratory illness among adults in gas vs electric cooking homes	Mitchell <i>et al.</i> (1974); See also Keller <i>et al.</i> (1979a, b)
See Mitchell <i>et al.</i> (1974) for monitoring	Members of 120 households (subsample of 441 households above)	No significant difference among adults in acute respiratory disease incidence in gas vs electric cooking homes	Keller <i>et al.</i> (1979a, b)

<sup>a</sup> Forced expiratory volume at 1 sec.

<sup>b</sup> Forced vital capacity

SOURCE: U.S. EPA (1982)

#### Exhibit 4-4. Selected studies of human exposure to carbon dioxide.

EXPOSURE CONCENTRATION AND DURATION	EXPOSURE METHOD	EFFECTS	REFERENCE
4%, 2 wks exposure bracketed by two 2-wk control periods	Chamber, 24 subjects	No psychomotor impairment; no decrement in complex task performance by healthy young subjects	Storm and Giannetta (1974)
4.2%, 5 days and 11 days; 3%, 30 days; exposures bracketed by two 3-5 day control periods	Chamber, 12 subjects total; 4 in each of 3 groups	Increased arterial and cerebrospinal fluid bicar- bonate; decreased pH; occasional mild headaches and awareness of increased ventilation during first 24-hrs of exposure; some ectopic foci noted during exercise but small sample size hampered interpretation; decreased tolerance to exercise noted	Sinclair <i>et al.</i> (1969)
3%, 5 days bracketed by two 5-day control periods	Space Cabin Simulator; 7 subjects	No changes in ammonia or titratable acidity; no changes in serum electrolytes, blood sugar, serum creatinine, or liver function; no significant changes in exercise or psychomotor studies	Glatte <i>et al.</i> (1967)
1.5%, 42 days 0.7-5%, 50-60 days	Chamber*; Submarines (13 Polaris patrols)	Increases in respiratory minute volume, tidal volume, physiological dead space; decrease in vital capacity; respiratory acidosis, increase in $pCO_2$ , decrease in pH; decrease of plasma chloride, red cell sodium increase, potassium decrease; decrease in plasma calcium metabolism, urine calcium, urine magnesium, increase in red cell calcium. In the submarine study a decrease in respiratory and gastrointestinal disease was noted with decreasing $CO_2$ (and other pollutants).	Schaefer (1979)
1% and 2%, 30 days	Chamber, 2 subjects in each of 2 exposures	At 2% significant increases in $pCO_2$ in blood and alveolar air, decrease in ability to perform strenuous exercise; decrease in blood pH, increase in pulmonary ventilation; changes at 1% were not considered to be significant; authors conclude that prolonged $CO_2$ exposure causes acidosis, hypodynamia, and fatigue but effects are reversible	Zharov <i>et al.</i> (1963)

\*Similar effects were noted in subjects in both the chamber exposure and submarine exposure.

SOURCE: Adapted from U.S. CPSC (1984)

**Exhibit 4-5. Selected studies of asthmatic subjects exposed to sulfur dioxide.**

SULFUR DIOXIDE CONCENTRATION <sup>a</sup> (ppm)	DURATION OF EXPOSURE (min)	NUMBER AND TYPE OF SUBJECT	TYPE OF EXPOSURE	TYPE OF ACTIVITY	EFFECTS <sup>b</sup>	REFERENCE
1, 3, 5	10	7, normal 7, atopic 7, asthmatic	Mouthpiece	Rest	<i>SRaw</i> increased significantly at all concentrations for asthmatic subjects, only at 5 ppm for normal and atopic subjects. Some asthmatics exhibited marked dyspnea requiring bronchodilation therapy	Sheppard <i>et al.</i> (1981a)
1.0 0.1, 0.25, 0.5	5 10	6, asthmatic 7, asthmatic	Mouthpiece	Exercise	<i>SRaw</i> significantly increased in the asthmatic group at 0.5 and 0.25 ppm of sulfur dioxide and at 0.1 ppm in the two most responsive subject. At 0.5 ppm three asthmatic subjects developed wheezing and shortness of breath	Sheppard <i>et al.</i> (1980, 1981b)
0.50	180	40, asthmatic	Oral chamber Nose clips	Rest	<i>MMFR</i> significantly decreased 2.7%; recovery within 30 minutes	Jaeger <i>et al.</i> (1979)
0.5	10	5, asthmatic	Mouthpiece	Exercise	<i>SRaw</i> increases were observed over exercise baseline rates for 80% of the subjects.	Linn <i>et al.</i> (1982)
0.25, 0.5	60	24, asthmatic	Chamber	Exercise	No statistically significant changes in <i>FVC</i> or <i>SRaw</i>	Linn <i>et al.</i> (1982)
0.30	120	19, asthmatic	Chamber	Exercise	No pulmonary effects seen with 0.3 ppm of sulfur dioxide and 0.5 ppm of nitrogen dioxide exposure compared to exercise baseline	Linn <i>et al.</i> (1980)

<sup>a</sup>0.1 ppm of sulfur dioxide  $\approx$  262  $\mu\text{g}/\text{m}^3$ ; 0.05 ppm  $\approx$  1310  $\mu\text{g}/\text{m}^3$ ; 1.0 ppm  $\approx$  2620  $\mu\text{g}/\text{m}^3$ ; 5.0 ppm  $\approx$  13,100  $\mu\text{g}/\text{m}^3$ ; 10 ppm  $\approx$  26,200  $\mu\text{g}/\text{m}^3$ ; 50 ppm  $\approx$  131,000  $\mu\text{g}/\text{m}^3$ .

<sup>b</sup>Significant increase or decrease noted here refers to "statistically significant" effects, independent of whether the observed effects are "medically significant" or not. Abbreviations are as follows: *SRaw*, specific air way resistance; *MMFR*, maximum mid-expiratory flow rate; *FVC*, forced vital capacity.

SOURCE: World Health Organization (WHO) 1987. *Air Quality Guidelines for Europe*. Copenhagen, WHO Regional Office for Europe, 1987 (WHO Regional Publications, European Series, No. 23). Used with permission.

**Exhibit 4-6. Composition of mainstream and sidestream smoke.**

CHARACTERISTIC OR COMPOUND	CONCENTRATION, mg/CIGARETTE <sup>a</sup>		
	MAINSTREAM SMOKE (1)	SIDESTREAM SMOKE (2)	RATIO, 2:1
<b>General characteristics:</b>			
Duration of smoke production, s	20	550	27.5
Tobacco burned	347	411	1.2
Particles, no. per cigarette	$1.05 \times 10^{12}$	$3.5 \times 10^{12}$	3.3
<b>Particles:</b>			
Tar (chloroform extract)	20.8	44.1	2.1
	10.2 <sup>b</sup>	34.5 <sup>b</sup>	3.4
Nicotine	0.92	1.69	1.8
	0.46 <sup>b</sup>	1.27 <sup>b</sup>	2.8
Benzo [a] pyrene	$3.5 \times 10^{-5}$	$1.35 \times 10^{-4}$	3.9
	$4.4 \times 10^{-5}$	$1.99 \times 10^{-4}$	4.5
Pyrene	$1.3 \times 10^{-4}$	$3.9 \times 10^{-4}$	3.0
	$2.70 \times 10^{-4}$	$1.011 \times 10^{-3}$	3.7
Fluoranthene	$2.72 \times 10^{-4}$	$1.255 \times 10^{-3}$	4.6
Benzo [a] fluorene	$1.84 \times 10^{-4}$	$7.51 \times 10^{-4}$	4.1
Benzo [b/c] fluorene	$6.9 \times 10^{-5}$	$2.51 \times 10^{-4}$	3.6
Chrysene, benz [a] anthracene	$1.91 \times 10^{-4}$	$1.224 \times 10^{-3}$	6.4
Benzo [b/k/j] fluoranthrene	$4.9 \times 10^{-5}$	$2.60 \times 10^{-4}$	5.3
Benzo [e] pyrene	$2.5 \times 10^{-5}$	$1.35 \times 10^{-4}$	5.4
Perylene	$9.0 \times 10^{-6}$	$3.9 \times 10^{-5}$	4.3
Dibenz [a, j] anthracene	$1.1 \times 10^{-5}$	$4.1 \times 10^{-5}$	3.7
Dibenz [a, h] anthracene, ideno-(2, 3-ed) pyrene	$3.1 \times 10^{-5}$	$1.04 \times 10^{-4}$	3.4
Benzo [ghi] perylene	$3.9 \times 10^{-5}$	$9.8 \times 10^{-5}$	2.5
Anthanthrene	$2.2 \times 10^{-5}$	$3.9 \times 10^{-5}$	1.8
Phenols (total)	0.228	0.603	2.6
Cadmium	$1.25 \times 10^{-4}$	$4.5 \times 10^{-4}$	3.6
<b>Gases and vapors:</b>			
Water	7.5 <sup>c</sup>	298 <sup>d</sup>	39.7
Carbon monoxide	18.3	86.3	4.7
	—	72.6	—
Ammonia	0.16	7.4	46.3
Carbon dioxide	63.5	79.5	1.3
NO	0.014	0.051	3.6
Hydrogen cyanide	0.24	0.16	0.67
Acrolein	0.084	—	—
	—	0.825	—
Formaldehyde	—	1.44	—
Toluene	0.108	0.60	5.6
Acetone	0.578	1.45	2.5
Polonium-210, pCi	0.04-0.10	0.10-0.16	1-4

<sup>a</sup> Unless otherwise noted<sup>b</sup> Filtered cigarettes<sup>c</sup> 3.5 mg in particulate phase; rest in vapor phase<sup>d</sup> 5.5 mg in particulate phase; rest in vapor phase

SOURCE: NRC (1981)

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## 4.2. PESTICIDES

Pesticides are chemicals which are used to kill or control pests. A pest is any organism that is not wanted in a particular location (for example, in the home or garden). Termites, cockroaches, fleas, rodents, ants, moths, caterpillars, dandelions and other weeds, fungi, bacteria, and molds in buildings are examples of pests. Pesticides can be categorized into insecticides, herbicides, fungicides, rodenticides, disinfectants or antimicrobial agents, and plant growth regulators.

Because most pesticides are inherently toxic, proper use and storage are needed to minimize the potential adverse effects from exposure. Unfortunately, consumers tend to be casual about pesticides, perhaps assuming they are innocuous since they can be purchased in grocery stores, drug stores, and hardware stores, and because these products can be used without a license or special protective clothing. As a result, each year there are cases of poisonings by these products which could have been prevented through proper use of the products or through the application of alternative methods of pest control.

The use of pesticides is widespread. In 1985 agricultural uses in the U.S. accounted for 77% of the total usage (over 1 billion pounds), and farmers spent about \$4.6 billion on pesticides (U.S. EPA, 1987). Nonagricultural uses of pesticides are also significant. During 1984, almost 230 million pounds of herbicides, insecticides, fungicides, and rodenticides were used for nonagricultural purposes (U.S. GAO, 1986). Of this total, about 28.7% was used in homes and gardens, and the remainder was used by industry, government, and commerce.

According to 1988 estimates, lawn care pesticides in the U.S. account for about 67 million pounds of active ingredients (about 8% of the total active ingredients applied for agricultural purposes), and sales have increased to over \$700 million annually (U.S. GAO, 1990). It is estimated that about 11% of single family households use commercial applicators for lawn care. Diazinon and 2,4-D have been determined to be the most widely used lawn care

pesticides; about 6 million pounds of diazinon and 4 million pounds of 2,4-D are used on residential lawns each year (U.S. GAO, 1990).

Exhibit 4-7 summarizes some general statements of the health effects, products, and uses of 50 active ingredients in pesticides used in and around residences. The actual risks of any of these pesticides will depend on a variety of factors including the application method, protective measures, and ventilation.

### Measured Concentrations in Homes

A nationwide survey conducted by EPA during 1976 and 1977 of household pesticide use found that about 91% of households use pesticides (U.S. EPA, 1987). In the home, pesticides are used to kill pests on lawns, trees, shrubs, flowers, and vegetables. Pesticides are almost universally used to control termite infestations either before or after construction. Pesticides are applied to living spaces to rid them of unwanted pests. And, people use these products on themselves or their pets to prevent the bites of mosquitos, chiggers, flies, ticks, fleas, and other pests.

In 1985, EPA extended its earlier work by developing a methodology for determining pesticide exposures in the general population of the U.S. (U.S. EPA, 1990). The methodology used in this study, which is known as the Non-occupational Pesticides Exposure Study (NOPES), was designed as a means of developing estimates of exposure to some of the most commonly used household insecticides via air, drinking water, food, and dermal contact. In the two cities which were studied (Jacksonville, Florida and Springfield/Chicopee, Massachusetts), the average number of pesticides in the home was 4.2 for Jacksonville and 5.3 in Springfield/Chicopee.

Exhibit 4-8 summarizes some of the data (indoor concentrations only) from the study. For the majority of the 33 target compounds which were studied, indoor air concentrations were substantially higher than outdoor air concentrations, and personal

air concentrations were usually similar to indoor air concentrations. Another finding of this study was that seasonal variations existed for many of the compounds. This effect appears to be compound specific and complex, and it probably reflects the interaction of many variables including temperature, patterns of pesticide usage, use of heating and cooling systems, and occupant activities.

The study also attempted to assess the relative contributions of air, food, water, and dermal exposure in the two tested cities. Based on limited data it appears that exposure from water ingestion was negligible. Food appeared to be a dominant contributor for some compounds, while air dominated for others. Limited data were collected for dermal exposures, and the importance of this pathway needs further study.

Exhibit 4-9 summarizes some additional measurements of pesticides in buildings under different conditions. These and other data suggest some pesticides which are sprayed will persist for long periods at varying concentrations. It is also possible for these chemicals, particularly termiticides, to migrate up and down through cracks and crevices in the building and by air currents.

### Hazards

Most pesticides are inherently toxic, and the potential hazards posed by these chemicals are magnified by improper use and storage. During the 1976 and 1977 nationwide survey, EPA found that less than 50% of the people who participated in the survey read pesticide labels for application procedures. About 85% of the people used pesticide products without reservation, and only 9% used these products with caution (as cited in U.S. EPA, 1987).

In addition to direct exposures as a result of improper use, secondary exposure can also occur when people are unknowingly exposed as a result of some other activity. For example, pesticides sprayed onto fields can drift into homes, schools, or other build-

ings. Or, if an office area, public building, or home is entered before an applied pesticide has cleared, people and animals can be exposed to potentially hazardous levels.

Pesticide formulations that have resulted in higher concentrations indoors include bug bombs or home foggers which are packaged in pressurized containers. These formulations contain pesticides such as DDVP (2,2-dichlorovinyl dimethyl phosphate) which have a relatively high volatility (vapor pressure of  $1.2 \times 10^{-3}$  mm Hg). If homes are reentered too soon after application, acute health problems can occur because initial concentrations are high (in the range of  $\text{mg}/\text{m}^3$ ).

A widely used product of concern is the pest strip. These products contain DDVP as the main ingredient. DDVP, which is an organophosphate pesticide, may also be listed in the product literature as dichlorvos or *Vapona*. DDVP is a concern because it is classified as a possible human carcinogen, and it also causes liver and nerve damage in animals. Pesticides from these strips vaporize into the surrounding air, and prolonged exposure is likely to increase health risks.

Another concern is the use of pest repellents which are applied to the skin and clothing as sprays, lotions, or sticks. Many of these products contain DEET (diethyltoluamide) which may also be listed in the product description as detamide, metaldehyde, MGK, or OFF. Regardless of the formulation, DEET is rapidly absorbed by the skin and into the blood system. There have been reports of acute neurotoxicity in children exposed to DEET-containing products, both through heavy normal use and accidental ingestion (CU, 1987). Headaches, skin irritation, contact dermatitis, and behavioral disorders can also result from exposure to DEET (Morgan, 1989). Because of these potential effects, the use of DEET, especially in children should be minimized.

The application of pesticides to control subterranean termites is also of concern. Prior to 1987, it was

thought that when cyclodiene termiticides such as chlordane were applied correctly for subterranean termite control, the residents of treated homes would not be exposed to the pesticide. However, studies in 1987 demonstrated that pesticides used for subterranean termite control can be found at low levels in the air of properly treated homes. As a result, EPA has taken a series of actions which have led to the withdrawal of cyclodiene termiticides from the market.

### Pesticide Formulations

Pesticides are packaged in a variety of forms including baits, dusts, "bombs," slow-release insecticide strips, flea collars, mothballs, dry powders, aerosols sprays, solutions, and wettable powders which readily mix with water.

Pesticide products contain both active and inert ingredients. Active ingredients are biologically active (the pest killer). Inert ingredients are added to the formulation to affect its characteristics in some way. The term "inert" is misleading because it is a legal term, not a chemical term. It does not mean that the compound cannot adversely affect humans or animals.

Typically, a pesticide formulation is mostly inert ingredients. There are about 1200 inert ingredients which can be used to dissolve the pesticide, provide a surface on which solids can adsorb, stabilize the product, improve handling and application, or intensify the killing power of the pesticide.

Many insecticides are lipophilic (soluble in fat). Insecticides are commonly dissolved in petroleum distillates which are mixtures of low molecular weight aliphatic and aromatic hydrocarbons. Toluene or xylene are added to some formulations to stabilize the insecticide or make it more emulsifiable. Alcohols, glycols, ethers, or chlorinated solvents are used as carriers (also called vehicles) for insecticides which are not strongly lipophilic. These carriers also make the insecticide more likely to be absorbed through the skin.

### Classification of Inert Ingredients

Inert ingredients may be more toxic than some active ingredients. However, inert ingredients are considered to be proprietary, and generally are not required to be identified by the product label. An exception are inert ingredients which EPA classifies as being of "immediate toxicological concern" (a list of chemicals including carbon tetrachloride, formaldehyde, methylene chloride, and others). Pesticides with these chemicals must either be reformulated or have a label which states: "This product contains the toxic inert ingredient ...."

In 1985, EPA established a classification system to allow inert ingredients to be regulated according to

the risks these chemicals pose. List 1 are those inert ingredients of immediate toxicological concern; 28 of these chemicals are suspected carcinogens. List 2 includes those which are classified as potentially toxic (62 chemicals). List 3 contains those inert ingredients for which there is insufficient data for classification (over 800 chemicals), and list 4 includes inert ingredients which pose a minimal risk (273 chemicals).

Most of the inert ingredients have not been tested for long term effects. Unfortunately, there is insufficient information to classify the toxicity of about  $\frac{2}{3}$  of the inert ingredients, and it is also possible for a chemical that has been banned as an active ingredient in pesticides to be used as an inert ingredient.

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### Exhibit 4-7. Summary of health effects, products, and uses of 50 active ingredients in household pesticides.

PESTICIDE COMMON NAME  
(SOME, NOT ALL,  
CONSUMER PRODUCTS)

USES

COMMENTS

#### INSECTICIDES

##### Organophosphates

Acephate (Ortho Orthene Systemic Insect Control; Ortho Isotox Insect Killer)	lawns, turf, ornamentals,	cholinesterase inhibitor; possible human carcinogen
Chlorpyrifos (Ortho Flea-B-Gon; d-Con Home Pest Control Killer Johnston's No-Roach, Raid Home Insect Killer—professional strength)	lawns, ornamentals, termites, ants & roaches, ticks and chiggers control	cholinesterase inhibitor; substitute for chlordane; applied in granular form outdoors, as aerosols and emulsifiable concentrates indoors; dietary exposure exceeds guidelines due to widespread use
Diazinon (Spectracide products, Johnston's No-Roach, Real-Kill Ant & Roach)	lawns; turf; ornamentals; indoors in no-pest strips, flea collars	cholinesterase inhibitor; one of the most widely used chemicals in consumer pesticides; applied as aerosols and in granular form
Dichlorvos (DDVP) (Black Flag Ant & Roach Killer; Raid Wasp & Hornet Killer; Bag-A-Bug Gypsy Moth Lure; No-Pest Strips)	indoors and garden	cholinesterase inhibitor; possible human carcinogen; protective clothing must be worn during use; primarily used in "no-pest strips" by consumers to kill flying insects
Disulfoton (Ortho Systemic Rose & Flower Care; Ross Systemic Insecticide Root Feeder Cartridges; Jobe's Insecticide Spikes; Bonide Systemic Granules)	fruits & vegetables, potted house plants, ornamentals	cholinesterase inhibitor; > 2% formulations require certified applicator

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### Exhibit 4-7. Summary of health effects, products, and uses of 50 active ingredients in household pesticides (continued).

PESTICIDE COMMON NAME (SOME, NOT ALL, CONSUMER PRODUCTS)	USES	COMMENTS
<b>INSECTICIDES (continued)</b>		
<b>Malathion</b> (Bonide Rose Spray; Ortho Orchard Spray; Johnston's No-Roach Spray; Gro-Well Fruit Tree Spray; Sergeant's Flea & Tick Dip for Dogs)	ornamental trees & shrubs, orchards, pet products, household insecticides	low toxicity cholinesterase inhibitor; cancer studies are not adequate and will be redone; widely used in home products; one of GAO's top 10 home chemicals; also used in mosquito control programs; banned by Florida in 1986 for community mosquito control
<b>Naled</b> (Bansect Flea & Tick Collars; Sergeant's Flea & Tick Collars)	pet flea collars, mosquito control, orchards & vegetables	metabolizes to dichlorvos
<b>Pyrethroids</b>		
<b>Allethrin</b> (d-Con Home Pest Control; Gro-Well Ant and Roach Spray; Sergeant's Indoor Fogger; Sergeant's Skip-Flea Shampoo; Raid Yard-Guard Outdoor Fogger)	house & garden insecticides, pet products	synthetic pyrethrin of low toxicity; widely used by consumers and professionals to control household pests; also used by professionals as a termiticide
<b>Permethrin</b> (Black Flag Roach Ender; Raid Fumigator Cake; Sudbury Flea & Tick Dip)	same as above	synthetic pyrethrin; possible human carcinogen
<b>Phenothrin</b> (Ortho Home & Garden Insect Killer; Combat Flying Insect Fogger; d-Con Flea & Tick Killer II; Raid Yard Guard Outdoor Fogger III)	same as above	synthetic pyrethrin
<b>Resmethrin</b> (d-Con Wasp & Hornet Killer; Raid Yard Guard Outdoor Fogger, Formula II; Rid-A-Bug Flea & Tick Killer; Ortho Flea-B-Gon Flea Killer)	same as above	synthetic pyrethrin
<b>Tetramethrin</b> (Combat Flying Insect Killer; Raid Flying Insect Killer; Ortho Home & Garden Insect Killer; Raid House & Garden, Formula II)	same as above	synthetic pyrethrin; possible human carcinogen
<b>Rotenone</b>		
(Ortho Rotenone Dust; Ortho Tomato & Vegetable Insect Spray; Gro-Well Organic Insecticide; Sergeant's Ear Mite Preparation for Cats)	fruit & vegetable gardens, pet products, human lice & chigger dusts, fish poison	human exposure has not been measured; widely used; viewed as comparatively safe, but not fully tested; natural botanical derivative

# **Exhibit 4-7. Summary of health effects, products, and uses of 50 active ingredients in household pesticides (continued).**

PESTICIDE COMMON NAME (SOME, NOT ALL, CONSUMER PRODUCTS)	USES	COMMENTS
<b>INSECTICIDES (continued)</b>		
<i>Pyrethrins</i>		
(Raid Flying Insect Killer; Black Flag Triple Action; Raid House & Garden; Hot Shot Fly & Mosquito; Hartz 2 in 1 Flea & Tick Dip for Dogs/Cats; A-200 Pyrinat Anti-Lice Shampoo)	house & garden products, pet products, anti-lice shampoos	viewed as comparatively safe, but not fully tested; natural botanical derivative
<i>Carbamates</i>		
Bendiocarb (TAT Ant Traps; Raid Traps)	ant, roach, and flea control indoors; ornamentals; insecticide-impregnated shelfpaper; turf	cholinesterase inhibitor; widely used by professionals for control of indoor pests; applied as a dust or wettable powder; consumer exposure occurs almost entirely from home uses; EPA recommends application of ready-to-use products by professional only
Carbaryl (Spectracide Sevin Liquid, Ortho Sevin Garden Dust, Sergeant's Flea and Tick Powder for Dogs, Bonide Rose Spray)	fruit & vegetable gardens; turf; pet products—flea collars and dusts; ornamentals; indoor use	low toxicity cholinesterase inhibitor; commonly used insecticide for control of pests indoors and outdoors; applied to leaf surfaces as wettable powder and dust; should not be used on pregnant dogs because it may cause birth defects in dogs
Propoxur (Black Flag Ant & Roach Killer; Combat Ant & Roach Instant Killer; Ortho Hornet & Wasp Killer; Sergeant's Flea & Tick Spray; Daltek Flea & Tick Collars)	indoor use; ant & roach killers; pet products; mosquito foggers	probable human carcinogen; cholinesterase inhibitor; toxic residue for weeks after application; infants crawling on treated surfaces may be exposed dermally; widely used
Chlordane	termite control	probable human carcinogen; cancelled in 1988; product may still be stored because shelf supplies were allowed to be depleted; most widely used termiticide before withdrawal; applied as a liquid poured or injected into the soil around the building foundation
Dicofol (Bonide Rose Spray; Ortho Isotox Insect Killer; Pratt Nocate Insect Spray)	vegetable gardens, indoor insect & mite control	possible human carcinogen; home use is not large; DDT & related compounds may be present as contaminants
Lindane (HCH, BHC) (Kwell shampoo; Roxo Borerkill; Gro-Well Borer Killer; Ortho Lindane Borer and Leaf Miner Spray)	house & garden use; shelf paper; anti-lice shampoos; pet products; termite control	possible/probable human carcinogen; use against termites (house) is restricted to unoccupied buildings; exposure from Kwell shampoo can be high if used too often or left on skin too long
Methoxychlor (Black Flag Insect Spray; Ortho Tomato & Vegetable Dust; Sergeant's Cat Flea Powder; Gro-Well Fruit Tree Spray)	house & garden use; pet products	many toxicology data gaps; formula used to control pantry pests; primarily applied as a liquid spray, widely used for mosquito and fly control outdoors

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### Exhibit 4-7. Summary of health effects, products, and uses of 50 active ingredients in household pesticides (continued).

PESTICIDE COMMON NAME (SOME, NOT ALL, CONSUMER PRODUCTS)	USES	COMMENTS
<b>INSECTICIDES (continued)</b>		
<i>Metboprene</i>		
(Dexol Red Spider & Mite Killer; Dexol White Fly & Mealy Bug Spray; Spectracide Professional Flea Control; Raid Flea Killer <i>Plus</i> )	cockroach, mosquito, and flea control; control of mealy bugs & spider mites on house plants	considered to be quite safe; chronic data gaps
<i>Synergists</i>		
MGK 264 (Black Jack Ant & Roach Killer; d-Con Flea & Tick Killer; Hartz 2 in 1 Flea & Tick Dip for Dogs/Cats; Ortho High Power Indo Fogger; Raid Fogger)	house use; pet products	inhalation & contact exposure could be significant; widely used
Piperonyl butoxide (Raid House & Garden, Formula II; Ortho Tomato & Vegetable Insect Spray; Hartz 2 in 1 Rid Flea Shampoo for Dogs)	house & garden use; pet products	widely used; direct inhalation is an important exposure route
<b>FUNGICIDES</b>		
Benomyl (DuPont Tersan 1991; Gro- Well Benomyl Systemic Fungicide)	vegetables & ornamentals; lawn & turf	possible human carcinogen; accounts for 55% of fungi- cides worldwide; many fungi are resistant to it
Captan (Ortho Tomato & Vegetable Dust; Ortho Orthocide Garden Fungicide; Bonide Rose Spray; Gro-Well Fruit Tree Spray)	fruit, vegetables, ornamentals; turf; house plants; paints; materials; (pets, human anti-fungal shampoos; cosmetics)*	probable human carcinogen; EPA estimates shampoos may pose cancer risk of 1 in 10,000; registration cancelled for many commercial food crops but home pesticide use is permitted; widely used by consumers and professionals; usually applied as a wettable powder
Chlorothalonil (Ortho Liquid Lawn Disease Control; Ortho Multi-Purpose Fungicide; Ortho Vegetable Disease Control)	ornamentals, turf, lawns; fruits, vegetables; paint & grout additive; wood preservative	probable human carcinogen; insufficient data on home use
Folpet (Ortho Phaltan Rose & Garden Fungicide)	paints; plastics	probable human carcinogen; cancelled on ornamentals and in wood preservatives; >20% formulations cannot be sold to consumers; protective clothing required
Maneb (Dexol Maneb Garden Fungicide; Security Maneb Spray)	ornamentals & vegetable gardens	ethylthiourea, a metabolite, is a probable human carcinogen, teratogen, antithyroid agent, and possibly, a mutagen



### Exhibit 4-7. Summary of health effects, products, and uses of 50 active ingredients in household pesticides (continued).

PESTICIDE COMMON NAME (SOME, NOT ALL, CONSUMER PRODUCTS)	USES	COMMENTS
<b>FUNGICIDES (continued)</b>		
Sulfur and Lime Sulfur (Pic Sulfur Candle, fumigant; Ortho Orthorix Spray Fungicide; Safer Garden Fungicide and Miticide)	bedbug control, fumigants; insect & mildew control on ornamentals and food plants	low toxicity, but may cause irritation
TBTO (Cuprinol Stain & Wood Preservative; Cabot's Wood-Preserving Stain)	anti-fouling agent in marine paints; wood preservatives	limited data; skin absorption may be significant
Triforine (Ortho Funginex Rose Disease Control; Ortho Orthenex Insect & Disease Control)	ornamentals & vegetables	complete data base
Zineb (Security Zineb Spray)	ornamentals, fruits, vegetables	limited data
<b>OTHER INGREDIENTS</b>		
Deet (Off; Muskol Spray; Cutter Stick and Cutter Cream; Blockade flea products) toxicology	insect repellent; pet flea repellent	rapid skin penetration & blood absorption; acute neurotoxicity possible in children; widely used, but long-term toxicity is not known; additional data being generated
Metaldehyde (Snarol Snail & Slug Killer Pellets; Ortho Bug-Geta & Bug-Geta Plus; Deadline Slug & Snail Bait)	slug & snail baits	inhalation & skin absorption not a concern
Methiocarb (Ortho Slug-Geta)		complete data base
<b>HERBICIDES</b>		
Ammonium Sulfamate (Ortho Brush Killer A; Science Ammate Weed & Brush Killer)	brush control	many data gaps
Benefin (Greenview Crabicide; Rockland Balan Crabgrass Preventer)	crabgrass control	widespread use in lawn care; limited data; new data being generated
2,4-D (Ortho Weed-B-Gon; Scott's Spot Dandelion Control; hundreds of others)	weed killer; lawns & gardens	commonly used lawn herbicide for the control of broadleaf weeds and dandelions; primary application is in granular lawn fertilizers; professionals commonly apply as a spray; cancer and epidemiology studies are being developed and reviewed
DCPA (Gro-Well Garden Weeder; Ortho Garden Weed Preventer; Gro-Well Pre-Vent Weed Control)	lawn & garden crabgrass & weed control	widespread use in lawn care; considered to be low in toxicity; some data gaps

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### Exhibit 4-7. Summary of health effects, products, and uses of 50 active ingredients in household pesticides (*continued*).

PESTICIDE COMMON NAME  
(SOME, NOT ALL,  
CONSUMER PRODUCTS)

USES

COMMENTS

#### HERBICIDES (*continued*)

Dicamba (Spectracide Lawn Weed Killer; Scott's Spot Dandelion Control)	lawns & turf	lack cancer study in second species; relatively low toxicity
Fluazifop (Fluazifop-butyl) (Ortho Grass-B-Gon-Grass Killer)	grass control along walks & in gardens	minimal data gaps
Glyphosate (Ortho Kleenup Spot Weed & Grass Killer; Roundup L & G Lawn & Garden Formulation; Ortho Fence & Grass Edger II)	lawn & garden weed control	dermal & eye exposure a concern during application & mixing; protective clothing required for agricultural uses but not home use; home-use data is limited
Mecoprop (MCP) (Ortho Weed-B-Gon; Spectracide Lawn Weed Killer; Gro-Well Dandelion & Broadleaf Weed Killer; Dexol Spot Weeder)	broadleaf control in lawns	widely used; many data gaps
Methanearsonates (Gro-Well Crabgrass Killer; Ortho Crabgrass & Dandelion Killer; Ortho Crabgrass Killer, Formula II)	lawn & turf, crabgrass control	inhalation & dermal exposure is a concern; limited data
Pendimethalin (Scott's Lawn Pro Step 1 Crabgrass Preventer Plus Fertilizer)	grass & weed control in lawns & gardens	considered to have low toxicity; limited home-use data
Prometon (Gro-Well No-Gro Weed & Grass Killer; Ortho Triox Vegetation Killer)	grass & weed control in lawns & gardens	limited data
Simazine (E-Z Clor; Algi-Kleer)	algae control in fish ponds, aquaria; orchard & berry-patch weed control	potential exposure in treated pools; limited data
Triclopyr (Ortho Brush-B-Gon; Ortho Poison Ivy and Poison Oak Killer)	brush & poison ivy/oak control	limited data
Trifluralin (Ortho 3-Way Rose & Flower Care; Greenview Preen)	control of grasses & broadleaf weeds in lawns, turf, flower, & orchards	possible nitrosamine contaminant; manufacturers are required to guarantee minimal levels of contaminant

\* Use of fungicides on humans and pets is regulated by FDA; these uses are not under the purview of FIFRA.

SOURCE: Format adapted from Consumers Union (1987); health effects information revised by the U.S. EPA Office of Pesticide Programs (1990).

**Exhibit 4-8. Selected weighted summary statistics for indoor air concentrations of pesticides in Jacksonville and Springfield/Chicopee (ng/m<sup>3</sup>).<sup>a</sup>**

PESTICIDE		SUMMER	SPRING	WINTER	SUMMER	SPRING	WINTER
		Jacksonville			Springfield/Chicopee		
Gamma-BHC	mean	20.2	13.4	6.0	*	0.5	9.5
	max	245.0	1530.0	75.0		5.0	118.0
Chlorothalonil	mean	5.3	2.2	6.7	*	0.1	0.1
	max	264.0	51.0	523.0		35.0	9.2
Heptachlor	mean	163.4	153.9	72.2	*	31.3	3.6
	max	1600.0	2370.0	684.0		253.0	152.0
Ronnel	mean	0.2	0.0	0.0	*	0.2	0.0
	max	20.0	0.0	0.0		8.8	4.8
Dichlorvos	mean	134.5	86.2	24.5	*	4.3	1.5
	max	2280.0	2910.0	1090.0		324.0	158.0
Alpha-BHC	mean	1.2	1.2	1.1	*	0.2	0.0
	max	32.0	28.0	32.0		8.0	0.0
Hexachlorobenzene	mean	1.3	0.4	0.3	*	0.0	0.1
	max	21.0	7.7	5.3		0.0	5.7
Chlorpyrifos	mean	366.0	205.4	120.3	*	9.8	5.1
	max	2170.0	4350.0	1043.3		252.0	291.0
Aldrin	mean	31.3	6.8	6.9	*	0.0	0.3
	max	1840.0	320.0	106.0		0.0	3.9
Dacthal	mean	0.2	0.0	0.3	*	1.6	0.3
	max	12.0	0.0	3.2		32.0	15.0

(continued next page)

**Exhibit 4-8. Selected weighted summary statistics for indoor air concentrations of pesticides in Jacksonville and Springfield/Chicopee (ng/m<sup>3</sup>)<sup>a</sup> (continued).**

PESTICIDE		SUMMER	SPRING	WINTER	SUMMER	SPRING	WINTER
		Jacksonville			Springfield/Chicopee		
Heptachlor Epoxide	mean	0.5	0.8	0.8	*	0.0	0.0
	max	11.0	160.0	30.0		0.0	0.0
Oxychlordan	mean	0.1	0.0	0.0	*	0.0	0.0
	max	5.2	0.0	6.5		0.0	0.0
Captan	mean	1.9	2.2	0.1	*	0.1	0.0
	max	44.0	254.0	21.0		22.0	6.4
Folpet	mean	0.5	0.7	0.6	*	0.7	0.0
	max	23.0	65.0	24.0		36.0	0.0
2,4-D	mean	1.8	0.0	2.5	*	2.1	0.0
	max	48.0	0.0	58.0		104.0	0.0
Dieldrin	mean	14.7	8.3	7.2	*	1.0	4.2
	max	177.0	61.0	57.0		8.8	40.0
Methoxychlor	mean	0.2	0.3	0.2	*	0.0	0.0
	max	17.0	55.0	7.0		0.0	0.0
Dicofol	mean	0.0	11.0	0.0	*	0.0	0.0
	max	0.0	581.0	0.0		0.0	0.0
Cis-Permethrin	mean	0.5	1.9	1.3	*	0.0	0.0
	max	33.0	153.0	62.0		0.0	0.0
Trans-Permethrin	mean	0.4	1.1	0.8	*	0.0	0.0
	max	31.0	56.0	37.0		0.0	0.0

**Exhibit 4-8. Selected weighted summary statistics for indoor air concentrations of pesticides in Jacksonville and Springfield/Chicopee (ng/m<sup>3</sup>)<sup>a</sup> (continued).**

PESTICIDE		SUMMER	SPRING	WINTER	SUMMER	SPRING	WINTER
		Jacksonville			Springfield/Chicopee		
Chlordane	mean	324.0	245.6	220.3	*	199.4	34.8
	max	3020.0	4380.0	2050.0		1700.0	735.0
4,4'-DDT	mean	**	1.0	0.5	*	0.0	0.6
	max		13.0	11.0		6.3	15.0
4,4'-DDD	mean	**	0.0	0.0	*	0.0	0.0
	max		0.0	0.0		0.0	0.8
4,4'-DDE	mean	**	0.6	0.2	*	0.9	0.6
	max		15.0	8.8		8.4	3.5
Ortho-phenylphenol	mean	96.0	70.4	59.0	*	44.5	22.8
	max	1040.0	1240.0	1440.0		560.0	286.0
Propoxur	mean	528.5	222.3	162.5	*	26.7	17.0
	max	7920.0	2030.0	1370.0		505.0	669.0
Bendiocarb	mean	85.7	5.5	3.4	*	0.2	0.4
	max	1500.0	89.0	68.0		10.0	38.0
Atrazine	mean	0.0	0.0	0.0	*	0.0	0.0
	max	0.0	0.0	0.0		0.0	0.0
Diazinon	mean	420.7	109.2	85.7	*	48.4	2.5
	max	13700	2370.0	1080.0		1810.0	27.0

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**Exhibit 4-8. Selected weighted summary statistics for indoor air concentrations of pesticides in Jacksonville and Springfield/Chicopee (ng/m<sup>3</sup>)<sup>a</sup> (continued).**

PESTICIDE		SUMMER	SPRING	WINTER	SUMMER	SPRING	WINTER
		Jacksonville			Springfield/Chicopee		
Carbaryl	mean	68.1	0.4	0.0	*	0.3	0.0
	max	3190.0	97.0	0.0		16.0	0.0
Malathion	mean	20.8	15.0	20.4	*	5.0	0.0
	max	1890.0	240.0	1660.0		275.0	0.0
Resmethrin	mean	0.1	0.0	0.0	*	0.0	0.0
	max	19.0	0.0	0.0		0.0	0.0

<sup>a</sup> ng/m<sup>3</sup>; nanograms per cubic meter (1000 ng = 1µg)

\*These pesticides were not sampled during the summer in Springfield/Chicopee.

\*\*These pesticides were not sampled during the summer in Jacksonville.

SOURCE: U.S. EPA (1990)

**Exhibit 4-9. Measurements of pesticides in buildings.**

PESTICIDE	CONCENTRATION RANGE, $\mu\text{g}/\text{m}^3$	COMMENTS	REFERENCES
		Dormitory	Leidy <i>et al.</i> (1982)
Diazinon (emulsion)	38.4	treatment room, day of treatment	
	9.7	treatment room, 7 days later	
	7.1	treatment room, 21 days later	
	0.9	adjacent room, day of treatment	
	1.0	adjacent room, 21 days later	
	0.4, 0.5	rooms above and below treatment room; day of treatment	
	0.6, 0.4	rooms above and below; 21 days later	
		Dormitory	Wright <i>et al.</i> (1981)
Bendiocarb (0.5% wettable powder)	7.7	day of treatment	
	ND*	3 days later	
Carbaryl (5% dust)	1.3	day of treatment	
	0.2	1 day later	
	0.01	3 days later	
Acephate (1% suspension)	1.3	day of treatment	
	2.9	1 day later	
	0.3	3 days later	
Diazinon (1% suspension)	1.6	day of treatment	
	0.6	1 day later	
	0.4	3 days later	
Chlorpyrifos (0.5% suspension)	1.1	day of treatment	
	1.1	1 day later	
	0.3	3 days later	
Fenitrothion (1.0% suspension)	3.3	day of treatment	
	1.1	1 day later	
	0.5	3 days later	
Propoxur	15.4	day of treatment	
	2.7	1 day later	
	0.7	3 days later	

(continued next page)

**Exhibit 4-9. Measurements of pesticides in buildings (continued).**

PESTICIDE	CONCENTRATION RANGE, $\mu\text{g}/\text{m}^3$	COMMENTS	REFERENCES
		6 Single-family homes	Wright & Leidy (1982)
Chlordane (1% emulsion)	2.75 $\pm$ 1.33 3.32 $\pm$ 1.38 5.01 $\pm$ 0.97	3 houses, day of treatment 6 mos. later 12 mos later	
Termide <sup>R</sup> (0.5% chlordane + 0.25% heptachlor)	4.48 $\pm$ 1.70 5.81 $\pm$ 5.01 2.77 $\pm$ 2.69  1.41 $\pm$ 0.64 1.80 $\pm$ 1.47 1.00 $\pm$ 0.70	3 houses, day of treatment 6 mos later 12 mos later  3houses, day of treatment 6 mos later 12 mos later	
		carpet swatches were contaminated with pesticide after application	
gamma-HCH (17 houses)	0.01 - 2.9; 0.56 (mean)	17 houses  concentrations in interior areas other than roof voids, from 1 to 10 years after treatment	Dobbs & Williams (1983)
Dieldrin (16 houses)	0.01 - 0.5; 0.11 (mean)		
		4368 Houses	Olds (1987)
		results for initial sampling; considerable variability on resampling; time between application and sampling not given	
Chlordane/Heptachlor	3.00 - 87.7	0.89% > NAS guideline	
Aldrin	1.40 - 1.55	0 > NAS guideline	
Chlorpyrifos	0.51 - 34.62	0.02% > NAS guideline	
Diazinon	0.51 - 34.62	no NAS guideline	



**Exhibit 4-9. Measurements of pesticides in buildings (continued).**

PESTICIDE	CONCENTRATION RANGE, $\mu\text{g}/\text{m}^3$	COMMENTS	REFERENCES
		5038 Houses	Lillie & Barnes (1987)
Chlordane		% of houses with identical level (time between treatment and sampling not given)	
		Time of Treatment preconstr.      postconstr.	
	NDL**		
	• slab (ducts in slab)	77%	28%
	• crawl space	84%	5%
	• slab (ducts in attic)	47%	96%
	NDL to $\leq 2$		
	• slab (ducts in slab)	17%	49%
	• crawl space	11%	48%
	• slab (ducts in attic)	53%	4%
	$>2$ to $\leq 5$		
	• slab (ducts in slab)	5%	18%
	• crawl space	4%	28%
	• slab (ducts in attic)	0	0
	$\geq 5$		
	• slab (ducts in slab)	1%	5%
	• crawl space	1%	19%
	• slab (ducts in attic)	0	0

\* ND - not detected

\*\* NDL - nondetectable level

**HEALTH EFFECTS OF PESTICIDES****Poisonings**

During 1987, 57,430 cases of pesticide exposure were reported to poison control centers, and 98% of these were due to accidental exposures. Insecticides accounted for about 66% of the total cases, followed by rodenticides (17%), moth repellents (7.7%), herbicides (7.2%), and fungicides

(2.3%). About 60% of the cases involved children less than 6 years of age. (Blondell, 1989)

During the period 1980 to 1985, at least 46.5% of the accidental pesticide related deaths in the U.S. occurred in the home (40.9% of the locations were not specified). Organophosphate insecticides were responsible for about 32% of the deaths. Seventeen percent of the victims were under the age of 5; 29.6% were between 25 and 44 years of age; 23.9%

were between 45 and 64 years of age; and 22% were over the age of 65 (Blondell, 1989).

Pesticide poisonings are the second most common source of childhood poisonings. A new trend to develop products with less offensive odors makes poisonings more likely. Consumers should know that the availability of these products is increasing in the marketplace, and the absence of this warning signal may lull users into a false sense of security.

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Prevention of poisoning through proper selection, storage, and use of pesticides is the key to reducing adverse health effects. Although medical treatments can counteract the pesticide poisoning, they apply to acute exposures and many treatments pose risks to the health of patients.

### Symptoms of Acute and Chronic Exposures

Many pesticides (for example, organophosphates and organochlorines) affect more than one organ system and produce a variety of symptoms which can progress rapidly from mild to fatal. Some pesticides produce reactions almost immediately while others result in delayed reactions. The specific symptoms that will result from a given exposure situation depend on the pesticide and its site of action, the dose received, and the sensitivity of the exposed individual. It should be noted that some individuals may be more sensitive to pesticides and other chemicals than the general population.

Irritation of the skin, eyes, and respiratory tract are common effects of pesticides. Skin exposure can result in itching, redness, swelling, blistering or an acne-like condition. The mucous membranes and the lining of the respiratory tract are especially sensitive, and inhaled pesticides can produce stinging, swelling, difficulty breathing, and increased mucous production. Flu-like symptoms are common.

Gastrointestinal tract symptoms include salivation, nausea, vomiting, abdominal cramps, and diarrhea. Nervous system effects include fatigue, headache,

dizziness, weakness, behavioral and mood disturbances, decreased or blurred vision, tingling and numbness of the extremities, tremors, pinpoint and nonreactive pupils, paralysis, coma, and death. Shock, hypertension, and arrhythmias of the heart can result when the cardiovascular system is affected. The kidneys and blood can also be damaged.

Some pesticides are sensitizers, and they result in more severe and potentially life-threatening reactions with subsequent exposures to small amounts.

Chronic exposure to some pesticides can result in damage to the liver, kidneys, and nervous system. Typical clinical findings include muscular weakness, and numbness and tingling of the extremities (peripheral neuropathy).

A history of recent pesticide use and the presence of these types of symptoms should suggest the possibility of pesticide poisoning.

### Health Effects Data

There are significant gaps and uncertainties in the health effects data base. For example, the lowest dose that results in acute effects is not known with certainty for most pesticides. In addition, the effects of chronic exposures and the doses at which these effects occur are not well documented. Deficiencies in the data base for long-term health effects are also important because of the potential exposure to pesticides in schools, parks, retail stores, mass transit vehicles, or other public areas; and nonoccupational exposures, in general, are poorly characterized.

Of particular concern are the carcinogenic, mutagenic, and teratogenic potential of pesticides. The data base for assessing these effects is inadequate to support definitive conclusions, but some animal and short-term tests suggest that many pesticides may be carcinogenic or genotoxic (Borzsonyi *et al.*, 1984; U.S. GAO, 1986; AMA Council on Scientific Affairs, 1988).

In addition to the animal and cell studies, there are epidemiologic studies of occupationally exposed workers which suggest that subacute poisoning does occur as a result of continuous low-level exposure (Sharp *et al.*, 1986; Xue, 1987; Stokes and Brace, 1988). Also, a study by Lowengart *et al.* (1987) underscores the concern for health effects in children resulting from home pesticide use. Although this study was not designed to evaluate the relationship between household chemicals and cancer, the data in the study showed an association between pesticide exposure in children and infants and childhood leukemia. However, other studies confirming this work are needed.

## REGULATORY FRAMEWORK

### Federal

EPA regulates pesticide formulations under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) of 1947 and its amendments. All pesticides must be registered with EPA before the products can be sold or distributed. Each product must have a label which identifies the EPA registration number, ingredients, proper use, health effects, warnings, and cautions.

Registration is based on an overall risk/benefit standard which requires the EPA to consider the economic, environmental, and social costs and benefits of pesticide use. Pesticides can be registered if the pesticide performs its stated function when used according to label instructions, without posing an *unreasonable risk* of adverse effects on human health or the environment. EPA has a Science Advisory Panel of outside experts which reviews major pesticide decisions or regulations.

The toxicological data that are required for registering pesticides used in and around the home depends on the nature, magnitude, and duration of expected exposures if the pesticide labels are reasonably followed. Some basic data such as acute toxicity studies for labeling the pesticide formulation are required routinely. Longer term studies such as

reproduction carried over 2 generations of breeding and cancer studies in rats and mice are required only for nonfood uses which could result in high exposures over a significant period of a person's lifetime. Pesticides used on food crops have been tested in all types of studies including long-term chronic and cancer testing.

An important provision of FIFRA requires EPA to review "old" pesticides (previously registered) to ensure that these products meet current scientific and regulatory standards. Pesticides which were considered to be "reasonably safe" were to be reregistered, and those which were considered to be "unreasonably unsafe" were to be cancelled. Prior to 1988, EPA was able to evaluate 185 active ingredients of about 600 previously registered pesticide active ingredients. The 1988 amendments accelerate and expedite the reregistration process which should enable EPA to evaluate the remaining chemicals more quickly.

EPA can also place a pesticide into "Special Review" if it believes the chemical poses a serious potential health or environmental risk. Special Review is an intensive investigation of the pesticide's risks and benefits.

EPA can limit the use of a chemical in some applications, but may decide its use is safe in others. For example, diazinon is one of the most widely used ingredients in consumer pesticide products. In 1988 EPA banned the use of diazinon on sod farms and golf courses because of its toxicity to certain birds and other nontarget species. Diazinon can still be applied to lawns because lawns are not the usual habitat for the waterfowl that are at risk.

If a pesticide is considered to be a significant health hazard, EPA or other appropriate agency can take one of the following actions: 1) cancel the registration; 2) cancel the registration and withdraw the product; 3) place restrictions on use or application of the compound; 4) suspend the registration pending resolution of the hazard or receipt of data; 5) set tolerance limits for pesticide residues on

foodstuffs; or 6) establish maximum permissible limits for the pesticide in drinking water.

As EPA evaluates pesticides, it publishes fact sheets which identify the manufacturer, date of registration, uses, toxicity, and regulatory action. These fact sheets and registration information for individual pesticides are a useful source of information.

### Warning Labels

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EPA requires pesticides to be labeled according to one of four toxicity categories based on a series of tests which relate to acute effects such as eye or skin irritation and other harmful effects that result shortly after the pesticide exposure occurs.

Depending on the health effects evaluation, products may be labeled **DANGER** (highly poisonous), **WARNING** (moderately poisonous), or **CAUTION** (least hazardous). Unfortunately, based on EPA's 1987 survey, it seems highly likely that many consumers do not discriminate among these different labels.

Registration and labeling, however, have limitations. In 1986 the GAO noted, "The public is not told about the uncertainties surrounding chronic health risks." (U.S. GAO, 1986). In 1988 the California Senate Office of Research echoed the GAO's concerns when it concluded that "labeled precautions for consumers may often provide only a minimal, and in certain instances inadequate, basis for avoiding hazards, especially infants and children" (Jennings, 1988).

EPA does require some pesticide products to contain warnings about potential chronic effects, but the labeling regulations do not require disclosure of chronic health hazards or the lack of full assessments of chemicals.

### Local Authority

Regulation of lawn chemicals is one area in which state and local jurisdictions have attempted to

inform the public about pesticide use. Some states such as Rhode Island, Massachusetts, Maryland, Minnesota, and Iowa have enacted laws which require the posting of warnings for the application of lawn chemicals. These regulations require notifications of pesticide applications, listing of the pesticides to be applied, and the disclosure of health and environmental effects.

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## 4.3 FORMALDEHYDE AND OTHER VOLATILE ORGANIC COMPOUNDS

### Sources of Formaldehyde

#### Residential Buildings

Formaldehyde (HCHO) is a flammable, colorless gas with a characteristic odor. The odor threshold for HCHO is about 1 ppm, but it can be detected at levels as low as 0.05 ppm by some people (NRC, 1981). It is one of the most widely used chemicals in the United States. About half of the HCHO produced annually (6 billion pounds in 1983) is used to make urea- and phenol-HCHO resins which, in turn, are used to produce adhesives, bonding and laminating agents, foam insulation, fabrics, coatings, and paper (U.S. HUD, 1984). Phenol-HCHO based resins, which are less susceptible to moisture degradation, are used to make interior and exterior grade products (softwood plywood, waferboard, and oriented strand board). Urea-HCHO resins are used only on interior grade products because they are susceptible to moisture deterioration.

HCHO can be released from a variety of products (Exhibit 4-10), but the primary residential sources are hardwood plywood, particleboard, medium-density fiberboard (MDF), and other pressed wood products. All of these pressed wood products are produced by combining wood pieces or chips with an adhesive and other chemicals (including urea-HCHO resins) and pressing them together in hot hydraulic presses. The potential for HCHO emissions is the greatest for MDF, followed by particleboard and hardwood plywood.

Hardwood plywood is used to make decorative wall paneling, furniture, cabinets, doors, and flooring. Softwood plywood also has a variety of applications, but it does not contain HCHO. Particleboard is used primarily as underlayment, mobile home decking, and to make industrial board which, in turn, is used to make many products including furniture and kitchen cabinets. MDF is used

primarily in furniture and cabinets as a cost effective alternative to solid wood.

During the last several years, manufacturers of particleboard, hardwood plywood, and MDF have taken measures to reduce the amount of HCHO that is used to make the board. MDF, however, as of 1986 was considered to be a relatively higher emitter of HCHO than the other two products (U.S. CPSC, 1986).

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Another important use of urea-HCHO resin is in the production of urea-HCHO foam insulation (UFFI) which is foamed-in-place. Between 1975 and 1981 about 435,000 homes were insulated with UFFI (U.S. CPSC, 1982). Because of concerns about UFFI, the CPSC banned the installation of UFFI in homes and schools as of August 10, 1982. This ban, which was intended to prevent the risk of injury from cancer as well as the occurrence of acute illness, was contested by the industry and overturned by the Fifth Circuit Court of Appeals in 1983.

### Commercial Buildings

Any commercial building that is newly constructed or recently renovated can be a potential source of HCHO emissions. Important potential sources of HCHO in commercial buildings include any materials made of MDF, particleboard, and hardwood plywood. These materials include flooring materials, paneling, and furniture. In addition, any fabrics or other fibers that have been treated to be permanent press, soil and wrinkle resistant, and water repellent may be additional sources. Confined areas where smoking is permitted could have elevated levels of HCHO and other aldehydes because of the buildup of these combustion byproducts.

### Measured Concentrations of HCHO

Formaldehyde is perhaps one of the most widely characterized indoor air contaminants. Exhibit 4-11 summarizes some of the measurements which have

been made in mobile homes, conventional homes, offices, and a variety of public buildings.

These and other studies have shown that manufactured housing could be expected to have higher average concentrations of HCHO than conventional housing, probably because of the greater number of sources and higher surface to volume ratio. It should be noted that construction techniques have changed for manufactured housing and average concentrations in these homes may be lower than in the past.

HCHO concentrations in conventional houses insulated with UFFI are generally higher than in houses with other types of insulation. Measurements of HCHO concentrations in nonresidential buildings have generally demonstrated lower concentrations than in conventional or mobile homes.

Although general trends have been noted, the reported data also show that a wide range of concentrations can exist in any type of construction depending on the age of the structure, season, time of day, climatic factors, and presence of sources.

### Health Effects of Formaldehyde

Concerns about exposure to HCHO have resulted in thousands of complaints to agencies such as the CPSC and in numerous lawsuits. These complaints have related primarily to effects resulting from acute exposures, but increasingly consumers are concerned about health effects resulting from chronic exposures and the potential carcinogenicity of HCHO.

HCHO is a known irritant and sensitizer. The frequency and severity of irritant effects from HCHO has been shown to increase with concentration and length of exposure. Symptoms of upper airway irritation include a tingling sensation in the nose, dry throat, and sore throat. These symptoms usually coexist with tearing, burning, stinging, and pain in the eyes (NRC, 1981). These effects can occur within a few minutes after exposure to HCHO

depending on the exposure concentration and the sensitivity of the individual. At higher levels, inhalation of HCHO produces lower airway irritation and pulmonary effects which are characterized by coughing, chest tightness, and wheezing.

Skin contact with HCHO has been reported to result in irritation, allergic contact dermatitis, and urticaria. These effects may be caused by direct contact with HCHO or formalin (HCHO in solution with methanol), or by HCHO-releasing agents (cosmetics, germicides, incompletely cured resins) and the decomposition of HCHO-containing resins (textiles). Repeated contact with low concentrations of HCHO can result in sensitization reactions.

Additional reported effects of HCHO exposure include nosebleeds and runny noses, persistent swelling of nasal turbinates, headaches, fatigue, memory and concentration problems, nausea, dizziness, and breathlessness (U.S. EPA, 1987a).

HCHO has also been reported to be associated with altered reproductive function in women and fetotoxic effects, but additional work is needed to validate these findings. It has been shown to be mutagenic in a variety of test systems, including humans (U.S. EPA, 1987a).

Irritant effects have been associated with concentrations in the range of 0.1 to 3 ppm, and concentrations as low as 0.03 ppm have been reported to cause effects in sensitive individuals. It has been estimated that 10% to 12% of the U.S. population may have hyperreactive airways which may make them more susceptible to the irritant effects of HCHO; this estimate includes asthmatics (NRC, 1981).

The Committee on Toxicology of the National Academy of Sciences (NRC, 1980) evaluated data available in 1980, and it concluded that there is no population threshold effect level for the irritant effects of HCHO in humans. Based on its review,

the Committee concluded that less than 20% of the population would experience slight to mild irritation and discomfort when exposed to less than 0.25 ppm HCHO. More recently, CPSC also concluded that there may not be a threshold limit concentration for HCHO (U.S. CPSC, 1986). The WHO Working Group on Assessment and Monitoring of Exposure to Indoor Air Pollutants (1983) concluded that indoor HCHO concentrations of less than 0.05 ppm were of limited or no concern and concentrations greater than 0.10 ppm were of sufficient concern to call for corrective action.

The most controversial health effect from exposure to HCHO is its carcinogenic potential in humans. The debate surrounding the role of HCHO as a carcinogen began with a study sponsored by the Chemical Industry Institute of Toxicology (CIIT) in 1980 in which it was reported that nasal cancer developed in 103 of 240 laboratory rats exposed to 14.3 ppm HCHO and in two rats exposed to 5.6 ppm HCHO. Nasal cancer also developed in 2 of 240 mice exposed to 14.3 ppm HCHO (Kerns *et al.*, 1983).

Since the results of the CIIT study were made available, there have been other animal and human epidemiologic studies which suggest that HCHO should be presumed to pose a carcinogenic risk to humans. The Federal Panel on Formaldehyde (FPF, 1982), the International Agency for Research on Cancer (IARC, 1982), the CPSC (1986), and the U.S. EPA (1987a) have concluded that HCHO poses a carcinogenic risk to humans.

In 1987 the U.S. EPA classified HCHO as a "Probable Human Carcinogen" (Group B1) based on sufficient animal and limited human evidence and other supporting data (U.S. EPA, 1987). In 1989 EPA, in consultation with EPA's Science Advisory Board, undertook efforts to update the 1987 assessment in light of new hazard data and recent advances in risk assessment methodology. The new methodology incorporates pharmacokinetic data which provides a closer approximation to a delivered dose and uses monkey DNA binding data as the

basis for human dosimetry. This update effort will likely significantly reduce the 1987 cancer risk estimates.

## Sources of Other Volatile Organic Compounds

### Sources

Organic compounds can be divided into three categories based on volatility. Volatile organic compounds (VOCs) exist entirely in the vapor phase at ambient temperature and have vapor pressures greater than about 1 mm Hg. Semivolatile organic compounds (SVOCs) have vapor pressures in the range of  $10^{-7}$  to 1 mm Hg and are present both in the vapor and particle-bound state. Nonvolatile organic compounds are those that are present only as particulates and have vapor pressures less than  $10^{-7}$  mm Hg (Riggin and Petersen, 1985).

Over 250 different organic compounds have been measured in indoor air at levels greater than 1 ppb (Sterling, 1985), and over 900 volatile organic compounds have been identified in indoor air (U.S. EPA, 1989). These compounds are incorporated into almost all materials and products that are used in construction materials, consumer products, furnishings, pesticides, and fuels. Drinking water (typically well water) that is contaminated with VOCs can also be an indoor air source when contaminated water is used for showering, bathing, cooking, and other uses that potentially result in the release of VOCs. Some examples of VOCs and the products which contain them are given in Exhibit 4-12. Exhibit 4-13 contains examples of some emission rates for selected VOC-containing products.

A national survey conducted by EPA (1987b) on the usage of household solvents has provided insight into the sources of six solvents contained in consumer products and the usage of those products by consumers. The solvents which were studied include methylene chloride and five potential substitute chemicals: 1,1,1-trichloroethane,

trichloroethylene, tetrachloroethylene, carbon tetrachloride, and 1,1,2-trichlorotrifluoroethane. EPA examined a total of 1026 brands of household products, which were grouped into 67 product categories, and the use patterns of 5000 adults. These studies demonstrated that exposure to VOCs is widespread through the use of consumer products, but the significance of these exposures is not known.

Almost half of the brands surveyed contained at least one of the six target chlorocarbons. Methylene chloride and 1,1,1-trichloroethane were the predominant chemicals—34% of the brands tested positive for methylene chloride and 14% for 1,1,1-trichloroethane. Methylene chloride was found in 78% of the paint removers/strippers and 60% of the aerosol spray paints tested. 1,1,1-Trichloroethane was found in most of the typewriter correction fluids, suede protectors, and brake quieters/cleaners tested.

Less than 4% of the brands tested were positive for any of the four remaining chlorocarbons. Trichloroethylene was found in 78% of the typewriter correction fluids tested. Tetrachloroethylene was found in 58% of the brake quieters/cleaners tested. Carbon tetrachloride was not found at the 1% level in any of the products tested.

In addition to the findings of specific concentrations of chemicals in household solvent products, the study found that concentrations of chlorocarbons varied considerably between brands of the same product type, and in a few brands, concentrations differed by geographic regions of the country. One of the most important findings of this study was that product labels are often inadequate; only 56% of the brands with chlorocarbons were labeled as containing these chemicals.

### Extent of Use

The EPA household solvent products survey (U.S. EPA, 1987b) showed that on average people had used slightly fewer than 7 products during their lifetime. During a 12-month period prior to the



survey, participants reported that they used almost 5 products on average.

Products were ranked according to the incidence of "ever used." The most frequently used products were contact cements/super glues/spray adhesives (60.6% of the population), latex paint (55.2%), and wood stains/varnishes/finishes (42.9%). The lowest incidence of ever used products (less than 3%) was for automotive products (transmission cleaners, brake quieters/cleaners, and gasket removers).

The 5 most frequently used products during the previous 12-month period were typewriter correction fluid, solvent cleaners, spot removers, specialized electronic cleaners, and tire/hubcap cleaners. These products were also used for the shortest amounts of time (from 7.5 minutes for typewriter correction fluid to 29.5 minutes for solvent cleaners). Latex paint, oil paint, paint removers/stippers, adhesive removers, and wood stains/varnishes/finishes were the 5 products which were used less frequently, but for the longest periods of time (from 117 minutes for wood stains/varnishes/finishes to 295 minutes for latex paint).

The survey also showed that respondents were somewhat aware of the potential adverse effects of using these products. Over 70% of the respondents reported that they kept a door or window open to the outside when using nonautomotive primers, latex paint, outdoor water repellents, and paint removers and strippers.

### Measured Concentrations

The data base for VOCs and other organic compounds includes studies of healthy and sick buildings. Some examples of VOCs measurements in residential and nonresidential buildings are given in Exhibit 4-14.

These data along with the consumer use surveys conducted by EPA show that exposure to VOCs is

widespread and highly variable. In general, VOCs can be expected to be higher in buildings immediately after construction or renovation compared to older buildings. The use of consumer products can be expected to predominate VOC emissions after building-related VOCs decrease in concentration.

The Team Studies conducted by Wallace and others (Wallace, 1987) have provided important information about actual exposures to VOCs. These studies showed that:

- Indoor personal exposures were greater than mean outdoor concentrations for each of 11 target VOCs.
- Breath levels correlated significantly with personal air exposures but not with outdoor air levels for nearly all the chemicals.
- Inhalation accounted for more than 99% of the exposure for all contaminants studied, except for the trihalomethanes.
- Specific sources of exposure were identified and included smoking (aromatics such as benzene, styrene, ethylbenzene, and m,p-xylene in breath); passive smoking (same chemicals in indoor air); visiting dry cleaners (tetrachloroethylene in breath); pumping gas or being exposed to auto exhaust (benzene in breath); various occupations such as chemicals, plastics, wood processing, scientific laboratories, garage or repair work, metal work, printing (aromatic chemicals in daytime personal air).
- Other sources which were hypothesized included room air fresheners, toilet bowl deodorizers, or moth crystals (p-dichlorobenzene in indoor air); and use of hot water in the home (chloroform in indoor air).

## Health Effects of Other Volatile Organic Compounds

Exposure to VOCs can result in both acute and chronic health effects. Exhibit 4-12 summarizes some health effects for selected contaminants. Most of the available health effects data have been developed from animal studies or occupational studies. In general, the health effects data base for VOCs, especially, low-level or intermittent exposures, is not complete.

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Many of the VOCs are potent narcotics and result in the depression of the central nervous system. VOCs can also result in irritation of the eyes and respiratory tract and sensitization reactions which involve the eyes, skin, respiratory tract, and heart. At higher concentrations, many of these chemicals have been shown to result in liver and kidney damage.

Symptoms of VOC exposure (depending on the dose) could include fatigue, headache, drowsiness, dizziness, weakness, joint pains, peripheral numbness or tingling, euphoria, tightness in the chest, unsteadiness, blurred vision, skin irritation, irritation of the eyes and respiratory tract, and cardiac arrhythmias (Rosenberg, 1990).

The term "solvent encephalopathy" is used to describe a group of symptoms (major symptoms—headache, irritability, difficulty concentrating, and fine-motor deficits) attributed to VOC exposures. A dose-effect relationship has not been described, but effects occur at levels well below the threshold limit values for individual solvents, and there appears to be a relationship between duration of exposure and the time required to resolve symptoms after exposure stops. VOCs are present in office environments at concentrations that have been associated with solvent encephalopathy (Hodgson, 1988).

Many of the VOCs which have been measured indoors are known human carcinogens (benzene) or animal carcinogens (carbon tetrachloride, chloroform, trichloroethylene, tetrachloroethylene, and p-dichlorobenzene). VOCs such as 1,1,1-trichloro-

roethane, styrene, and  $\alpha$ -pinene are mutagens and possible carcinogens. Other VOCs such as octane, decane, and undecane are possible co-carcinogens.

**Cancer Risk Estimates:** Cancer risk estimates developed by EPA for exposure to some VOCs are given in Exhibit 3-2, Section 3 of the *Reference Manual*. Other investigators have also estimated the cancer risk from VOCs. Wallace (1986) estimated that six VOCs (benzene and the other 5 animal carcinogens listed above) contribute 1000 to 5000 excess cancer cases per year nationwide. Tancrede *et al.* (1987) estimated the cancer risk of 9 VOCs which had previously been measured in New Jersey (Bayonne and Elizabeth), 19 VOCs in California (Los Angeles), and 44 VOCs in Dutch houses. The estimated mean individual risk (the sum of the mean individual risks for each of the VOCs) was 0.019-0.03 for the residents of New Jersey and 0.002 for the residents of California. The estimated mean risk for the contaminants based on the Dutch data was 0.001-0.002. The unit risk estimates were computed using human and animal data, by analogy with other chemicals, and other methods.

When the risks were computed based only on those chemicals for which there was either animal bioassay data or human epidemiological data, the estimated risk was 0.003 for New Jersey, 0.001 for California, and 0.0002-0.001 for The Netherlands. Estimated risks for radon (0.0520), passive smoking (0.002-0.008), and formaldehyde (0.034) were also shown for comparison. Tancrede *et al.* concluded that even though their estimates were conservative, the calculations suggested exposure to VOCs through indoor air were important. Although there are few risk assessments available for VOCs in indoor air, VOCs appear likely to pose a significant cancer risk (U.S. EPA, 1989).

**Sick Building Syndrome and Multiple Chemical Sensitivity:** There is some evidence VOCs can provoke some of the symptoms typical of sick building syndrome. Mølhave observed increased mucous irritation and impaired memory in healthy subjects (who previously demonstrated symptoms of

sick building syndrome) who were exposed to 22 VOCs at total VOC concentrations of 5 mg/m<sup>3</sup> and 25 mg/m<sup>3</sup> (Mølhave *et al.*, 1987).

Kjaergaard *et al.* (1987) also demonstrated a dose-dependent response in 63 randomly selected healthy subjects who were exposed to n-decane in the range of 0 to 100 ppm. Exposed subjects experienced mucous membrane irritation, decreased tear film stability, and sensation of increased odor intensity and reduced air quality. The authors concluded that these results support the hypothesis that VOCs can provoke some of the symptoms of sick building syndrome.

Individuals who appear to demonstrate multiple chemical sensitivity report severe reactions to

a variety of VOCs and other organic compounds which are released by building materials and various consumer products including cosmetics, soaps, perfumes, tobacco, plastics, dyes, and other products. Many of the chemicals contained in these products are potent sensitizers.

These reactions can occur after exposure to a single sensitizing dose or sequence of doses, after which time, a far lower dose can provoke symptoms. Reactions can also be provoked as a result of chronic exposure to low doses. Ashford and Miller (1989) summarize some of the studies that have been conducted that attempt to link multiple chemical sensitivity to exposure to VOCs and other organic compounds.

#### Exhibit 4-10. Potential sources of formaldehyde indoors.

Pressed-wood products	hardwood plywood, particle board, medium-density fiberboard (MDF), decorative paneling
Insulation	urea-formaldehyde foam insulation (UFFI), fiberglass made with HCHO binders
Combustion sources	natural gas, kerosene, tobacco, automobile exhaust
Paper products	grocery bags, waxed paper, facial tissues, paper towels, disposable sanitary products
Stiffeners, wrinkle resisters, and water repellents	floor coverings (rugs, linoleum, varnishes, plastics), carpet backings, adhesive binders, fire retardants, permanent press textiles
Other sources	plastics, cosmetics, deodorants, shampoos, disinfectants, starch-based glues, adhesives, laminates, paints, fabric dyes, inks, fertilizers, fungicides

SOURCE: Adapted from NRC (1981)

### Exhibit 4-11. Measurements of formaldehyde concentrations in different types of buildings.

TYPE OF BUILDING	CONCENTRATION (ppm)			REFERENCE
	MINIMUM	MAXIMUM	MEAN	
Conventional homes with chipboard (n=23)	0.07	1.82	0.51	Andersen <i>et al.</i> (1975)
Conventional homes (n=80)	0.4 <sup>a</sup>	8.1 <sup>a</sup>		Sardinas <i>et al.</i> (1979)
All homes (n=100)	<0.1	3.68	0.35 (median)	Dally <i>et al.</i> (1981)
U-F foamed conventional homes (n=14)	0.1	1.09	0.47 (median)	
U-F wood products conventional homes (n=13)	0.1	0.92	0.1 (median)	
Mobile homes (n=65)	<0.1	3.68	0.1 (median)	
Mobile home day care centers (n=7)	0.2	0.45	0.35	Olsen & Dossing (1982)
Permanent day care centers (n=2)	0.04	0.09	0.07	
Mobile homes (n=39)	0.02	3.69	0.42	Ritchie & Lehen (1985)
Conventional homes (n=489)	0.01	5.52	0.15	
Mobile homes (n=137)	0.1	2.84	0.46	Hanrahan <i>et al.</i> (1985)
Conventional homes (n=36)	<0.008	<0.14	0.04	Stock & Mendez (1985)
Energy efficient homes (n=7)	0.04	0.11	0.07	
Apartments (n=19)	0.02	0.27	0.08	
Condominiums (n=10)	<0.008	0.29	0.06	

**Exhibit 4-11. Measurements of formaldehyde concentrations in different types of buildings (continued).**

TYPE OF BUILDING	CONCENTRATION (ppm)			REFERENCE
	MINIMUM	MAXIMUM	MEAN	
Energy efficient condominiums (n=3)	0.15	0.2	0.18	
Nonmanufactured homes (n=48)			0.41	Sexton <i>et al.</i> (1986)
Mobile homes - all (n=633)	<0.010	0.464	0.072	
Pre-1981 mobile homes (n=266)	<0.010	0.386	0.061	
Post-1981 mobile homes (n=391)	0.012	0.464	0.080	
New buildings <sup>b</sup> (n=3)	ND	0.192	-	Shelden <i>et al.</i> (1987)
Old buildings <sup>c</sup> (n=3)	ND	0.103		
Office buildings (n=3)	0.025	0.039	0.031	Bayer & Black (1988)

<sup>a</sup> Draeger tubes<sup>b</sup> Office, nursing home, hospital<sup>c</sup> Office, office/school, nursing home

**Exhibit 4-12. Health effects and sources of selected volatile organic compounds.**

COMPOUND	HEALTH EFFECTS <sup>(1)</sup>	SOURCES AND USES
Formaldehyde	probable human carcinogen; eye and respiratory tract irritant; a variety of low-level symptoms	listed in Exhibit 4-10
Benzene	carcinogen; respiratory tract irritant	plastic and rubber solvents; cigarette smoking; paints, stains, varnishes, filler, other finishes; inhalation of gasoline vapor
Xylenes	narcotic; irritant; affects heart, liver, kidney and nervous system	adhesives, joint compound, wallpaper, caulking compounds, floor covering, floor lacquer, grease cleaners, shoe dye, tobacco smoke, kerosene heaters, varnish, solvent for resins, enamels; used in non-lead automobile fuels, pesticides, dyes, pharmaceuticals
Toluene	narcotic; may cause anemia	solvents, solvent-based adhesives, water-based adhesives, edge-sealing, moulding tape, wallpaper, joint compound, calcium silicate sheet, vinyl floor covering, vinyl coated wall paper, caulking compounds, paint, chipboard, kerosene heaters, tobacco smoke
Styrene	narcotic; affects central nervous system; possible human carcinogen	plastics, paints, synthetic rubber, and resins
Toluene diisocyanate (TDI)	sensitizer; probable human carcinogen	polyurethane foam aerosols
Trichloroethylene	animal carcinogen; affects central nervous system	solvent for paints, varnishes, oil and wax, cleaning compounds, degreasing products, dry-cleaning
Ethyl benzene	severe irritation to eyes and respiratory tract; affects central nervous system	solvents, in styrene-related products
Methylene chloride (Dichloromethane)	narcotic; affects central nervous system; probable human carcinogen	paint removers, aerosol finishers; acoustical office partitions

**Exhibit 4-12. Health effects and sources of selected volatile organic compounds (continued).**

COMPOUND	HEALTH EFFECTS	SOURCES AND USES
Para-dichlorobenzene	narcotic; eye and respiratory tract irritant; affects liver, kidney, and central nervous system	moth crystals, room deodorizers
Benzyl chloride, Benzal chloride	central nervous system irritants and depressants; affects liver and kidney; eye and respiratory tract irritant	vinyl tiles plasticized with butyl benzyl phthalate
2-butanone (MEK)	irritant; central nervous system depressant	floor/wall covering, calcium silicate sheet, fiberboard, caulking compounds, particleboard, tobacco smoke
Petroleum distillates	central nervous system depressant; affects liver and kidney	cleaning products, solvents, paint thinners
4-phenylcyclohexene	eye and respiratory tract irritant; central nervous system effects	byproduct of styrene butadiene latex, an adhesive used in most synthetic fibers carpets

<sup>1</sup>For many indoor pollutants, there is insufficient data to determine the levels at which the specific effects listed would actually occur and the extent to which these levels are experienced in non-industrial indoor environments.

*SOURCE:* Tucker (1988), Dreisbach (1980), Turiel (1985)

**Exhibit 4-13. Examples of volatile organic compound measurements in indoor air.**

CONTAMINANT	CONCENTRATION ( $\mu\text{g}/\text{m}^3$ )			REFERENCE
	MINIMUM	MAXIMUM	MEAN	
Benzene				
Kitchens (n = 15)	6	7	15	Seifert & Abraham (1982)
Other rooms (n = 15)	6	14	18	
Outdoors, next to dwellings (n = 5)	4	33	29	
Toluene				
Kitchens (n = 15)	34	3800 <sup>a</sup>	60	
Other rooms (n = 15)	17	173 <sup>a</sup>	62	
Outdoors, next to dwellings (n = 5)	16	60	35	
m- and p-Xylene				
Kitchens (n = 15)	18	77 <sup>a</sup>	29	
Other rooms (n = 15)	10	47	21	
Outdoors, next to dwellings (n = 5)	4	32	28	
Ethylbenzene				
Kitchens (n = 15)	6	33	15	
Other rooms (n = 15)	1	22	11	
Outdoors, next to dwellings (n = 5)	4	20	13	
Various types of buildings <sup>b</sup>				Wallace <i>et al.</i> (1983)
Benzene	0.4	120	20	
Carbon tetrachloride	0.5	14	2.5	
Trichloroethylene	0.3	47	3.6	
Chloroform	0.2	200	8	
Dichlorobenzenes	0.2	1200	41	
Ethylbenzene	0.3	320	13	
o-Xylene	0.4	49	7.8	
m- and p-Xylene	0.4	120	21	
Styrene	0.1	54	3.1	
1,1,1-Trichloroethane	0.7	880	50	
Tetrachloroethylene	0.2	250	10	
2 Schools, 2 homes, and 1 office				van der Wal <i>et al.</i> (1987)
n- and i-Pentanal	10	12		
n-Hexanal	2	7		
n-Octanal	1	21		
N-Nonanal	7	50		
m-Decanal	2.5	17		
Benzaldehyde	4	5		
Toluene	13	69		
Higher Aromatic Hydrocarbons	14	600		
n-Alkanes	8	1700		
Chlorinated Hydrocarbons	4	42		



**Exhibit 4-13. Examples of volatile organic compound measurements in indoor air (continued).**

CONTAMINANT	CONCENTRATION ( $\mu\text{g}/\text{m}^3$ )			REFERENCE
	MINIMUM	MAXIMUM	MEAN	
New buildings, (office, nursing home, hospital)				Sheldon <i>et al.</i> (1988)
Total VOCs <sup>c</sup>			21-1100	
Aromatic Hydrocarbons <sup>d</sup>			11-270	
Aliphatic Hydrocarbons <sup>e</sup>			4.7-810	
Chlorinated Hydrocarbons <sup>f</sup>			3.9-56	
Oxygenated Hydrocarbons <sup>g</sup>			ND-9.6	
Older buildings, (office, office/school, nursing home)				Sheldon, <i>et al.</i> (1988)
Total VOCs <sup>c</sup>			18-130	
Aromatic Hydrocarbons <sup>d</sup>			12-74	
Aliphatic Hydrocarbons <sup>e</sup>			1.9-18	
Chlorinated Hydrocarbons <sup>f</sup>			4.7-46	
Oxygenated Hydrocarbons <sup>g</sup>			ND-4.3	
3 Nonresidential buildings <sup>h</sup>				Bayer and Black (1988)
Total VOCs			237-1090	
1,1,1-Trichloroethane			14.8-214	
Benzene			12.9-43.2	
Ethylbenzene			1.16-17.2	
o-Xylene			3.66-16.8	
Toluene			7.84-98.7	
3-Methylpentane			1.42-37.6	
Hexane			4.7-68.7	
1, 2, 3-Trimethylbenzene			<0.02-0.522	
Heptane			1.24-38.9	
1, 4-Dioxane			<0.02-20.1	
Acetone			11.1-62.7	
4-Methyl-1-pentanone			0.343-27.9	
Butylacetate			10.6-48.3	
Homes in 2 cities over the course of 3 sampling periods in 3 years				Wallace (1987)
Total VOCs			200-338	
1,1,1-Trichloroethane			45-94	
m, p-Dichlorobenzene			45-71	
m, p-Xylene			36-52	
Tetrachloroethylene			11-45	
Benzene			NC <sup>i</sup> -28	
Ethylbenzene			9.2-19	
o-Xylene			12-16	
Trichloroethylene			4.6-13	
Chloroform			4.0-8.0	
Styrene			2.1-8.9	
Carbon Tetrachloride			ND <sup>j</sup> -9.3	

(continued next page)

**Exhibit 4-13. Examples of volatile organic compound measurements in indoor air (continued).**

CONTAMINANT	CONCENTRATION ( $\mu\text{g}/\text{m}^3$ )			REFERENCE
	MINIMUM	MAXIMUM	MEAN	
	Homes in 1 city over the course of 3 samplings periods in 1 year			Wallace (1987)
n-Octane			2.3-5.8	
n-Decane			2.0-5.8	
n-Undecane			2.7-5.2	
n-Dodecane			2.1-2.5	
$\alpha$ -Pinene			2.1-6.5	
o-Dichlorobenzene			0.3-0.6	
1, 1, 1-Trichloroethane			16-96	
m- and p-Xylene			11-28	
m- and p-Dichlorobenzene			5.5-18	
Tetrachloroethylene			5.6-16	
o-Xylene			4.4-13	
Ethylbenzene			3.7-11	
Trichloroethylene			3.8-7.8	
Styrene			1-3.6	
Chloroform			0.6-1.9	
Carbon Tetrachloride			0.8-1.3	
1, 2-Dichlorobenzene			0.1-0.5	
p-Dioxane			0.2-1.8	

<sup>a</sup> not included in the calculation of the mean

<sup>b</sup> overnight air samples, Elizabeth-Bayonne, NJ; additional measurements are given in Wallace (1987) and TEAM publications

<sup>c</sup> specific levels of individual contaminants are given in Sheldon *et al.* (1988)

<sup>d</sup> benzene; o- and m-xylene; styrene; ethylbenzene; isopropylbenzene; n-propylbenzene; o- and m-toluene; 1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene

<sup>e</sup>  $\alpha$ -pinene, n-decane, n-undecane, n-dodecane

<sup>f</sup> 1,2-dichloroethane; 1,1,1-trichloroethane; trichloroethylene; p-dichlorobenzene

<sup>g</sup> n-butylacetate; 2-ethoxyethylacetate

<sup>h</sup> Atlanta, GA; spring season; additional VOCs are given in Bayer and Black (1988)

<sup>i</sup> not calculated-high background contamination

<sup>j</sup> not detected in most samples

**Exhibit 4-14a. Examples of selected volatile organic compound emission rates for materials and typical household products found indoors.**

EMISSION RATES OF SELECTED MATERIALS ( $\mu\text{g/g}$ ) <sup>a</sup>								
Compound Name	Adhesives	Coating	Fabric	Foam	Lubricant	Paint	Rubber	Tape
1,2-Dichloroethane	0.80	—	—	0.75	—	—	—	3.25
Benzene	0.9	0.6	—	0.7	0.20	0.90	0.10	0.69
Carbon Tetrachloride	1.00	—	—	0.18	—	—	4.20	0.75
Chloroform	0.15	—	0.10	0.04	0.20	—	0.90	0.05
Ethylbenzene	—	—	—	—	—	527.8	—	0.20
Limonene	—	—	—	—	—	—	—	—
Methyl Chloroform	0.40	0.20	0.07	1.00	0.50	—	0.10	0.10
Styrene	0.17	5.20	—	0.02	12.54	33.50	0.15	0.10
Tetrachloroethylene	0.60	—	0.30	65.00	0.60	—	0.20	0.08
Trichloroethylene	0.30	0.09	0.03	0.10	0.10	—	0.07	0.09
Sample Size (n)	98	22	30	68	23	4	90	66

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EMISSION RATE OF SELECTED HOUSEHOLD PRODUCTS ( $\mu\text{g/g}$ ) <sup>b</sup>									
Compound Name	Cosmetics	Deodorants	Health & Beauty Aids	Elect. Equip.	Misc. Housewares	Ink & Pen	Paper	Photo Equip.	Photo Film
1,2-Dichloroethane	—	—	—	0.06	—	—	—	—	—
Benzene	—	—	1.85	0.02	1.10	0.40	0.03	1.51	0.04
Carbon Tetrachloride	—	—	—	0.00	0.04	0.20	—	2.50	—
Chloroform	—	—	—	0.23	4.85	10.00	0.10	2.50	0.10
Ethylbenzene	—	—	—	0.80	—	—	—	10.50	0.13
Limonene	—	0.40	1.00	—	1.80	—	—	—	—
Methyl Chloroform	0.20	—	0.01	0.03	0.19	0.10	0.26	0.08	1.90
Styrene	1.10	0.15	0.17	0.05	0.02	0.30	—	0.04	0.10
Tetrachloroethylene	0.70	—	—	0.05	—	2.00	0.42	—	—
Trichloroethylene	1.90	—	0.11	0.01	0.06	0.07	0.10	0.03	0.13
Sample Size (n)	5	9	23	71	23	25	12	35	26

SOURCE: <sup>a</sup>Ozkaynak *et al.* (1987)

**Exhibit 4-14b. Additional examples of volatile organic compound emission rates for selected materials found indoors.**

MATERIAL <sup>a</sup>	EMISSION RATE ( $\mu\text{g}/\text{m}^2/\text{hr}$ )			
	ALIPHATIC OXYGENATED ALIPHATIC HYDROCARBONS	AROMATIC HYDROCARBONS	HALOGENATED COMPOUND	ALL TARGET HYDROCARBONS
Latex caulk	252	380	5.2	637
Latex paint (Glidden)	111	52	86	249
Carpet adhesive	136	98	- <sup>b</sup>	234
Vinyl cove molding	31	26	1.4	60
Linoleum tile	6.0	14	0.62	46
Large diameter telephone cable	14	35	4.0	45
Black rubber molding	24	78	0.88	103
Small diameter telephone cable	33	26	1.4	60
Carpet	27	9.4	-	36
Vinyl edge molding	18	12	0.41	30
Particle board	27	1.1	0.14	28
Polystyrene foam insulation	0.19	20	1.4	22
Tar paper	3.2	3.1	-	6.3
Primer/adhesive	3.6	2.5	-	6.1
Latex paint (Bruning)	-	3.2	-	3.2
Water repellent mineral board	1.1	0.43	-	1.5
Cement block	-	0.39	0.15	0.54
PVC pipe	-	0.53	-	0.53
Duct insulation	0.13	0.15	-	0.28
Treated metal roofing	-	0.19	0.06	0.25
Urethane sealant	-	0.13	-	0.13
Fiberglass insulation	-	0.08	-	0.80
Exterior mineral board	-	0.03	-	0.03
Interior mineral board	-	-	-	-
Ceiling tile	-	-	-	-
Red clay brick	-	-	-	-
Plastic laminate	-	-	-	-
Plastic outlet cover	-	-	-	-
Joint compound	-	-	-	-
Linoleum tile cement	-	-	-	-

<sup>a</sup> emission rates for cove adhesive are not reported; sample was overloaded. It is estimated that cove adhesive is one of the emitters of VOCs with emissions of target compounds  $>4700 \mu\text{g}/\text{m}^2$ .

<sup>b</sup> no detectable emissions

SOURCE: Sheldon *et al.* (1988)

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#### 4.4. BIOLOGICAL CONTAMINANTS

The home and workplace can harbor a variety of airborne allergens and pathogens. About 50% to 60% of all community acquired illness is due to respiratory infections and most of these are caused by viruses (Feeley, 1985); but, bacterial diseases and allergic reactions caused by biological sources can pose significant problems in homes and public facilities such as day care centers, hospitals, hotels, nursing homes, schools, and office buildings (Feeley, 1985).

##### Pathogens and Illness

Biogenic agents (those produced by living organisms) in the indoor environment generally have limited direct toxicity, and more often, result in infection or allergic responses. The term bioaerosol refers to biogenic agents that are airborne.

Most viral and bacterial diseases are spread by direct person to person contact (kissing, hugging, touch-

ing) or indirectly as a result of droplets in air which are produced by talking, sneezing, and coughing.

In addition to these modes of transmission, some evidence suggests that these diseases can be transmitted through building-related airborne pathways (such as the heating, ventilating, and air-conditioning system). For example, an epidemic of measles (28 cases after an incubation period of about 10 days) in an elementary school near Rochester, New York was traced to a student in the second grade and a ventilation system that served fourteen classrooms. The ventilation system recirculated air from room to room before being exhausted outside. The investigators concluded that the ventilation system was responsible for the outbreak since the student did not occupy the same room as the other children who became infected (Riley *et al.*, 1978).

In a more recent study, Brundage *et al.* (1988) demonstrated that army trainees who were housed in new energy-efficient barracks with mechanical ventilation had acute febrile respiratory disease rates that were 51% higher, on average, than trainees who were housed in older barracks. These results support the hypothesis that risks of respiratory infection are increased among susceptible populations in buildings that have tightly sealed envelopes and closed ventilation systems.

Infectious agents can also enter the indoor environment from the outside air. Once inside, they can be incubated, amplified, and disseminated by humidifiers, air conditioners, and other building components.

### *Legionella*

*Legionella* is a major cause of respiratory illness worldwide and accounts for 1-13% of all pneumonias seen in hospitals in the United States, Canada, England, and Germany (Feeley, 1985). The bacteria are ubiquitous and can survive in water for long periods of time—up to a year under certain conditions (Skaliy and McEachern, 1979).

Epidemics caused by *Legionella* occur most commonly during the summer and early fall while sporadic cases of disease occur throughout most of the year. The characteristics and causes of some of these epidemics are discussed in Imperato (1981) and Band *et al.* (1981).

Sources of *Legionella* in residences and office buildings include contaminated forced-air heating systems, humidifiers, water flooding, hot water systems, hot tubs, vaporizers, nebulizers, and external sources, primarily cooling towers and evaporative condensers but also dusts from construction and landscaping activities. *Legionella* has also been isolated from potable drinking water.

Two important bacterial diseases which are both caused by *Legionella pneumophila* are Legionnaires' disease and Pontiac fever. These two diseases, which are referred to as legionellosis, are not spread via person-to-person contact. Rather, they can be spread both indoors and outdoors through the soil/air or water/air link.

**Legionnaires' disease:** One of the most dramatic and frightening cases of indoor airborne bacterial infections is the mysterious illness that affected veterans attending the American Legion Convention in Philadelphia in 1976. A pneumonia-like illness was contracted by 182 persons who were either in or near the Bellevue Stratford Hotel. Twenty-nine people died (Fraser *et al.*, 1977). The organism that caused the disease, a gram negative bacillus named *Legionella pneumophila* was first isolated in 1977 at the Centers for Disease Control. The illness, named after the group that was most affected in 1976, has come to be known as Legionnaires' disease.

Legionnaires' disease is a form of legionellosis that is a very severe multi-systemic illness that can affect the lungs, gastrointestinal tract, central nervous system, and kidneys. It is characterized by a low attack rate (2-3%), long incubation period (4-10 days), and severe pneumonia. Hospitalization is required and about 2-3% of cases are fatal even with

proper treatment. It has been estimated that in the U.S., *Legionella* species account for 8% to 10%, or 50,000 to 60,000 cases of community-acquired pneumonias (Fang, 1988).

**Pontiac fever:** Pontiac fever was first recognized in 1968 when, during a one-week period, 95 of 100 employees at the Oakland County Health Department in Pontiac, Michigan became ill with a flu-like illness (Glick *et al.*, 1978). Although a causative agent was not conclusively demonstrated, *L. pneumophila* was implicated 10 years later based on indirect fluorescent antibody tests on sera from patients who came down with the illness. The air-conditioning system was identified as the source and mode of transmission of the agent.

Pontiac fever is a milder clinical form of legionellosis. It is characterized by a high attack rate (90%) and a short incubation period (2-3 days). It is not fatal and it can be resolved without hospitalization. Characteristic symptoms include fever, chills, headache, and muscle ache; additional symptoms may include sore throat, coughing, nausea, diarrhea, and chest pain.

## Allergens

The term "allergic reaction" or "sensitization reaction" refers to a condition in which an immune response results in exaggerated or inappropriate reactions that are harmful to the host. An individual typically experiences an allergic reaction after the second contact with a specific allergen. In order for a substance to produce an allergic reaction, the substance or metabolic product of the substance has to act as a hapten and combine with an endogenous protein to form an antigen. The antigen is capable of eliciting the formation of antibodies. The initial exposure results in an antigen-antibody interaction which results in the manifestation of allergy.

Allergies are commonly acquired health problems which are mediated by a variety of immunologic processes. The substances that cause allergies are

called allergens or antigens. The term airborne allergen refers to allergens that are carried by the air.

Allergens do not affect most people; rather, they provoke an allergic response in a small subset of the population. Allergens that cause reactions include both viable and nonviable agents. Viable agents include bacteria, fungi, amoebae, and algae. Common nonviable agents include house dust, insect and arachnid body parts and hulks, animal danders, mite fecal pellets, cockroach feces, remains of molds and their spores, pollens, and dried animal excretions.

Chemicals found in the home or workplace (plastics, metals, pharmaceuticals, detergents, hair dyes, bleaches) are not biogenic agents, but they have been known to produce allergic reactions in sensitive individuals.

## Illness Caused By Allergens

Several patterns of illness can arise from exposure to allergens including allergic reactions on the skin, in the nose, in the airways, or in the alveoli. It is not known why some people are allergic to otherwise harmless pollen grains or other airborne particles, but it is presumably due to differences in their immune systems. These differences may be partly genetic since allergy-based diseases (allergic rhinitis, asthma, contact dermatitis) often run in families. It has been estimated that about 20% of the U.S. population may have a genetic predisposition toward allergies (Burge, 1988).

In the respiratory tract, allergic reactions begin with a localized inflammatory reaction that may eventually be accompanied by secondary effects such as bacterial colonization (NRC, 1981). The airborne allergens that have the most potential to affect the lower lung are those with small aerodynamic diameters including molds and organic dusts. Most pollens have diameters greater than 12 microns and will affect the upper respiratory tract, but some may reach the lower portions of the lung.



Several important conditions are caused by airborne allergens including allergic rhinitis, allergic asthma, allergic bronchopulmonary aspergillosis, hypersensitivity pneumonitis, and humidifier fever.

**Allergic rhinitis:** Allergic rhinitis is an acute condition that resolves readily when the source is removed. It is commonly called "hay fever" when it is related to pollens produced by the change of seasons, and it affects about 15% of the population.

It is characterized by dilation and edema of the nasal mucosa and mucus secretion; typical symptoms include sneezing, itching, excessive mucus secretion, and obstruction of nasal passages. Conjunctivitis (irritation, itching, and reddening of the eyes) may also be associated with allergic rhinitis. Secondary bacterial infections may result from blocked sinuses and eustachian tubes.

**Allergic asthma:** Allergic asthma affects about 3% to 5% of the population in the U.S. (Reed, 1981). It is characterized by bronchospasm, edema of the bronchial mucosa, accumulation of bronchial mucus, or any combination of these conditions. The narrowing of the airways and production of mucus can block the airways. Typical symptoms include wheezing, shortness of breath, sneezing, itching of the nose, and rhinorrhea. Repeated attacks can lead to a narrowing of the airways which is reversible over short periods of time (spontaneously or with treatment).

Allergic asthma can be caused by a variety of viable and nonviable biological agents. Factors related to indoor air quality such as cigarette smoke, sulfur dioxide, and other particles and gases can precipitate attacks. Emotional stress and exposure to cold have also been shown to result in asthmatic attacks.

**Allergic bronchopulmonary aspergillosis (ABPA):** ABPA is an uncommon, progressive disease that is caused by an allergic reaction to the inhalation of a widely distributed soil fungus, *Aspergillus fumigatus*. Spores are about 3 microns in diameter and grow at

body temperatures. Episodes of ABPA most frequently occur during the winter when the counts of *Aspergillus fumigatus* are highest.

Other species of *Aspergillus* can also result in a variety of syndromes. ABPA is characterized by recurrent episodes of pulmonary eosinophilia, usually associated with asthmatic attacks. As the disease progresses, bronchiectasis (dilation of the bronchial tubes associated with significant mucus production), irreversible airway narrowing, and pulmonary fibrosis may occur in the upper lobes of the lung. Typical symptoms include coughing, wheezing, difficulty breathing, and low-grade fever.

**Hypersensitivity pneumonitis:** Hypersensitivity pneumonitis (also called extrinsic allergic alveolitis) is primarily an occupational disease of agricultural and industrial workers who are exposed to sensitizing agents in organic (especially fungal spores) and inorganic dusts. However, it can and does occur as a result of exposures to sensitizing agents in residential and office environments. Some examples of hypersensitivity pneumonitis include pigeon-breeder's or bird-fancier's lung which is caused by the inhalation of serum proteins in the droppings of pigeons and parakeets. The attack rate has been estimated to be between 0.1% and 21% in pigeon breeders (Parkes, 1982). The inhalation of thermophilic actinomycetes (a group of filamentous bacteria that superficially resemble fungi) growing in moldy hay can produce farmer's lung. Exposure to inorganic compounds such as toluene diisocyanate (isocyanate lung) and copper sulfate (vineyard sprayer's lung) can also produce pneumonitis. Exposure to thermophilic actinomycetes in residential or office ventilation systems can result in ventilation pneumonitis. Fungi which have been implicated in ventilation pneumonitis include *Aspergillus*, *Penicillium*, *Alternaria*, *Rhizopus*, *Paecilomyces*, and *Aureobasidium*. Regardless of the agent, estimated rates of pneumonitis in office workers range from 1.2% (Arnold *et al.*, 1974) to 4% (Gamble *et al.*, 1986).

Hypersensitivity pneumonitis can result from intermittent exposure to high concentrations of allergens or continuous exposure to low concentrations of allergens. The symptoms and progression of the disease are the same, regardless of the agent causing the disease (NRC, 1981). Continuous exposure to low concentrations of allergens often does not result in the appearance of overt symptoms, but at a later time, less reversible stages of the disease can develop.

Sensitization causes an inflammatory reaction in the alveolar walls and peripheral bronchioles due to an allergic reaction between the agent and circulating antibodies and sensitized lymphocytes. The diagnosis of hypersensitivity pneumonitis is made by the physician based on the patient's history and results of some tests. These include restrictive pulmonary function tests, decreased exercise tolerance, granulomas and interstitial fibrosis on lung biopsy, reproduction of symptoms upon bronchial challenge with the suspected agent, and response to corticosteroid medications (Kreiss, 1989).

An acute attack causes symptoms which are similar to the flu: chills, fever, dry cough, shortness of breath, tightness in the chest, and fatigue. Symptoms typically occur within 4 to 6 hours after exposure, and may persist for 12 hours to 10 days. Changes in lung function can return to normal over a period of about a month after the condition develops. Between attacks, the individual may be symptom free and feel fine. Over a period of time, the lung gradually develops fibrous scar tissue. Irreversible pulmonary fibrosis, followed by pulmonary failure, and death can occur in severe cases.

*Humidifier fever* is a type of pneumonitis that is probably due to allergic reactions of the alveolar wall. It has been related to amoebae, bacteria, and fungi. *Bacillus subtilis* (Parrot and Blyth, 1980), amoebae including *A. polyphaga* and *N. gruberi* (Edwards, 1980), and bacterial endotoxin (Rylander *et al.* 1978, 1984) are specific agents which have been implicated in this condition. Sources of these agents include humidifier reservoirs, air

coolers, air conditioners, spas, and aquaria.

The disease is characterized by episodes of flu-like symptoms (chills, muscle aches, malaise) and fever without prominent pulmonary symptoms and signs. Symptoms develop 4 to 8 hours after exposure and resolve spontaneously, usually within 24 hours without long-term effects. Lung function changes may include a restrictive ventilatory defect with a decrease in gas transfer that improves over a period of days. Pulmonary fibrosis does not occur and chest x-rays do not show abnormalities (NRC, 1981).

Chronic humidifier fever has been reported from residential humidifiers (Kreiss and Hodgson, 1984), but the prevalence of the disease (acute and chronic forms) in the home environment has not been evaluated. In Great Britain, an attack rate of 2% to 3% has been estimated in office buildings with mechanical ventilation based on reports of symptoms (Finnegan *et al.* 1984). Epidemics in the workplace are rare, but when they do occur, attack rates are high (30% to 75%).

An additional potential problem associated with the use of some types of humidifiers is the formation of fine particles during the operation of the humidifier. Highsmith *et al.* (1988) measured fine particle concentrations greater than 590  $\mu\text{g}/\text{m}^3$  when an ultrasonic humidifier was operated in a kitchen using tap water containing 303 mg/l total dissolved solids. Using distilled water does reduce, but not eliminate, the formation of fine particulates. Even when the ultrasonic humidifier was operated using purchased distilled water, whole house fine particulate concentrations greater than 40  $\mu\text{g}/\text{m}^3$  were measured. Fine particle concentrations greater than 6300  $\mu\text{g}/\text{m}^3$  were measured when the ultrasonic humidifier was operated in a closed room situation.

Even when distilled water was used by the manufacturer, fine particles were generated. Impeller units generated less than one-third of the aerosol mass compared to the ultrasonic units, and steam units generated no measurable increase in fine particles.

The health consequences of these particulates have not been evaluated.

## Allergenic Agents

### House Dust Mite

One important agent that has been implicated in allergenic conditions such as allergic rhinitis or allergic asthma is the house dust mite. It is not the actual house dust mite that causes disease, but allergens which are probably present in the excreta of the mite, some of which is of inhalable size (Tovey *et al.* 1981). The highest levels of allergens from house dust mites that occur indoors have been shown to be associated with respirable particles in the size range 0.8 to 1.4 microns (Reed and Swanson, 1984).

The house dust mite, which is an arachnid, is about 300 microns long, and it can be found in almost every home. Mites are translucent and cannot be seen with the naked eye. The most commonly found mites include *Dermatophagoides pteronyssinus* (in Europe) and *D. farinae* (in North America) (NRC, 1981).

Mite populations vary depending on atmospheric moisture and food sources. Growth is favored by a temperature of 25 °C and a relative humidity greater than 45%. Below 45% RH at 20 °C to 22 °C, almost no house dust mites are able to survive (Korsgaard, 1982).

House dust mites are important causes of allergic rhinitis and asthma in climates with humid, mild conditions (NRC, 1981). In North America, the mite population is at a maximum during the summer when windows are open and ventilation is good; levels drop in winter when the heating season begins and the relative humidity drops to 10% to 20% (Arlian *et al.*, 1982).

Dust mites feed on the skin scales of humans and other animals. The mites, however, cannot feed on

new skin; rather, they require skin scales that have been defatted. This explains why these mites are found in mattresses, bedclothes, and heavily used upholstered furniture. High concentrations of other specialized mites that cause allergic conditions can also be found in interior spaces that are used to store or process agricultural products.

### Fungi

Fungi are a major group (over 100,000 species) of chlorophyll-less eukaryotic organisms which are formed by hyphae with chitinous or cellulosic rigid cell walls. Most fungi are saprophytic (live off dead organic matter for food), and some fungi require specific substrates for growth and reproduction (dung and wood-rotting fungi, for example). Many can use any nonliving organic matter, providing temperature and moisture conditions are met.

Fungi reproduce either by specialized cells (spores) that are produced on fruiting branches or by fragmentation of the fungus body (mycelium). Fungi have both sexual and asexual stages which can result in allergenic effects, and there may be more than one spore type for each stage. The identification of fungi and spores can be difficult. Many fungi cannot be identified without fruiting structures. Another complicating factor is that fungal names have undergone changes, and the names for the various life cycle stages may be different because they were described at different times (Burge, 1985).

Major fungi classes of interest include Zygomycetes, Ascomycetes (powdery mildews), Basidiomycetes (rusts, smuts, mushrooms), and a fourth class Deuteromycetes or Fungi Imperfecti, which is an artificial grouping of asexual fungus stages (Burge, 1985). The imperfect fungi are perhaps the most important class from an indoor air quality perspective because this class includes *Aspergillus*, *Cladosporium*, *Alternaria*, *Penicillium*, and other saprophytes which are commonly found indoors.

Any organic material that is wet can support the growth of fungi. In the outdoor environment fungi can utilize soil, animal and bird droppings, dead leaves, grass, tree bark, dead wood, and fallen fruits. Indoors, any damp, nonliving organic surface can be colonized by fungi; these surfaces include carpet, upholstery fabric and fillers, wood, concrete, painted surfaces, wall coverings, soap scum on tiles and porcelain surfaces. Humidifiers and air conditioners can also serve as reservoirs for fungi. Some fungi have even become adapted to growth in dry house dust environments (Rijckaert, 1981) and carpeting that is not water damaged (Gravesen *et al.*, 1986).

**Measured concentrations:** The most abundant spore types are produced continuously outdoors during the growing season at concentrations ranging from  $10^3$  to  $10^5/\text{m}^3$ ; these fungi can reach levels of  $10^0$  to  $10^4/\text{m}^3$  indoors. In the outdoor environment, airborne spore concentrations are reduced in areas with snow cover (dispersion of spores is prevented) and where temperatures fall below freezing (spore production is decreased). Spore counts are usually highest in late summer and autumn, although *Aspergillus fumigatus* is more common in autumn and winter (NRC, 1981).

Spores may be introduced into the home from the outside or result from unrestrained growth inside if conditions are favorable. Exhibit 4-15 identifies some fungi which have been isolated indoors.

In the ambient air, concentrations of *Aspergillus fumigatus* rarely exceed  $150 \text{ spores}/\text{m}^3$ , but concentrations in specific sources such as compost piles can exceed several million spores/ $\text{m}^3$ . The concentration in clean interiors is also low, ranging from 0 to  $200 \text{ spores}/\text{m}^3$  (NRC, 1981). Recoveries of thermophilic actinomycetes (filamentous bacteria) in domestic air are generally less than  $3000 \text{ counts}/\text{m}^3$  while occupational exposures can be 10 times higher (Burge *et al.*, 1980).

Factors such as shading of homes and organic debris outdoors have been found to be significantly associated with higher spore concentrations indoors

(Kozak *et al.*, 1985). Indoors, there is a direct relationship between mold growth and airborne spore levels and humidity levels between 25% and 70% (Burge, 1985). Mold growth is suppressed below 25% RH, and humidities above 70% are optimal for growth.

Kozak *et al.* (1985) reported on sources of fungi problems in 186 homes that were surveyed using rotorod and Anderson samplers over a period of 4 years in southern California. Of the 80 homes sampled with both types of sampling devices, 63 had a history of water damage and were suspected of having an endogenous mold problem. Forty-nine percent of these homes had more than one problem area.

The most likely areas with mold problems were the bathroom (31% of cases), living room (18.4%), family room/den (16.5%), and a bedroom (11.7%). The most likely materials were jute-backed carpeting and baseboards (53.5% of problems), wicker straw baskets (17.5%) and walls, ceilings, and window frames (13.6%). The most frequent causes were chronic water spills (35% of problems), followed by recurrent water leaks from plumbing (20.4%) and one-time disasters such as roof leaks and structural defects (10%). Exhibit 4-15 provides a list of molds identified in 68 California homes.

**Disease-producing fungi:** *Alternaria*, *Cladosporium*, *Aspergillus* and *Merulius lachrymans* have been identified as important causes of allergic asthma and rhinitis. Other spores which may colonize the airways include *Candida*, *Scedosporium*, *Scopulariopsis*, *Geotrichium*, and *Paecilomyces* (NRC, 1981). Exhibit 4-16 includes a list of fungi that have been reported as allergenic. Contact with the respiratory tract may be brief, followed by clearance out of the airways, or it may be prolonged and followed by colonization of the airways.

Elimination of fungal growth is necessary for spore-sensitive individuals, but there is no consensus on dose-response relationships. Holmberg (1987) found that airborne levels greater than  $50 \text{ CFU}/\text{m}^3$

of thermotolerant *Aspergillus spp.* were a significant risk factor for irritation of the eyes and respiratory symptoms.

Some clinicians caution allergic patients against keeping living plants or processed plant materials in their homes because they have been implicated as substrates for saprophytic fungi which are allergens. However, Burge *et al.* (1982), in a study of 10 homes and 3 greenhouses in Michigan, concluded that healthy undisturbed houses are not a major exposure source for airborne fungus spores. Samples were collected before and after watering and also while plant foliage was disturbed by a small fan. This study, however, was done in a colder climate and the limited results may not apply to continuously warm and/or humid environments.

#### Other Allergenic Agents

Insect excretions are strong sensitizers that can result in allergic responses. Roach fecal pellets are

important sensitizers, but carpet beetles, houseflies, and bedbugs may also be implicated.

Domestic animals, particularly cats, but also dogs, rabbits, guinea pigs, birds, and horses can be important causes of allergic rhinitis and asthmatic attacks. It is generally accepted that the source of the allergen is animal dander, small scales of feathers or hair, or saliva (cat). Animal danders are very strong sensitizers, and highly sensitive people may develop allergic eczema or urticaria (hives) as a result of direct contact with the allergen. The feces of birds (parakeets and pigeons) can also result in allergic rhinitis, asthma, and hypersensitivity pneumonitis; the original source of the allergen is serum proteins which are secreted in the gut (Reed and Swanson, 1984).

Some individuals may also be allergic to components in tobacco smoke, chemical cleaners, dyes in carpeting, hair sprays, evergreen Christmas trees, and other chemical agents.

**Exhibit 4-15. Molds identified in 68 homes in southern California.**

MOLD GENERA	PERCENT OF HOMES IN WHICH GENERA ISOLATED	RANGE OF SPORES/m <sup>3</sup>	MEAN OF SPORES/m <sup>3</sup>
<i>Cladosporium</i>	100.0	12 - 4,637	437.7
<i>Penicillium</i> species	91.2	0 - 4,737	168.9
<i>Nonsporulating mycelia</i> <sup>a</sup>	89.7	0 - 494	44.3
<i>Alternaria</i>	87.0	0 - 282	30.7
<i>Streptomyces</i>	58.8	0 - 212	28.1
<i>Epicoccum</i>	52.9	0 - 153	9.6
<i>Aspergillus</i> species	48.5	0 - 306	15.0
<i>Aureobasidium</i>	44.1	0 - 294	8.0
<i>Drechslera</i> ( <i>Helminthosporium</i> )	38.2	0 - 94	6.9
<i>Gephalosporium</i>	36.7	0 - 59	5.3
<i>Acremonium</i>	35.3	0 - 188	3.6
<i>Fusarium</i>	25.0	0 - 47	4.5
<i>Botrytis</i>	23.5	0 - 54	2.9
<i>Aspergillus niger</i>	19.1	0 - 59	2.9
<i>Rhizopus</i>	13.2	0 - 24	1.4
<i>Rhodotorula</i>	11.8	0 - 29	1.5
<i>Beauveria</i>	10.3	0 - 12	0.7
<i>Chaetomium</i>	8.8	0 - 47	1.2
Unknown	8.8	0 - 34	1.2
<i>Scopulariopsis</i>	8.8	0 - 25	0.9
<i>Mucor</i>	7.4	0 - 41	1.4
<i>Curvularia</i>	7.4	0 - 12	1.1
<i>Rhinochadiella</i>	4.4	0 - 12	0.5
<i>Verticillium</i>	4.4	0 - 12	0.4
<i>Plenozythia</i>	4.4	0 - 6	0.3
<i>Pithomyces</i>	2.9	0 - 25	0.4
<i>Zygosporium</i>	2.9	0 - 18	0.4
<i>Paecilomyces</i>	2.9	0 - 12	0.3
<i>Stachybotrys</i>	2.9	0 - 12	0.3
<i>Aspergillus fumigatus</i>	2.9	0 - 5	0.2
<i>Nigrospora</i>	2.9	0 - 5	0.1
<i>Stysanus</i>	2.9	0 - 6	0.1
<i>Pleospora</i>	1.5	0 - 18	0.3
<i>Botryosporium</i>	1.5	0 - 12	0.2
<i>Trichoderma</i>	1.5	0 - 12	0.2
<i>Chrysosporium</i>	1.5	0 - 6	0.1
<i>Phoma</i>	1.5	0 - 6	0.1
<i>Sporobolomyces</i>	1.5	0 - 6	0.1
<i>Trichothecium</i>	1.5	0 - 6	0.1
<i>Ulocladium</i>	1.5	0 - 5	0.1
<i>Yeast</i>	1.5	0 - 5	0.1
<i>Geotrichum</i>	1.5	0 - 3	0.04

<sup>a</sup> Subcultures of nonsporulating mycelia from one home (grown on Moyer's multiple media) subsequently produced *Torula herbarium* colonies.

SOURCE: Kozak P.P., J. Gallup, L.H. Cummins, and S.A. Gillman. "Factors of importance in determining the prevalence of indoor molds." *Annals of Allergy*. 1979; 43: 88-94. Copyright ©, The American College of Allergists. Used with permission.

**Exhibit 4-16. Fungi reported as allergenic.****Myxomycetes**

*Fuligo*  
*Stemonitis*  
*Lycogala*

**Deuteromycetes**

*Alternaria*  
*Cladosporium*  
*Aspergillus*  
*Sporobolomyces*  
*Penicillium*  
*Epicoccum*  
*Fusarium*  
*Candida*  
*Rhodotorula*  
*Tilletiopsis*  
*Phoma*  
*Botrytis*  
*Helminthosporium*  
*Monilia*  
*Paecilomyces*  
*Sporotrichum*  
*Stemphylium*  
*Trichothecium*  
*Cephalosporium*  
*Gliocladium*  
*Aureobasidium*  
*Trichoderma*  
*Coniosporium*  
*Dicoccum*  
*Nigrospora*  
*Torula*  
*Spondylocadium*  
*Curvularia*  
*Epidermophyton*  
*Trichophyton*

**Zygomycetes**

*Mucor*  
*Absidia*  
*Rhizopus*

**Ascomycete - sexual stages**

*Xylaria*  
*Eurotium*  
*Erysiphe*  
*Daldinia*  
*Chaetomium*  
*Claviceps*  
*Microsphaera*  
*Saccharomyces*

**Basidiomycetes****Heterobasidiomycetes**

*Puccinia*  
*Ustilago*  
*Tilletia*  
*Urocystis*  
*Dacrymyces*

**Holobasidiomycetes**

*Chlorophyllum*  
*Podaxis*  
*Agaricus*  
*Armillaria*  
*Coprinus*  
*Hypholoma*  
*Ganoderma*  
*Merulius*  
*Polyporus*  
*Stereum*  
*Pleurotus*  
*Cantharellus*

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## SECTION 5.

### CONTROL OF INDOOR AIR CONTAMINANTS

This section supplements Lesson 5 of the *Learning Module*, which covers various options for controlling indoor air quality, and Section 8 of the *Reference Manual*, which provides inspection techniques for specific contaminants. Section 5.1 contains an overview of heating and distribution systems, and a general discussion of moisture control in residences.

Section 5.2 describes types of air cleaners and methods for testing their efficiency. It provides a summary of the ASHRAE (Standard 52-1976) and ANSI/AHAM (Standard AC-1-1988) methods for evaluating air cleaners. Section 5.3 consists of Exhibits 5-12 and 5-13, which are referenced in the *Learning Module*, and which provide listings of public interest, professional, and trade associations that are involved in controlling indoor air contaminants.

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## 5.1. RESIDENTIAL HEATING SYSTEMS AND MOISTURE CONTROL

### RESIDENTIAL HEATING SYSTEMS

#### Types of Heating Systems

The purpose of heating and cooling systems is to provide sufficient warmth during the winter and adequate cooling during the summer without discomfort to the occupants. There are many potential heating and cooling system configurations for residential use. These include conventional gas or oil furnaces, continuous condensing furnaces, electric furnaces and heaters, heat pumps, fireplaces and woodstoves, coal furnaces, and hydronic (hot water) heating systems.

Older homes (more than 50 years old) are likely to have a gravity furnace, hot water, or steam system. Homes built during the last few decades are likely to have forced-air systems, but some may have hydronic systems in which water is pumped through pipes and radiators. Hydronic systems were used after World War II in houses built on concrete slabs. Newer houses may have heat pumps or continuous condensing furnaces. And houses of all types and ages could have fireplaces and/or wood stoves for primary or supplementary heating.

#### Hot Air Systems

**Gravity systems:** Gravity-air systems consist of a furnace that heats air which is circulated through a ducting system. The gravity-air system has a furnace (often called an octopus) that occupies a large portion of a basement with large "arms" (delivery and return ducts) that extend from the furnace. The furnace is basically a metal box inside a larger one. As fuel burns, air in the larger box is heated and flows through individual ducts to the heat registers in different rooms. As the air cools, it sinks and travels back through the return air ducts to the furnace where the air is heated again. Combustion gases are exhausted through a chimney. Since there are no moving parts, this system is very

quiet. Humidifiers can be attached, but this system cannot accommodate other air cleaning equipment. Cold spots typically result along outer walls during cold days in houses that are not well insulated.

**Forced-air systems:** The forced-air system is similar to the gravity system, but it has a blower driven by an electric motor which pulls the cold air into the return ducts, blows it through the heat exchanger in the furnace, and back into the hot air ducting. Another difference is that the cold air ducts run to a main return duct from each room return rather than to the individual ducts as in a gravity system.

Forced-air systems are more efficient than gravity systems; the furnace does not need to be centrally located, and smaller furnaces can be used. The furnace can be located in a basement, attic, garage, or first floor of the house. Humidifiers and air-cleaning equipment can be accommodated. Forced-air systems are generally more comfortable because heat stratification is reduced.

#### Hot Water (Hydronic) Systems

**Gravity systems:** Hydronic gravity systems (hot water or steam) work on the same principle as the gravity-air system. Hot water (or steam) rises up through a boiler into pipes that connect to radiators. Water flows through the radiators and back to the boiler where it is heated again. These systems provide even heat, but they may be slow to respond to demands for more heat.

**Pump driven systems:** The hydronic pump driven system is the hot water equivalent of a forced-air system. This system is more efficient than the hot water gravity system and the boiler and pipes can be smaller. The boiler can be installed anywhere. Water can be carried through the radiators by a series loop, one-pipe, or two-pipe systems.

#### Electric Baseboard Heating Systems

Electrical baseboard heating systems can be installed for whole house heating or localized heat. The

system usually has one or more baseboards in each room, and each unit in a room can be individually controlled. This system does not require flues or chimneys. Baseboard units are typically resistance coils or antifreeze units.

### Gas/Oil Furnaces

Conventional gas and oil furnaces are similar except that the burners (and fuel) are different. Most gas furnaces have a burner with a number of jets; some have a single large jet in which the flame is spread by a deflector plate. Both types commonly have a pilot light which heats a thermocouple that holds open an electrical valve that supplies gas to the furnace. Oil furnaces have a combustion chamber into which oil is pumped through a spray nozzle and mixed with air which is blown into the chamber. The oil burner does not have a pilot light; instead, it is ignited by a high-voltage spark across a pair of electrodes positioned directly in the stream of oil and air. Exhibit 5-1 shows typical installations for oil furnaces in older homes.

In conventional natural-draft furnaces, the gas is supplied to the burner at low pressure and mixed with the required amount of air for combustion. The hot gases pass through a heat exchanger where air (or water) is heated, and the waste gases are then vented through a chimney to the outside. These systems are inefficient (flue gas temperatures are 300°F to 500°F) and large quantities of hot air can escape up the chimney even when the chimney is not operating because the draft hood and combustion chamber are open to the flue.

Mechanical (also called powered) combustion furnaces utilize a small electric fan to move the combustion gases; they do not need a chimney or draft hood, which increases efficiency. Combustion gases exit through a small vent, usually to an outside wall. If the blower is located upstream of the heat exchanger, the system is called a forced-draft system. If the blower is located downstream, the system is called an induced-draft system. Either of these furnaces can be configured as a direct-vent

furnace in which combustion air is obtained from outside the structure.

Continuous condensing furnaces are very efficient (up to 95%) because they have two or more heat exchangers that capture most of the heat that normally goes up the flue. The first heat exchanger operates in the same way as a conventional furnace; the additional exchangers condense the water vapor in the flue gases to extract the latent heat, and condensate is drained to a house sewer. The temperature of flue gases is lower (100 to 180°F) and the gases are exhausted through a small flue (often PVC pipe) by an induced draft fan. Standard features include spark ignition and a direct outside air feed to the combustion chamber.

All furnaces (gas, oil, or water) need safety devices which switch off the gas or power to the pump/blower motor in case the air or water reaches a temperature that exceeds the design temperature.

Exhibit 5-2 illustrates different configurations of gas-fired, forced-air furnaces that may be encountered in residential heating systems.

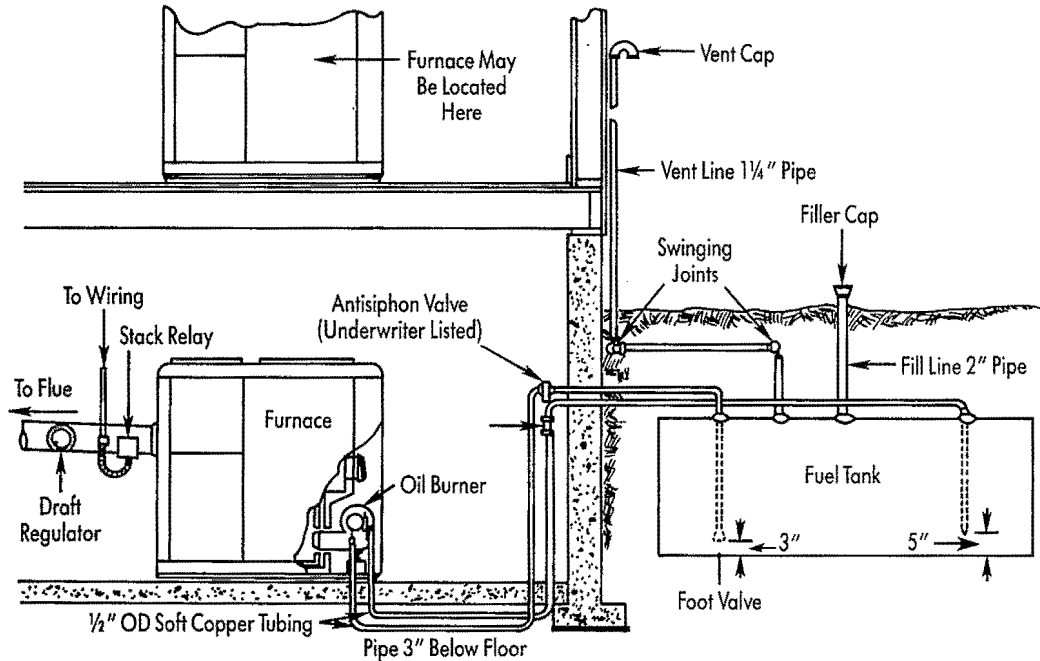
### Forced-Air Delivery Systems

Forced-air delivery systems include extended plenum and graduated trunk systems for basements, radial and crawl space plenum systems for crawl spaces, and slab-on-grade forced-air systems (Exhibit 5-3). Basement forced-air systems typically use an extended plenum duct system or a graduated trunk system. Crawl space systems include a radial system in which supply ducts radiate out from a supply plenum. Slab-on-grade forced-air systems consist of a down-flow furnace connected to radial supply ducts which are set in place before the concrete is poured.

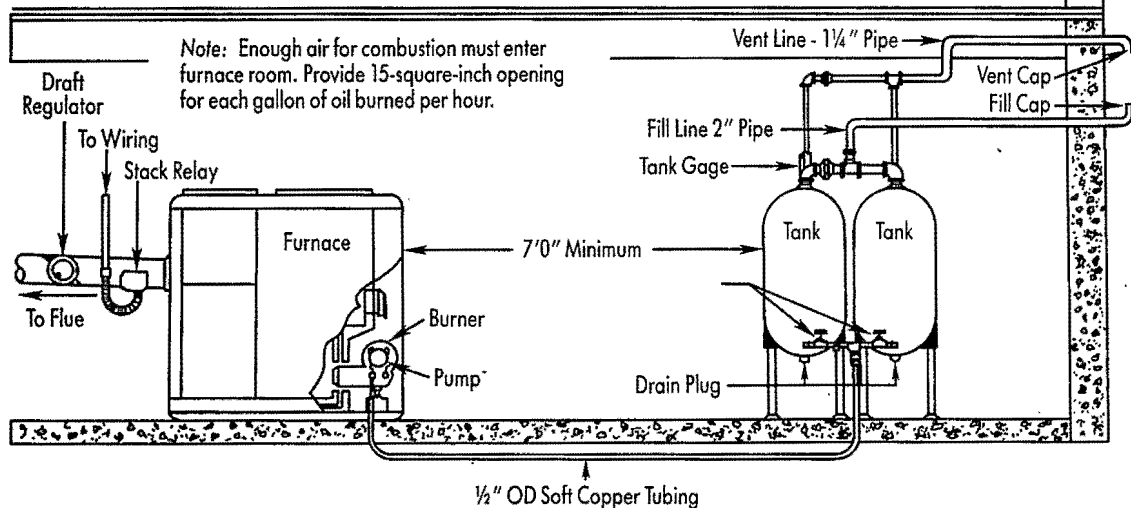
Regardless of the type of system used, warm air supply registers should be located against outside walls, preferably beneath windows so that rising warm air counteracts the falling cold air. Cold air return grills should be located in or near inside

**Exhibit 5-1. Oil furnace installation.****118****Piping Hook-up for Buried Outside Tank**

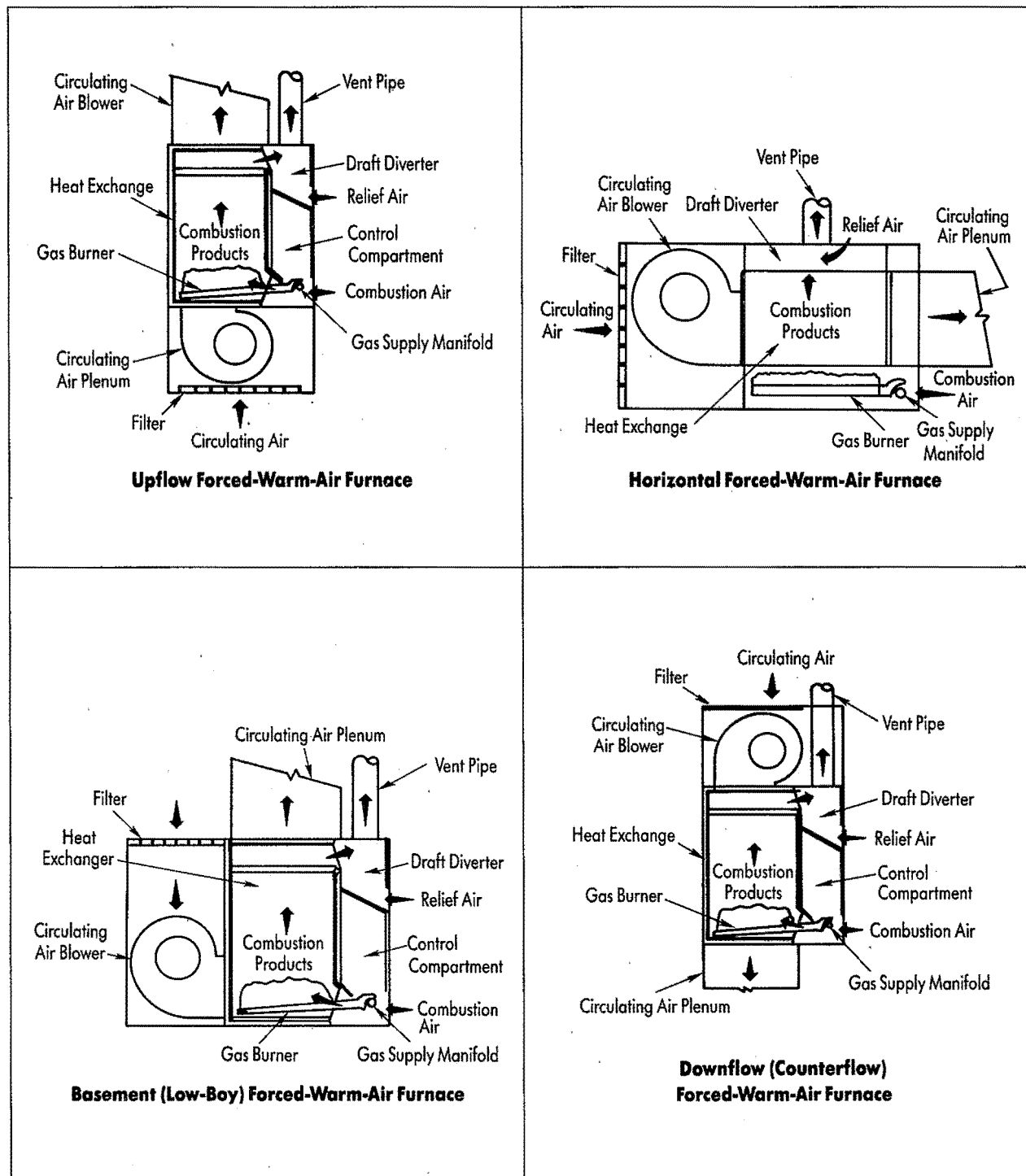
Note: Enough air for combustion must enter furnace room. Provide 15-square-inch opening for each gallon of oil burned per hour.

**Piping Hook-up for Inside Tank Installation**

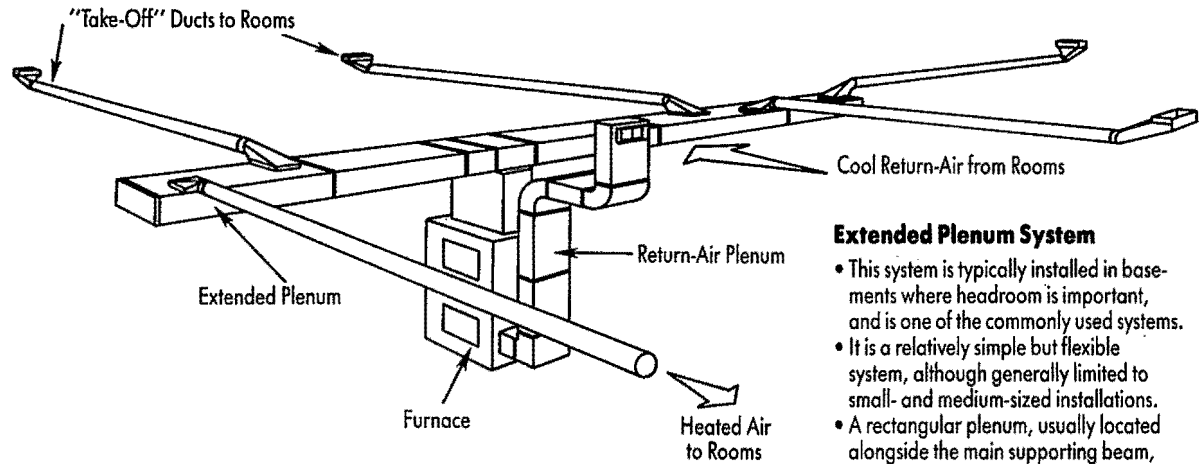
Note: Enough air for combustion must enter furnace room. Provide 15-square-inch opening for each gallon of oil burned per hour.



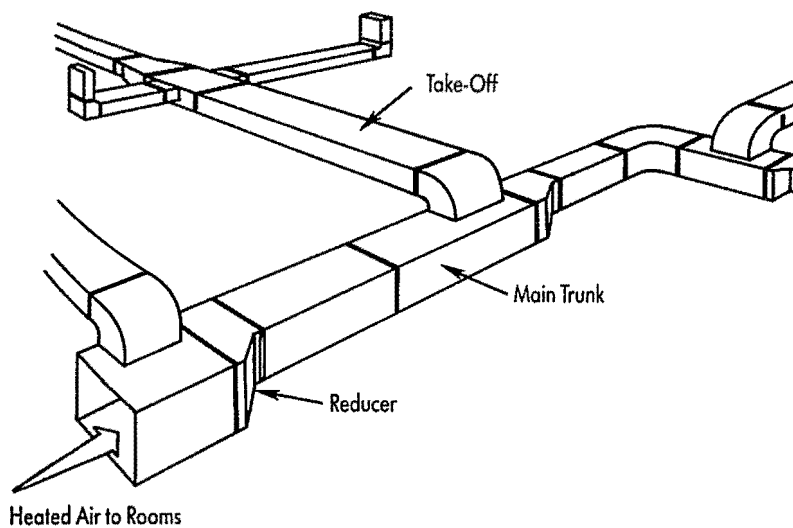
SOURCE: U.S. HUD (1976)

**Exhibit 5-2. Gas-fired forced-air furnace configurations.**

**SOURCE:** Reprinted with permission of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers from the 1988 ASHRAE Handbook—Equipment.

**Exhibit 5-3. Forced-air distribution systems****120****Extended Plenum Duct System****Extended Plenum System**

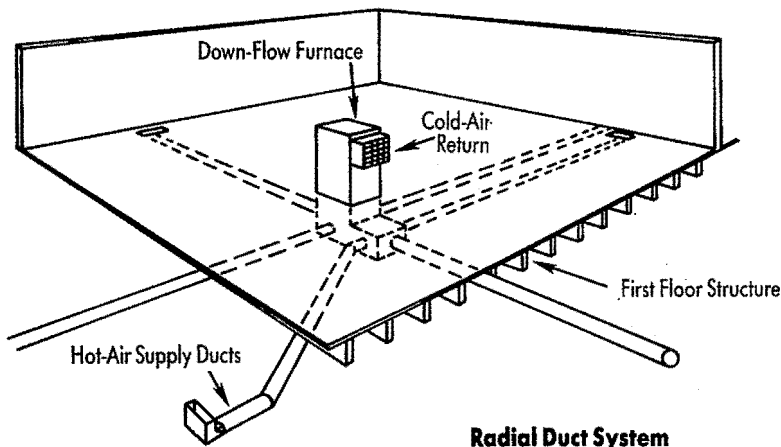
- This system is typically installed in basements where headroom is important, and is one of the commonly used systems.
- It is a relatively simple but flexible system, although generally limited to small- and medium-sized installations.
- A rectangular plenum, usually located alongside the main supporting beam, is extended from one or both sides of the furnace.
- Individual room "takeoff ducts" extend at right angles the plenum and can often be hidden in the space between floor joists for an unrestricted headroom.
- Either a single floor-level central cold-air return or a matching extended plenum return air duct with several pickups can be used.

**Graduated Trunk Duct System****Graduated Trunk System**

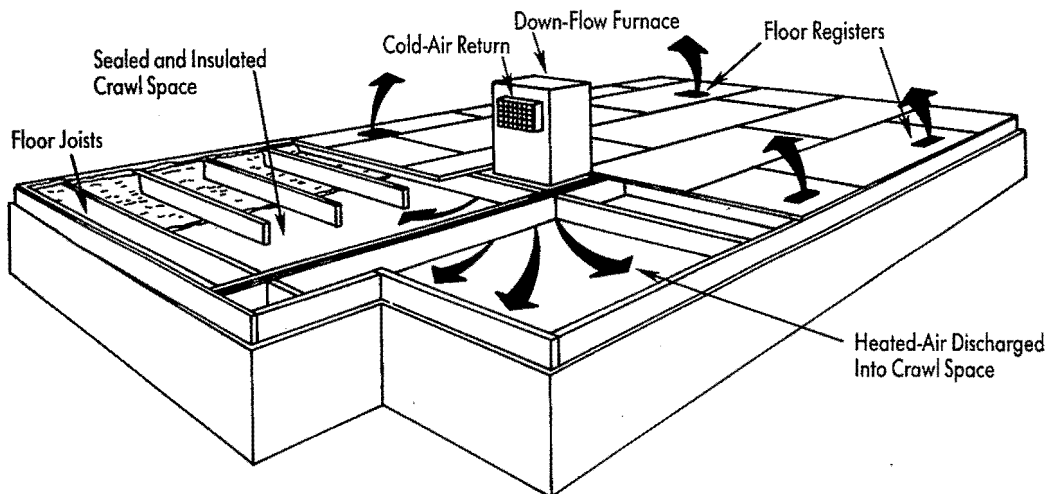
- This is similar to the extended plenum system but has a main supply trunk that is graduated in size to help balance delivery pressure after each takeoff.
- This is an ideal but expensive system and is generally used only for larger or more complex installations.

**SOURCE:** Peter A. Mann, P.A. 1989. *Illustrated Residential and Commercial Construction*. ©1989, Figures 14-11, 14-12, 14-13. Reprinted by permission of Prentice Hall, Inc. Englewood Cliffs, NJ 07632.



**Exhibit 5-3. Forced-air distribution systems (continued).****121****Radial Duct System****Radial System**

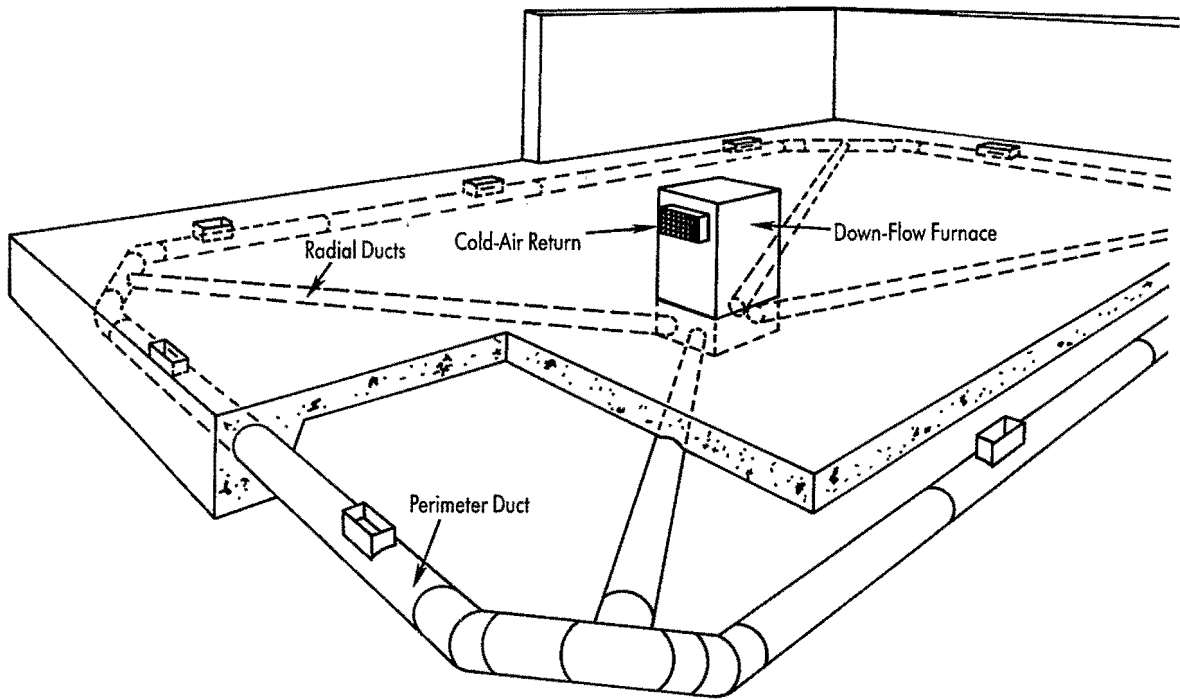
- This system requires a "down-flow" type of furnace that blows warm air downward to a distribution plenum beneath the floor.
- Individual room supply ducts radiate out from the supply plenum, as shown at the left, and are positioned below the floor joists.
- This system is generally used only in crawl space or slab-on-grade construction, where headroom below the supply ducts is of no concern.
- The cold-air return is usually through a single grille on or near the furnace head.
- In an unheated crawl space the supply ducts must be sealed and well insulated.

**Crawl Space Plenum System****Crawl Space Plenum System**

- In this system the crawl space itself is used as a plenum to distribute the warm air to the individual rooms.
- A down-flow furnace is located on the first floor and discharges warm air into the crawl space, where a positive pressure is created. The warmed air then flows upward through the open floor registers into the first-floor rooms. In addition to the convection effect, the floor is warm and radiates heat. This increases the mean radiant temperature and raises comfort levels.
- Variations in crawl space depth have little effect on the system's overall efficiency, and any type of foundation construction can be used.
- The foundations and crawl space floor must be treated as a fully heated basement and insulated to suit. The crawl space must be made airtight using a continuous and sealed air/vapor barrier.
- System costs are relatively low since no supply ducts are required and overall system efficiency tends to be quite high.

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(continued next page)

**Exhibit 5-3. Forced-air distribution systems (continued).****122****Perimeter Loop System****Perimeter Loop System**

This is similar to the radial system shown opposite with the addition of a perimeter loop connected to the radial supply ducts.

- Supply registers are located in the outer loop at suitable room positions.
- Fewer radial feeder ducts are needed, and the slab perimeter is kept relatively warm provided that the perimeter loop is not insulated.
- The feeders and loop are set in place before the concrete floor slab is poured. Ensure that the ducts are sloped downward toward the supply plenum for the collection of any water that may accumulate in the system.

The radial system can also be used in slab-on-grade construction but tends to result in cold floor areas at the slab perimeter.

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partition walls. Ducts should not be located in cold spaces such as outside walls.

A crawl space plenum system could also be used in which air from the furnace discharges into the crawl space. This creates a positive pressure and warm air flows upward through open floor registers. The foundation and crawl space floor must be insulated and the crawl space must be made airtight using a continuous and sealed air/vapor retarder. These systems may be susceptible to microbial or soil gas contamination of the ventilation air.

## MOISTURE CONTROL

This section provides an overview of sources and solutions to moisture problems; the basis of this discussion is *Moisture and Home Energy Conservation* (NCAT, 1983). This document is a useful reference, and it is available at minimal cost from the National Center for Appropriate Technology. In addition, books on the construction of energy efficient homes or retrofits of existing homes will also be helpful.

Moisture problems can occur in any part of the U.S. as a result of improper construction and control methods, but some areas, such as the coastal states or areas where winter temperatures average 35°F or less, have special problems. Moisture problems result from a combination of these climatic factors and many activities and situations inside and outside the home.

Sources inside the home can result in significant releases of water vapor (humidity). For example, the water vapor produced by a humidifier could be about 48 pounds in 24 hours; gas appliances produce about 88 pounds for each 1000 ft<sup>3</sup> of gas burned; washing and rinsing an 8 ft x 10 ft room produces about 2.5 pounds; drying 10 pounds of clothes produces about 10 pounds; and 4 occupants in the home produce about 3 pounds of water vapor each day (Hedden, 1982).

As moisture is produced it can be present as a vapor (gas), liquid, or solid. Water vapor travels through the home by air movement and diffusion, and liquid water travels by capillary action. This movement is largely controlled by differences between pressure inside of the house and outside of the house and the movement of water vapor from an area of higher pressure to an area of lower pressure.

Capillary action refers to the movement of liquid water from a source through a porous material such as soil. Capillary action can be an important route of water vapor entry through basements and crawl spaces. Diffusion is the direct movement of water vapor through the building materials; it occurs as interior sources contribute to the buildup of water vapor and the interior pressure increases. Water vapor is primarily transferred through air movement caused by wind or temperature and pressure differences between the interior and exterior of the structure.

During the winter, warm interior air may pass to the outside through cracks and openings in the building. If the warm, moist air comes into contact with cooler surfaces, the water vapor will condense onto the cooler surfaces (condensation). During the summer when the outside air is warmer and moister than inside air, the air flows into the house carrying moisture with it. Wind can also cause pressure differentials, and the downwind side of a house may show more signs of moisture because water vapor is being forced through this side.

The movement of moisture in, around, and through the envelope of the house is a prime consideration in the design and construction of the house. This is an area that is especially important in the design of energy efficient homes because of the relatively low air exchange rates in these homes. If water vapor is not controlled, many problems can result.

Too much water vapor can cause window sweating when warm, moist air contacts cold surfaces. Warm air holds more water vapor than cold air, and the

water in the warm air will condense on the cold surface as the air comes in contact with the window. Even if a storm sash is used, problems can result. If condensation appears on the inside window, the storm sash may be leaking cold air which cools the inner pane causing condensation; or there is simply too much moisture in the house. If the outside sash has condensation, the inside window is leaking warm, moist air which condenses on the cold exterior pane.

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A problem which is not immediately obvious is condensation which occurs inside walls. Condensation can occur in exterior walls without vapor retarders or in those that have vapor retarders on the cold side of the wall or on both the cold and warm sides. If a home is uninsulated, water vapor is released from warm interior air as it passes through the building envelope, and if the temperature is cold enough, this moisture freezes. Over the course of the winter, the ice builds up and melts as the weather warms. Over time, serious structural damage can result. If a house has insulation (loose, batt, or foam), but no vapor retarder, the same process occurs. The insulation does not prevent the moisture from passing through the envelope, and water vapor will condense inside the wall and also pass through the wood and lift paint off the surfaces. (Lifting paint is, therefore, one sign of moisture problems).

There must be sufficient humidity in the home to prevent drying and cracking of wood and irritation to mucous membranes, but it must be controlled to prevent mold, mildew, and structural damage to building components and furnishings. Striking a balance between these two extremes can be difficult, but it is not impossible. Most moisture problems can be solved by minimizing unnecessary sources, minimizing temperature differences, increasing air circulation and ventilation, and altering the moisture transfer rate with the use of vapor retarders.

- Controlling the source of moisture problems is usually a cost effective solution.

Strategies include fixing water leaks, ducting clothes dryer exhaust outdoors, reducing humidifier use, improving drainage, and using kitchen and bathroom exhaust fans.

- Since condensation depends on temperature differences, minimizing these can solve some problems. Strategies include insulating metal window frames, insulating heating and cooling system ducting, improving heating patterns, and installing a vapor retarder.
- The moisture transfer rate can be reduced by weatherizing before insulating, sealing all air leaks from the inside, using a vapor retarder for interior surfaces and in crawl spaces, using moisture resistant exterior wood or waterproofing it, using waterproofing on the exterior or interior of basement walls, installing exterior drainage systems, and eliminating any exterior moisture accumulation.
- Air circulation and ventilation strategies include venting moisture out of enclosed spaces (using existing fans); using ceiling fans to improve circulation; installing wall, roof, and crawl space vents; installing heat recovery ventilators; and installing whole house fans and roof ventilators.

### Installation of Vapor Retarders

The effectiveness of the vapor retarder is measured in permeance (perms) of the material. One perm equals one grain of water per square foot per hour per unit vapor pressure difference. The lower the perm rating of a material, the better it is at reducing the transfer of moisture. For example, 6 mil (1 mil = .001 inch) polyethylene (provides good control) has a perm rating of 0.06 perm compared to concrete, which has a rating of 3.2 perm (NCAT, 1983).

The purpose of a vapor retarder is to keep warm, moist air from coming in contact with surfaces that are below the dew point of the water vapor (the temperature at which condensation occurs). For this reason, a vapor retarder must be located on the warm side of the wall, floor, or ceiling, and it must be tight to prevent the transfer of water vapor.

### Conventional Retrofits

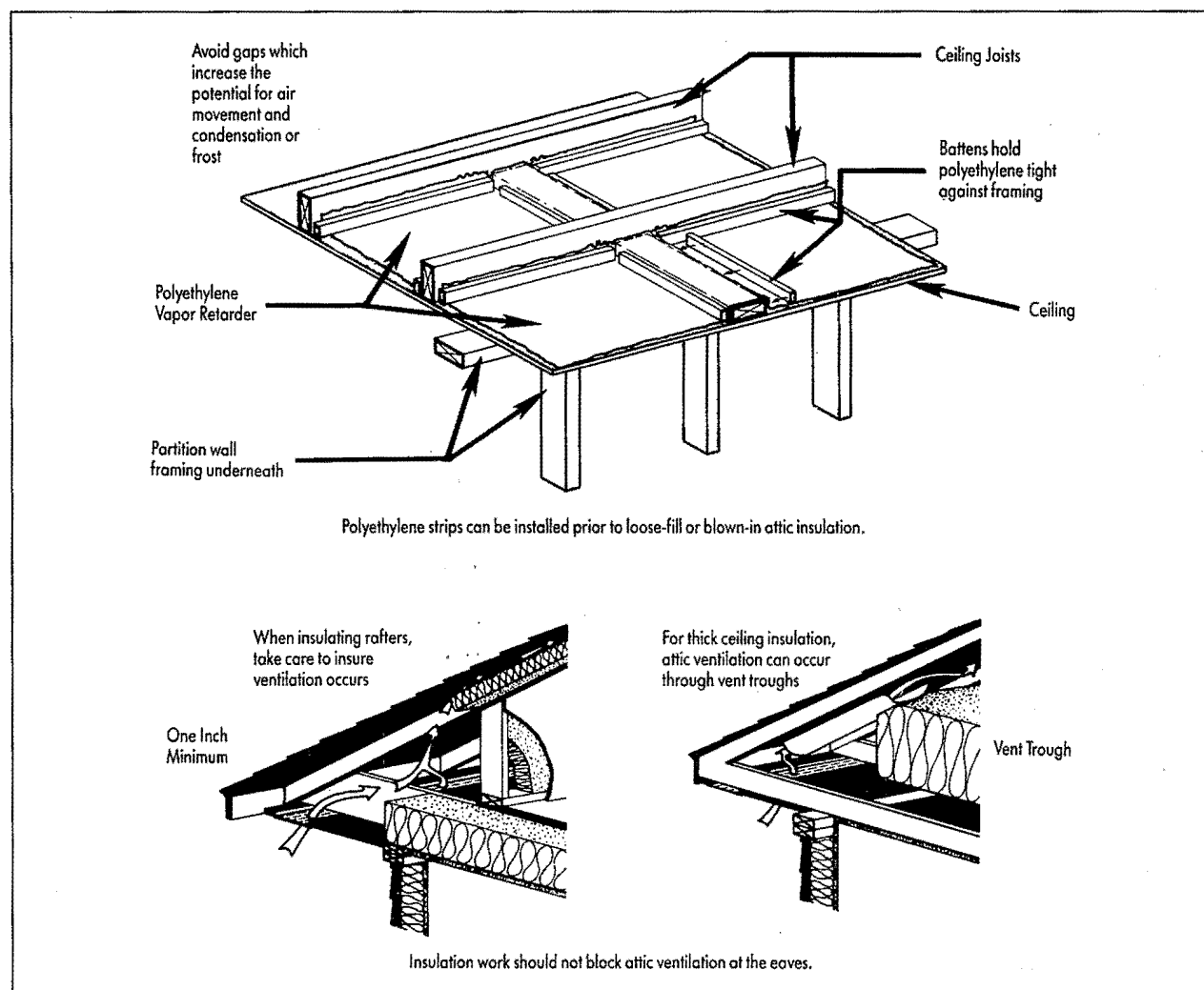
In the attic or ceiling, vapor retarders may be the only way to prevent moisture problems if sufficient

ventilation cannot be provided. It is important to install the vapor retarder carefully. Batt insulation can be tightly stapled to the rafters; or in attics with loose fill insulation, polyethylene can be cut into strips and tightly fitted between the joists (Exhibit 5-4). Regardless of the type of installation, there must be sufficient attic ventilation (eave, ridge, or vent).

In both warm and cold climates, crawl spaces carefully fitted with ground cover and floor vapor

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### Exhibit 5-4. Installation of a vapor retarder in the attic.



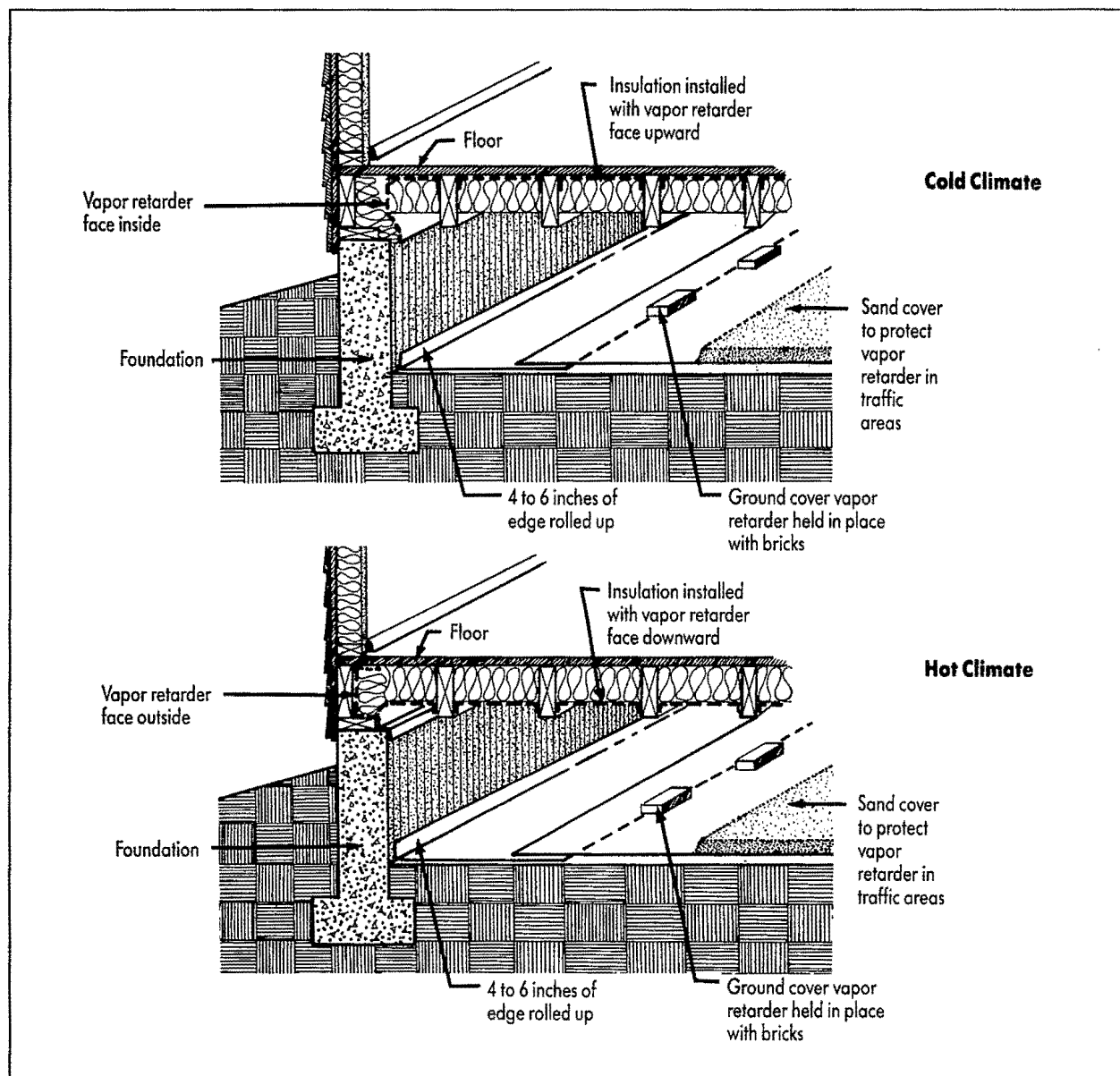
SOURCE: NCAT (1983)

retarders can prevent moisture problems. Ground vapor retarders are installed over the soil and can be held in place with weights or bricks; a more secure method is to cover the retarder with a layer of sand. Floor vapor retarders can also be added to provide greater protection and insulation. The installation differs depending on the climate. In cold climates,

the vapor retarder is installed on the warm side of the floor; in warm climates, the warm side is the bottom of the floor (Exhibit 5-5).

The most cost effective strategy for minimizing moisture problems in walls in retrofit installations is to seal air leakage points from the inside and

**Exhibit 5-5. Installation of a vapor retarder in the crawl space or floor.**



SOURCE: NCAT (1983)

outside of the wall. After ensuring that the leakage points have been sealed, a vapor retarding paint can be applied to the wall surfaces to provide some resistance to water vapor diffusion. In some instances it may be necessary to install a vapor retarder on interior walls.

Weeping windows should be weatherstripped and caulked inside first, and then weatherproofed outside. If an interior-side storm window is used, it must be sealed tightly around all edges. If an outer storm window is added, weep holes at the bottom are recommended. In very cold climates, triple-glazing is recommended.

### Vapor Retarders In New Construction

When moisture problems are encountered in new construction, problems are sometimes due to an improperly installed retarder. Exhibit 5-6 shows elements of a properly installed retarder. Any holes or other leakage points will allow moisture to be transferred. Seams must be carefully overlapped and sealed, gaps around windows, doors, floor/ceiling/wall joints, and electrical and plumbing installations must be sealed. This can be done with polyurethane foam and other sealants and products.

## Ventilation

Providing adequate ventilation to the living space can solve and prevent many indoor air quality problems. Adequate ventilation is necessary to maintain comfort and to prevent the buildup of indoor contaminants, moisture accumulation, and odor problems. Ventilation requirements are given in model and local building codes for conditioned and unconditioned spaces and combustion appliances (Lesson 7 of the *Learning Module* and Sections 7 and 8 of the *Reference Manual*).

Ventilation requirements can be expressed in cfm (lps) per person or cfm (lps) per unit area of floor space. ASHRAE recommends outdoor ventilation rates of 0.35 ach but not less than 15 cfm (7.5 lps) per person in residential construction (includes

single and multiple units) (ASHRAE, 1989). ASHRAE does not address ventilation requirements of combustion appliances or unconditioned spaces; these are given in building codes and codes developed by professional associations for specific appliances.

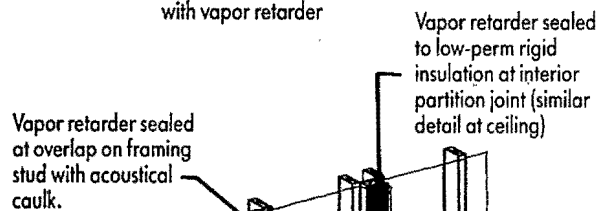
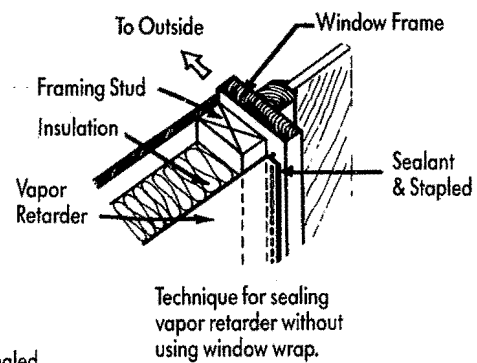
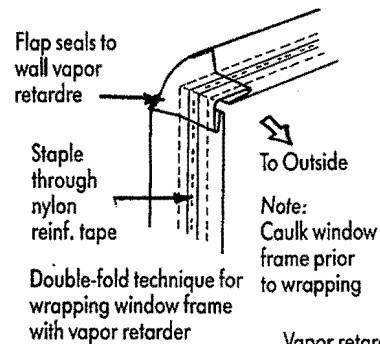
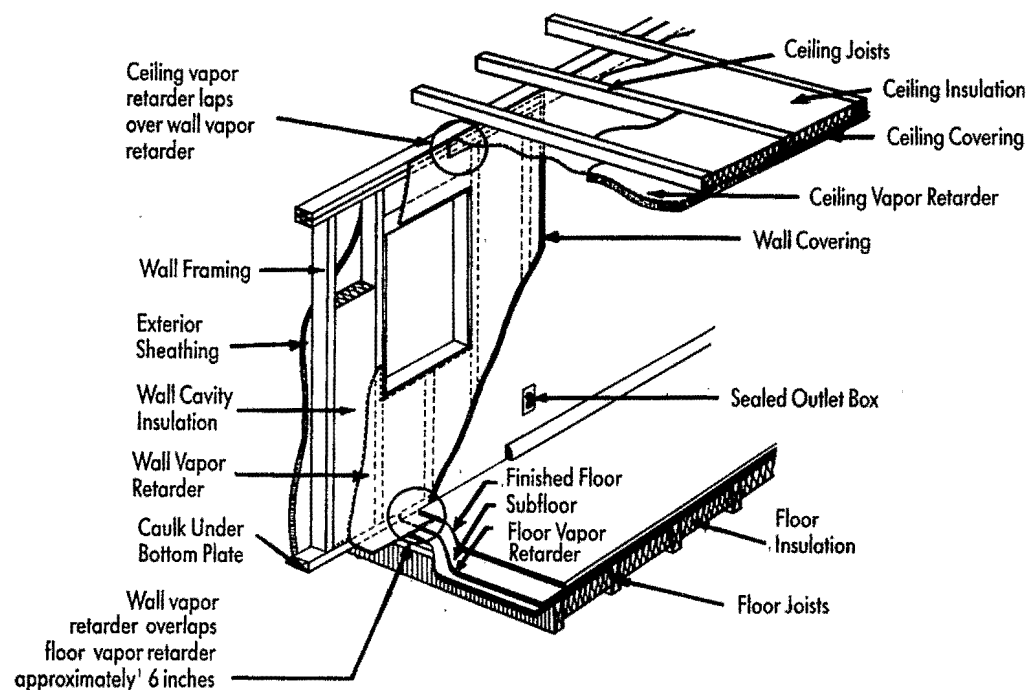
### Attic and Crawl Space Ventilation

Ventilation is needed in the attic during the summer to remove excess heat (temperatures of 150°F or more can be reached) and during the winter to remove excess humidity that moves through the ceiling and condenses in the insulation of a cold attic. Attics can be ventilated using natural or mechanical vents. Natural vents take advantage of the natural flow of air while mechanical ventilation relies on electrically powered exhaust fans.

The needed area for ventilation is determined by the area of the attic space, climate, and the presence of a vapor retarder in the attic. Four types of vents are generally used to provide natural ventilation in attics. Ridge vents provide a continuous opening along the ridge line of a pitched roof. Air can pass through, but rain and snow cannot enter the attic. Roof vents are rectangular or circular openings at intervals along the flat portion of the roof. Under eaves or soffit vents are installed under the eaves in discrete or continuous vents. Gable end vents are located in the gable and they can be rectangular, round, or triangular openings.

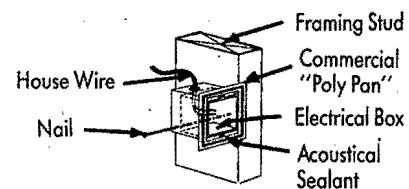
A ridge vent plus soffit vent configuration is considered to be the best system for naturally ventilating the attic. A roof and gable-end system are typically used in older homes (Exhibit 5-7). Houses with cathedral ceilings require a continuous air space above the insulation with continuous eave and ridge vents or individual vents in the eave as well as near the ridge for each rafter space.

The second most effective way of providing natural ventilation in roofs is a combination of turbine ventilators and soffit vents. Turbine ventilators that

**Exhibit 5-6. Installation of a continuous vapor retarder.****128**

Sealing vapor retarder seams and overlaps

(All vapor retarders should be sealed with a flexible, non-hardening, acoustical sealant. Pay special attention to seal window and door frames. All penetrations such as outlet boxes, plumbing and electrical lines, etc.)

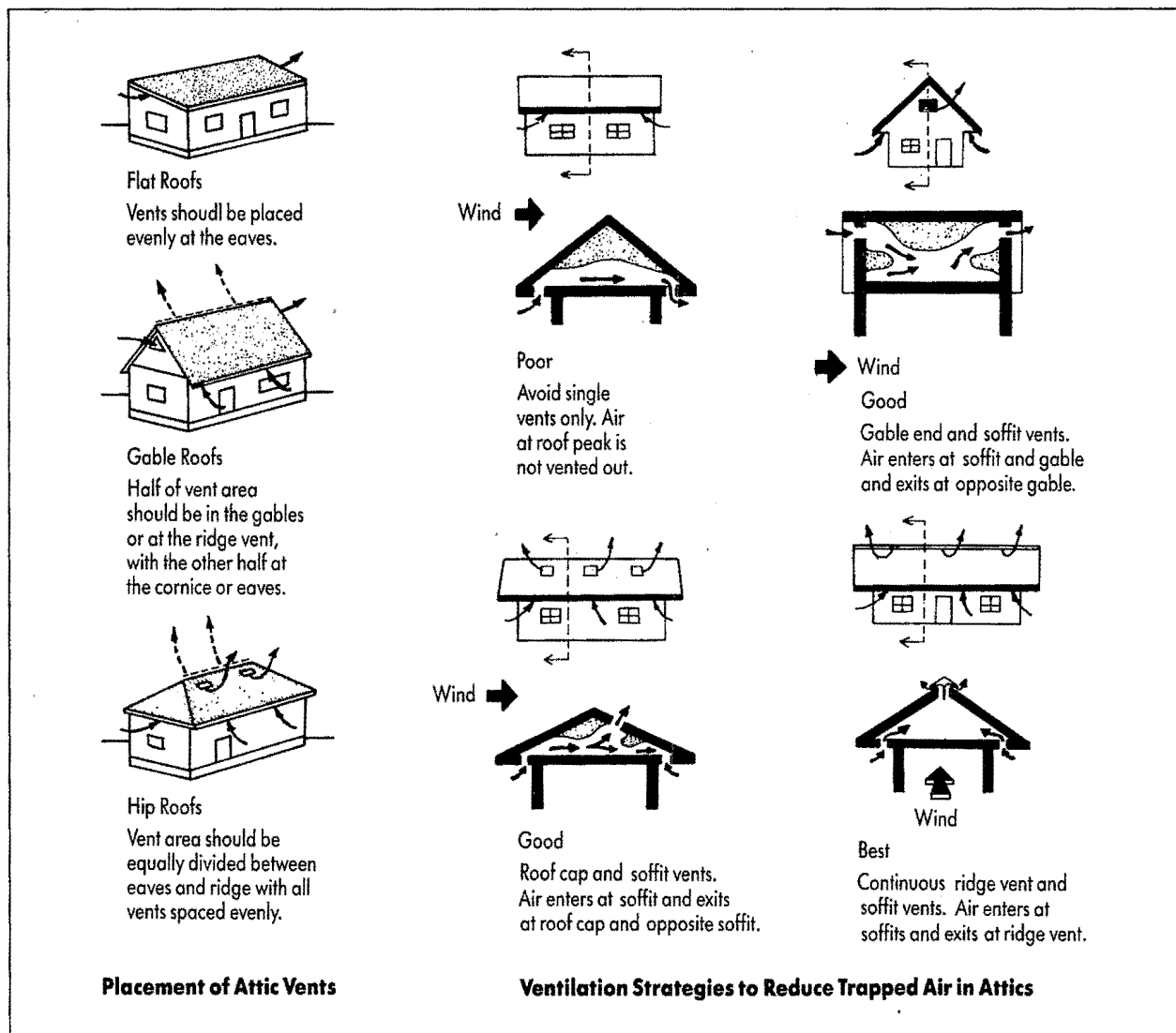


Sealing vapor retarder at electrical outlet box

Note: Put a bead of acoustical sealant on nail head and house wire penetration through "poly pan"

SOURCE: NCAT (1983)



**Exhibit 5-7. Attic ventilation strategies.**

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SOURCE: NCAT (1983)

are 12 and 14 inches in diameter are typically used, and they ventilate about 600 ft<sup>2</sup> and 700 ft<sup>2</sup>, respectively (Hedden, 1982).

Powered ventilation in conjunction with natural airflow can also provide adequate ventilation; the fans can be installed in gables or on the roof. Whole house fans, which are installed in the ceiling, draw air in through windows and exhaust the air into the attic and out the vents. There must be enough vent

area to exhaust the gases (1 ft<sup>2</sup> net free area for each 750 cfm of fan capacity) [Hedden, 1982]. It is important for any other ventilating fans (including kitchen and bathroom fans) to be exhausted directly outside and *not* into the attic space, otherwise air will be forced from the attic back into the living space.

**Sizing attic vents:** The area needed for venting depends on the area to be vented, location, presence

of a vapor retarder, and the type of vent obstructions. More vent area is needed if a vapor retarder is not used. Based on moisture control requirements, NCAT (1983) recommends the following procedure for determining the minimum area required for attic ventilation:

- 1) measure the area to be vented;
- 2) multiply the area by 0.0067 if there is no vapor retarder or 0.0034 if there is a vapor retarder in place;
- 3) multiply the area obtained in step two by one of the sizing factors in Exhibit 5-8 for the type of vent covering to obtain the total gross vent area needed; and
- 4) Determine the proper vent location (Exhibit 5-7).

The CABO code is less stringent and specifies a net free ventilating area of at least 1/150 of the area of the space to ventilate unless other conditions are met (CABO, 1989). This area may be reduced to 1/300, providing that at least 50% of the required area is provided by ventilators located in the upper portion of the space to be ventilated at least 3 feet above eave or cornice vents. If a vapor retarder having a transmission rate less than 1 perm is installed on the warm side of the ceiling, the net free cross-ventilation area must be at least 1/300 of the space ventilated (CABO, 1989).

**Sizing crawl space vents:** The NCAT recommendation for moisture control in the crawl space is similar to the procedure for attics. The area to be ventilated is measured, and whether or not there is a ground cover in place, the area is multiplied by 0.0067 (or 1/150). Then this area is multiplied by one of the factors in Exhibit 5-8.

The CABO code requirements potentially result in less ventilating area whether or not a ground cover is in place, but the difference is particularly greater

#### Exhibit 5-8. Sizing factors for different vent coverings.<sup>1</sup>

TYPE OF VENT COVERING	FACTOR
¼ inch mesh hardware cloth	1
½ inch (8 inch mesh screen)	1¼
No. 16 mesh insect screen (with or without plain metal louvers)	2
Wood louvers and ¼ inch mesh hardware cloth <sup>2</sup>	2
Wood louvers and ½ inch mesh screen	2¼
Wood louvers and No. 16 mesh insect screen	3

<sup>1</sup> In crawlspace ventilators, screen openings should not be larger than 1/4 inch; in attic spaces, no larger than 1/8 inch.

<sup>2</sup> If metal louvers have drip edges that reduce the opening, use the same ratio as shown for wood louvers.

SOURCE: NCAT (1983)

if a vapor retarder is in place. The CABO code specifies that the number of openings should not be less than 1 ft<sup>2</sup> for each 150 ft<sup>2</sup> of crawl space area, and there should be one opening within 3 feet of each corner of the building unless the building qualifies for an exemption. The CABO code allows the openings to be omitted on one side. Another exemption is that the total required area can be reduced to 1/1500 of the under-floor area when there is an approved ground floor vapor retarder and one opening is within 3 feet of each corner of the building (the vents can have operable louvers). In addition to these exemptions, ventilation openings can be vented to the interior of buildings where warranted by climatic conditions.

## 5.2. EVALUATION OF AIR CLEANERS

The evaluation of air cleaners requires information on the efficiency, airflow resistance, dust-holding capacity, effect of dust retention on efficiency and on resistance, and the maintenance which is required to maintain the air cleaner at top efficiency. There is no single test which adequately characterizes all filters or air cleaners. Testing is complex and there are many factors that affect the performance of air cleaners in actual use.

Ideally, testing procedures should approximate the conditions and contaminant concentrations which can be expected to exist during actual use of the devices. The use of standardized tests do allow the performance of different air cleaners and filters to be compared.

Test methods for evaluating air cleaner performance are contained in ASHRAE Standard 52-76 (ASHRAE, 1976) and Military Standard 282 (U.S. DOD, 1956), which is also referenced by ASHRAE. These tests are used to evaluate in-duct systems (filters and electronic air cleaners). Recently, the American National Standards Institute (ANSI) and the Association of Home Appliance Manufacturers (AHAM) have developed a standard for evaluating portable air cleaners.

A useful publication, *Residential Air-Cleaning Devices: A Summary of Available Information*, which summarizes the available information on residential air cleaners, is available from the Public Information Center, Environmental Protection Agency, Washington, DC. 20460.

### ASHRAE Test Methods

The ASHRAE Standard 52-76 test method specifies the evaluation of in-duct air cleaners based on collection efficiency (for total mass and by particle size), pressure drop across the filter, and dust-holding capacity.

### Fractional Efficiency Or Penetration Test

This test is used for high efficiency filters (efficiencies greater than 98%) which are used in clean rooms and nuclear applications. The Thermal DOP (di-octyl phthalate or bis-[2-ethylhexyl] phthalate) test is conducted by feeding a cloud of uniform particles (0.3 micron DOP) into the filter and determining the percentage of particles removed by the filter (U.S. DOD, 1956). The concentration of particles upstream and downstream of the filter is measured using a light-scattering photometer or condensation nuclei counter. Results are usually expressed in percent penetration (equal to 100 minus the percent efficiency) rather than efficiency because HEPA filters are almost 100% efficient.

### Weight Arrestance Test

The weight arrestance test measures the mass collection efficiency of a filter based on a standard synthetic dust of various particle sizes. The synthetic dust specified by ASHRAE (1976) is composed of 72% standardized dust fine, 23% Molocco black, and 5% cotton linters. The synthetic dust cloud has a particle size range that is larger than typical atmospheric dusts. This test is appropriate for evaluating low efficiency filters which remove larger particulates. These filters are used in residential furnaces, air-conditioning systems, or as upstream filters for other air cleaning devices. The test is not appropriate for evaluating the removal of respirable particulates.

### Dust Spot Efficiency Test

The dust spot efficiency test (ASHRAE, 1976) measures how well a filter reduces the soiling of residential interiors. The test is conducted by passing untreated atmospheric air through filter paper targets and measuring the difference in light transmittance before and after air is passed through the filter being tested. The spot efficiencies are

taken at intervals allowing the efficiency to be evaluated as a function of filter loading. This test is most appropriate for determining the efficiency of high to medium efficiency filters and electronic air cleaners.

### Dust-holding Capacity Test

Dust-holding capacity is the amount of a particular type of dust that an air cleaner can hold before its efficiency drops significantly as a result of the resistance imposed by the collected dust. Airflow resistance, or simply resistance, is the static pressure drop across the filter at a given airflow rate, and the term pressure drop is used interchangeably with resistance.

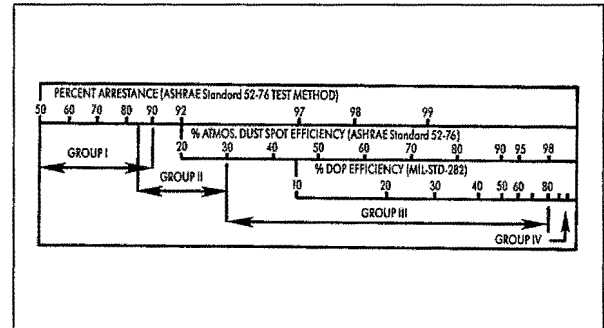
Because of filter variability, ASHRAE's test (ASHRAE, 1976) determines that the dust holding capacity has been reached based on the following criteria: 1) when the maximum pressure drop specified by the manufacturer or when two consecutive measures of arrestance are less than 85%, or 2) when one value is equal to or less than 75% of the maximum arrestance.

### Efficiency Ratings of Filters

Control strategies for indoor air contaminants have recognized the need for efficiency versus size data for submicron particles. Manufacturers have attempted to respond to this need by categorizing the removal efficiencies of filters based on particle size. However, these data are difficult to interpret because there is no standard method for determining the efficiency of air cleaners as a function of particle size.

Exhibit 5-9 summarizes the performance of viscous impingement and dry media filters (ASHRAE, 1988). Note that the percent arrestance, percent atmospheric dust spot efficiency, and percent DOP efficiency do not correlate with one another. For example, a filter with a 92% arrestance may be # 20% efficient based on the dust spot test. This lack of correlation is explained by the types of particles that each test measures.

### Exhibit 5-9. Comparative performance of viscous impingement and dry media filters.



#### Group I

Panel-type filters of spun glass, open cell foams, expanded metal and screens, synthetics, textile denier woven and nonwoven, or animal hair.

#### Group II

Pleated panel-type filters of fine denier nonwoven synthetic and synthetic-natural fiber blends, or all natural fiber.

#### Group III

Extended surface supported and nonsupported filters of fine glass fibers, fine electret synthetic fibers, or wet-laid paper of cellulose-glass or all-glass fibers.

#### Group IV

Extended-area pleated HEPA-type filters of wet-laid ultra-fine glass fiber paper. Biological grade air filters are generally 95% DOP efficiency; HEPA filters are 99.97 and 99.99%; and ULPA filters are 99.999%.

#### Notes:

1. Group numbers have no significance other than their use in this figure.
2. Correlation between the test methods shown are approximations for general guidance only.

**SOURCE:** Reprinted with permission of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers from the 1988 ASHRAE Handbook—Equipment.

Potential applications of these filters can be summarized in terms of efficiency ratings from the ASHRAE tests. Based on the atmospheric dust spot test to evaluate efficiency, the following applications and limitations apply (ASHRAE, 1979).

**Efficiency Rating <10%:** applications include window air conditioners; protection of heat exchanger from lint accumulations; relatively ineffective on smoke, settling dust, and pollen.

**Efficiency Rating of 10% to 20%:** applications include window air conditioners, packaged air conditioners, domestic warm air heating; effective on lint; somewhat effective on common ragweed pollen; relatively ineffective on smoke and staining particles.

**Efficiency Rating of 20% to 40%:** applications include air conditioners, domestic heating, central systems; at 20% efficiency, fairly effective on ragweed pollen; relatively ineffective on smoke and staining particles; effective as a prefilter for final cleanup filters for clean room; same applications at 40%, but with greater degree of effectiveness; somewhat effective in removing smoke and staining particulates.

**Efficiency Rating of 40% to 60%:** applications include building recirculated and fresh-air systems; domestic heating and air-conditioning; use as prefilters to high efficiency types; effective on finer airborne dust and pollen; reduce smudge and stain materially; slightly effective on fume and smoke; ineffective on tobacco smoke at 40%; slightly effective on tobacco smoke at 60%.

**Efficiency Rating of 60% to 80%:** 60% includes same uses as for 40%, but with better effectiveness; 80% used in hospitals and other controlled areas; effective on all pollens, majority of particles causing smudge and stain, fume, coal and oil smoke; partially effective on tobacco smoke; some types reasonably effective on bacteria, but filters (especially in large buildings) can become a medium for growth.

**Efficiency Rating of 80% to 95%:** applications include hospital surgeries, pharmaceutical preparation areas, and other controlled areas; very effective on particles causing smudge and stain, coal and oil smoke and fume; highly effective on bacteria but filters (especially in large buildings) may become a medium for growth; quite effective on tobacco smoke.

**Efficiency Rating > 95%:** applications include hospital surgeries, intensive care wards, clean rooms, pharmaceutical packaging; excellent protection against bacteria, radioactive dusts, toxic dusts, all smokes and fumes; filters above 98% efficiency are generally rated using the DOP test method (Military Standard 282).

### ANSI/AHAM Test Methods

The ANSI/AHAM AC-1-1988 standard rates (AHAM, 1988) the "clean air delivery rate" (CADR) of portable cleaners. The CADR is a measure of how much air a unit is delivering. The delivery of "fresh" air is given in cfm. The fresh air is not 100% fresh because some contaminants may not be removed from the airstream. A cleaner with a CADR rating of 100 can reduce the concentration of a given contaminant equivalent to reductions achieved by adding 100 cfm of fresh air.

Air cleaners with CADR certifications based on the ANSI/AHAM standard are evaluated in terms of the removal of dust (10 to 350 CADRs), tobacco smoke (10 to 300 CADRs), and pollen (25 to 400 CADRs).

Exhibit 5-10 shows a comparison of the removal of smoke, dust, and pollen for portable units as a function of CADR and room size, as estimated by AHAM. These figures are representative of air cleaning results based on tests in an airtight room, and they should only be used as guides. At higher CADRs, the importance of fallout from gravity becomes less important.

**Exhibit 5-10. Estimated percentage of particle removal for portable air cleaners by CADR and room size.**

PERCENTAGE OF PARTICLES REMOVED							
Room Size	CADR	Smoke (20 min)		Dust (20 min)		Pollen (10 min)	
		AC <sup>a</sup>	T <sup>b</sup>	AC <sup>a</sup>	T <sup>b</sup>	AC <sup>a</sup>	T <sup>b</sup>
5 x 6	10	49%	68%	49%	70%	—	—
	40	89%	97%	88%	98%	57%	93%
	80	95%	100%	95%	100%	75%	99%
9 x 12	40	53%	71%	52%	72%	24%	78%
	80	76%	89%	75%	89%	40%	86%
	150	89%	98%	89%	98%	58%	94%
12 x 18	80	53%	71%	52%	72%	24%	78%
	150	74%	87%	73%	88%	38%	85%
	300	89%	97%	—	—	—	—
	350	—	—	91%	99%	—	—
	450	—	—	—	—	69%	97%
18 x 24	150	51%	70%	50%	71%	23%	78%
	300	73%	87%	—	—	—	—
	350	—	—	77%	91%	—	—
	450	—	—	—	—	50%	91%
20 x 30	300	63%	79%	—	—	—	—
	350	—	—	67%	84%	—	—
	450	—	—	—	—	40%	86%

<sup>a</sup> Removal by the air cleaning device<sup>b</sup> Removal by air cleaning device plus natural settling

**Note:** Estimates ignore the effect of incoming air. For smoke and, to a lesser extent, dust, the more drafty the room, the smaller the CADR required. For pollen, which enters from outdoors, a higher CADR is needed in a drafty room.

**SOURCE:** U.S. EPA (1990). Adapted from Association of Home Appliance Manufacturers (AHAM). 1990. *AHAM Consumer Guide for Room Air Cleaners*. AHAM, 20 North Wacker Drive, Chicago, IL 60606. Used with permission of AHAM.

Exhibit 5-11 compares the amount of time required to achieve 90% removal of airborne particles based on CADRs. As a general rule the higher the CADR, the less time needed to remove the same amount of contaminants from a room of identical size because all things being equal, the more air a cleaner processes, the faster it can remove contaminants.

5.3 PUBLIC AND PRIVATE SECTOR ORGANIZATIONS INVOLVED IN INDOOR AIR QUALITY ACTIVITIES

Several public and private sector organizations have activities associated with the control of indoor air quality. Exhibit 5-12 lists the activities of public interest organizations. Exhibit 5-13 identifies activities of professional and trade organizations in the private sector.

Exhibit 5-11. Minutes to achieve 90% removal of airborne particles.<sup>1</sup>

	DUST	SMOKE	POLLEN
No air cleaner operating	128	144	22
CADRs—air cleaner operating			
25	49	51	17
40	36	37	15
80	21	21	12
150	12	12	8
300	6	6	5

<sup>1</sup>includes removal by fallout from natural forces

SOURCE: Association of Home Appliance Manufacturers (AHAM). 1990. *AHAM Consumer Guide for Room Air Cleaners*. AHAM, 20 North Wacker Drive, Chicago, IL 60606. Used with permission.

**Exhibit 5-12. Public interest organization indoor air activities.**

ORGANIZATION	ACTIVITIES
American Lung Association (ALA)	<ul style="list-style-type: none"> <li>• Developed a slide-tape presentation on indoor air pollution</li> <li>• Issued a position paper on indoor air pollution</li> <li>• Distributes information sheets on indoor air pollution hazards</li> <li>• Aggressive "Stop Smoking" campaign</li> </ul>
Americans for Nonsmokers' Rights (ANR)	<ul style="list-style-type: none"> <li>• Develops and distributes model clean indoor air legislation</li> </ul>
American Public Health Association (APHA)	<ul style="list-style-type: none"> <li>• Conducting study on validity and prevalence of multiple chemical sensitivity</li> <li>• Publishes a model housing code that includes indoor air quality</li> </ul>
Consumer Federation of America (CFA)	<ul style="list-style-type: none"> <li>• Testifies before Congress about indoor air concerns</li> <li>• Publishes quarterly newsletter, <i>Indoor Air News</i></li> <li>• Convened EPA-cosponsored IAQ conferences, 1986-1988</li> </ul>
Consumers Union (CU)	<ul style="list-style-type: none"> <li>• Publishes product testing results in <i>Consumer Reports</i> - recently tested air cleaners, unvented kerosene heaters, air-to-air heat exchangers, and radon detectors</li> </ul>
National Coalition Against the Misuse of Pesticides (NCAMP)	<ul style="list-style-type: none"> <li>• Publishes <i>Chemical Watch</i> fact sheets</li> <li>• Testifies before Congress about pesticide issues</li> </ul>
National Institute for Building Sciences (NIBS)	<ul style="list-style-type: none"> <li>• Improves building regulatory environment and facilitates the introduction of building technology</li> <li>• Prepared report on building standards related to indoor air</li> <li>• Provides guidance/information, conducts workshops/conferences on building IAQ issues</li> </ul>
Tobacco-Free Young America Project (TFYA)	<ul style="list-style-type: none"> <li>• Acquires and disseminates information on state and local smoking regulations</li> </ul>

SOURCE: Adapted from U.S. EPA (1989)



**Exhibit 5-13. Professional and trade association indoor air activities.**

ORGANIZATION	ACTIVITIES
Air-Conditioning Contractors of America (ACCA)	<ul style="list-style-type: none"> <li>• Publishes technical manuals on air-conditioning design, installation, and maintenance</li> </ul>
Air-Conditioning and Refrigeration Institute (ARI)	<ul style="list-style-type: none"> <li>• Rates performance of air-to-air heat exchangers, filter equipment assemblies, and refrigeration systems</li> <li>• Convenes a standing committee on indoor air quality</li> </ul>
Air and Waste Management Association (AWMA)	<ul style="list-style-type: none"> <li>• Convenes indoor air sessions at AWMA annual meetings</li> <li>• Convenes specialty conferences on indoor air-related issues</li> </ul>
American Conference of Governmental Industrial Hygienists (ACGIH)	<ul style="list-style-type: none"> <li>• Develops indoor air quality guidelines for industrial exposures</li> <li>• Convenes a committee on bioaerosols</li> <li>• Publishes a manual on air sampling instrumentation</li> </ul>
American Gas Association (AGA)	<ul style="list-style-type: none"> <li>• Develops standards addressing gas leaks and combustion product emissions</li> </ul>
American Industrial Hygienists Association (AIHA)	<ul style="list-style-type: none"> <li>• Convenes an Indoor Environmental Quality committee</li> <li>• Publishes industrial hygiene guidance documents</li> </ul>
American Insurance Association	<ul style="list-style-type: none"> <li>• Monitors environmental issues for liability implications to member insurers</li> </ul>
American Plywood Association (APA)	<ul style="list-style-type: none"> <li>• Recommends practices for handling preservative-treated wood products, using chlorpyrifos, and applying subfloor vapor barriers</li> </ul>
American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)	<ul style="list-style-type: none"> <li>• Develops "Ventilation for Acceptable Indoor Air Quality," Standard 62-1989</li> <li>• Develops thermal comfort and energy conservation standards</li> <li>• Publishes technical information</li> </ul>

*(continued next page)*

**Exhibit 5-13. Professional and trade association indoor air activities (continued).**

ORGANIZATION	ACTIVITIES
American Society of Testing and Materials (ASTM)	<ul style="list-style-type: none"> <li>• Convenes a technical committee on sampling and analysis of atmospheres</li> <li>• Develops test methods for atmospheric analysis</li> <li>• Publishes technical information</li> </ul>
American Institute of Architects (AIA)	<ul style="list-style-type: none"> <li>• Producing an environmental resource guide to help architects be more responsive to environmental concerns, including IAQ</li> </ul>
Building Owners and Managers Association (BOMA)	<ul style="list-style-type: none"> <li>• Provides information on all aspects of building ownership, operation and maintenance functions</li> <li>• Provides guidance to building owners and managers on prevention and mitigation of indoor air quality problems</li> </ul>
Business Council on Indoor Air	<ul style="list-style-type: none"> <li>• Provides information to members on indoor air trends and government and legislative activities on indoor air</li> <li>• Develops and represents positions on indoor air quality before government and legislative bodies to insure that policy is based on accurate and comprehensive information</li> </ul>
Chemical Specialties Manufacturers Association (CSMA)	<ul style="list-style-type: none"> <li>• Represents companies involved in the formulation of household and institutional care products</li> <li>• Develops and represents policy positions before various regulatory and legislative bodies</li> </ul>
Chemical Manufacturers Association (CMA)	<ul style="list-style-type: none"> <li>• Represents chemical manufacturers before various public and private sector bodies</li> </ul>
Electric Power Research Institute (EPRI)	<ul style="list-style-type: none"> <li>• Sponsors research of indoor air quality as it relates to energy consumption and HVAC systems</li> </ul>
Gas Research Institute (GRI)	<ul style="list-style-type: none"> <li>• Sponsors research of indoor air quality concerns of the natural gas industry</li> <li>• Licenses manufacturers of burner inserts for nitrogen oxide emission reduction</li> </ul>
Hardwood Plywood Manufacturers Association (HPMA)	<ul style="list-style-type: none"> <li>• Developed a voluntary standard for formaldehyde emissions from wood products</li> </ul>

**Exhibit 5-13. Professional and trade association indoor air activities (continued).**

ORGANIZATION	ACTIVITIES
Home Ventilation Institute (HVI)	<ul style="list-style-type: none"> <li>Develops standards for heat recovery ventilators</li> </ul>
National Association of Home Builders (NAHB)	<ul style="list-style-type: none"> <li>Supports research of building components and operating parameters which affect indoor air quality</li> <li>Conducts an annual survey of construction materials</li> <li>Provides technical assistance to home builders</li> </ul>
National Association of Realtors (NAR)	<ul style="list-style-type: none"> <li>Supports comprehensive federal legislation that increases the role of government in IAQ research and informative dissemination</li> <li>Committed to a new program of education on IAQ for its membership</li> </ul>
National Center for Appropriate Technology (NCAT)	<ul style="list-style-type: none"> <li>Publishes <i>Moisture and Home Energy Conservation</i></li> <li>Publishes technical information on energy conservation</li> <li>Provides grants and technical assistance on energy-related topics</li> </ul>
National Environmental Health Association (NEHA)	<ul style="list-style-type: none"> <li>Provides information to state and local environmental health officials on indoor air</li> <li>Co-sponsored the <i>Indoor Air Quality Learning Module</i> and <i>Reference Guide</i></li> </ul>
National Plywood Association (NPA)	<ul style="list-style-type: none"> <li>Developed a voluntary standard for formaldehyde emissions from particleboard</li> </ul>
Public Health Foundation (PHF)	<ul style="list-style-type: none"> <li>Developed a directory of state indoor air contacts and surveyed state indoor air quality programs</li> </ul>
Service Employees International Union	<ul style="list-style-type: none"> <li>Surveys and investigates indoor air problems of public service workers, educates members and promotes legislative and regulatory solutions</li> </ul>
Sheet Metal and Air-Conditioning National Association (SMACNA)	<ul style="list-style-type: none"> <li>Provides membership with education through manuals and a home study course</li> </ul>
Tobacco Institute	<ul style="list-style-type: none"> <li>Conducts programs to preserve the rights of smokers and member companies against unwarranted government restraint</li> </ul>

SOURCE: Adapted from U.S. EPA (1989)

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## **SECTION 6.**

### **INDOOR AIR QUALITY MEASUREMENTS**

Section 6.1 contains a detailed listing of indoor air monitoring equipment which can be used for personal or area monitoring of various contaminants. Section 6.2 discusses terms related to the measurement process, and Section 6.3 provides general information to be used in collecting representative samples and determining proper sampling sizes. Section 6.4 outlines basic considerations for calibrating field equipment and provides examples of forms that could be used for calibrations. Finally, Sections 6.5 and 6.6 provide overviews of passive samplers and measurement methods for air exchange rates, respectively.

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## 6.1. INDOOR AIR QUALITY SAMPLING METHODS

### Analytical Methods

Particle and aerosol detectors and gas and vapor detectors were introduced in Lesson 6 of the *Learning Module*. Additional information on gas and vapor detectors follows:

#### Gas and Vapor Detectors

In general, there are seven analytical methods that can be applied to the analysis of gases and vapors (Nader, Lauderdale, and McCammon, 1983). These methods can be incorporated into direct reading field instruments or laboratory-based instruments and techniques.

**Electrical** methods are those in which a sensor responds to chemical and/or physical properties of the contaminant so that the output of the sensor is related to the concentration of the contaminant. Electrical methods include conductivity, potentiometric, coulometric, and ionization detectors. These methods can be used for many contaminants including carbon monoxide, sulfur dioxide, oxygen, formaldehyde, ozone, and oxides of nitrogen.

**Electromagnetic** methods are those in which electromagnetic radiation (in the form of ultraviolet, visible, or infrared radiation) is scattered or absorbed by a contaminant and the energy changes are related to contaminant concentrations. Contaminants which can be analyzed using these methods include carbon monoxide, carbon dioxide, hydrocarbons, and a variety of organic chemicals.

**Chemi-electromagnetic** methods rely on a chemical reaction which is detected through the measurement of electromagnetic radiation. One of the most widely used methods is colorimetry in which a contaminant gas is collected and reacted with a reagent to form a unique colored chemical. The absorption or transmittance of visible light from a source is measured by a detector to determine

contaminant concentrations. Ultraviolet and infrared light sources can also be used. Additional chemi-electromagnetic techniques are photometric (chemiluminescent) methods, which involve the generation and release of radiation followed by detection using photometric techniques. These methods can be used to analyze sulfur dioxide, carbon monoxide, oxides of nitrogen, formaldehyde, and a variety of organic chemicals.

**Thermal** methods can be used to detect contaminants based on conductivity or combustion or to desorb contaminants from a substrate so they can be further analyzed using other methods such as chromatography. These instruments can be used to detect carbon monoxide, carbon dioxide, and combustible gases.

**Gas chromatography** is a technique which can separate complex mixtures of contaminants into individual components. The components of the mixture will migrate differentially as they are carried by a gas (carrier gas) through a porous column which contains a soptive medium. As the components are separated they will emerge from the column at a unique time, and they can be identified by different types of detectors (thermal conductivity, flame ionization, flame photometry, or electron capture).

Gas chromatography can be very useful when coupled with passive or active collection systems. Portable direct reading chromatographic analyzers are also available. These instruments can detect a broad range of organic chemicals. They are equipped with internal calibrators and libraries which are used to identify unknown contaminants. These devices must be evaluated carefully to ensure that they will be able to detect contaminants in the lower ranges typically encountered in nonindustrial environments.

**Magnetic** methods include mass spectroscopy and paramagnetic analyzers. Mass spectroscopy is a technique which is used in conjunction with gas chromatography to analyze a variety of contami-

nants after they have been collected using active or passive methods. Mass spectroscopy classifies ionized molecules, which have been deflected by a magnetic field, according to their mass and charge. Very small samples can be analyzed, and the method is specific.

Paramagnetic analyzers are magnetic analyzers which allow oxygen to be detected under the influence of a magnetic field.

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**Radioactive** detection methods are based on radioactive decay and the release of energy (alpha and beta particles; gamma rays) from radioactive contaminants. Several different types of instruments are available for measuring radon and other radioactive contaminants.

### Sampling Methods and Instruments

A list of sampling methods for individual contaminants is provided in Exhibit 6-1. Exhibit 6-2a provides a summary of some of the currently available instrumentation along with various characteristics of the instruments. The listing is the result of a survey of vendors which was conducted by the National Environmental Health Association and the School of Public and Environmental Affairs during 1987 and 1988 (Deal and Ritchie, 1988). The list is not inclusive since there were vendors who did not respond to the survey. The listing reflects those methods and equipment reported by the vendors at the time of the survey.

Products that are listed met two criteria for inclusion. First, the products are either portable or personal equipment (not stationary). Second, lower detectable limits, sampling ranges, and sampling flows (if applicable) are suitable for detecting commonly occurring indoor concentrations of contaminants.

Sampling equipment is based on several different analytical methods which are abbreviated in the listings of equipment. Exhibit 6-2b provides the

abbreviation for each method and a corresponding brief explanation of the method.

The manufacturer's code number is given in parentheses following each product. A key to the manufacturers, their corresponding code numbers, and the products they manufacture is provided in Exhibit 6-2b. Each product listed in Exhibit 6-2a includes nine categories of information about the product. These include: 1) Method; 2) LDL/Range; 3) Sampling Rate; 4) Training/Maintenance; 5) Price; 6) Personal/Portable; 7) Power; 8) Weight; and 9) Dimensions. These categories were selected for comparison purposes because of their usefulness in evaluating specific sampling needs.

**Method** refers to the sampling method employed by the product; a listing of the methods and corresponding abbreviations is given in Exhibit 6-2b.

**LDL/Range** is the lower detectable limit followed by the range as indicated by the manufacturer's specifications. A blank space preceding or following the slash (/) means that this category is not applicable to the product, or that the information was not provided by the manufacturer's specifications.

**Samp Rate** is the rate at which air is sampled through active samplers. Sampling rates are not given for passive samplers.

**T/M** is the training and maintenance required to operate the sampler. The codes "L" and "M," limited and moderate, respectively, are intended to be general indicators. Limited training is a few minutes to a few hours of self-instruction. Moderate training includes several hours of self-instruction or formal instruction. Limited maintenance refers to preventative maintenance as well as procedures such as regular filter changes. Moderate maintenance indicates occasional trouble-shooting, component replacement, and calibration. A blank before or after the slash (/) indicates that not enough information was provided to determine the required training or maintenance.



**Price** is the price listed in the literature provided by the manufacturer. Prices are generally subject to change at any time and should be regarded as approximate for a basic sampler without options.

**Per/Por** indicates whether the sampler is personal (Per) or portable (Por). Personal samplers are actually attached to the person or an article of clothing during the sampling period. Portable samplers are those that can easily be carried from place to place.

**Power** indicates whether the sampler operates on ac or dc power or both. A "p" following the power requirements means that the sampler utilizes a passive sampling method even though another aspect of the sampler requires power.

**Weight** and **Dimensions** indicate the weight and dimensions listed in the manufacturer's specifications.

#### Additional Reference Tables

In addition to the tables on sampling methods and instruments, this section contains tabulated information on battery-powered personal air samplers, properties of filters used in particulate sampling, storage properties of gases in plastic bags, limitations on solid adsorbents, sources for testing and calibration procedures, and standard reference materials. This information is contained in Exhibits 6-3 through 6-8.

**Exhibit 6-1. Collection and analytical methods for quantitative monitoring of some contaminants.**

CONTAMINANT	COLLECTION METHOD	ANALYTICAL METHOD
CO	pump diffusion direct reading	H <sub>2</sub> SO <sub>4</sub> electrolyte; solid polymer electrolyte electrochemical infrared
NO <sub>2</sub>	diffusion tube; badge (TEA adsorbent) pump; absorption diffusion direct reading direct reading	colorimetric colorimetric (automated) electrochemistry chemiluminescence electrochemistry
SO <sub>2</sub>	pump; absorption diffusion direct reading	colorimetric electrochemical electrochemical
radon and radon progeny	diffusion adsorption (charcoal) electrostatic filtration	etching; microscopic counting scintillation counting thermoluminescent dosimetry alpha counting
asbestos	pump/filter	gravimetric and spectrophotometry
respirable particles	direct reading direct reading direct reading	optical scattering electrostatic precipitation piezoelectric resonance
biological aerosols	pump/impaction	incubation; manual counting
metals	pump/filter	atomic absorption; neutron activation; X-ray fluorescence
volatile organics	pump/adsorbent	gas chromatography/ mass spectroscopy
organochlorine pesticides	pump/adsorbent (polyurethane foam)	gas chromatography/ mass spectroscopy
HCHO	pump; adsorption pump; adsorption diffusion; adsorption	colorimetric spectrophotometry colorimetric

# Exhibit 6-2a. Commercially available indoor air monitoring equipment.

NAME (MFR. CODE)	METHOD	LDL/RANGE	SAMP RATE	T/M	PRICE	PER/ POR	POWER	WT.	DIMENSIONS
<b>AEROSOLS</b>									
MIE Miniram (19)	Ph	0.10mg/m <sup>3</sup> / 0.10-100 mg/m <sup>3</sup>		L/M	\$2350	per	dc,p	0.4 kg	10x10x5 cm
Inspec-Aerosol Spectrometer (3)	DD			L/M		por			
Low-Pressure Impactor Model 20-900 (2)	I	0.08 µm / 0.08-1.0 µm	3 l/m	L/L		por			
MIE Model RAS-1 Real Time Aerosol Sensor (19)	Ph	0.01 mg/m <sup>3</sup> / 0-100 mg/m <sup>3</sup>	0.2 l/m	L/M	\$1975	por	ac/dc,p	1 kg	12x18.8x5.3 cm
Particle Fractioning Sampler (2)	I	0.4 µm / 0.4-10.0 µm	28.3 l/m	L/L		por	ac/dc	8.3 kg	23.5x22.2x12.7 cm
MIE RAM-S Real Time Aerosol Sensor (19)	Ph	0.1 mg/m <sup>3</sup> / 0-200 mg/m <sup>3</sup>	0.2 l/m	L/M	\$4676	por	ac	140 g	10.5x6.5x2.5 cm
Series 12A Automatic Syringe Samplers (7)	WC			M/M	\$3000	por	dc	14.5 kg	53x30x20 cm
Stainless Steel Syringe (7)	F			L/L	\$200-\$400/14	per	p		20-500 ml
<b>AMMONIA</b>									
Midget Air Sampler (2)	F		0.1 l/m	M/M	\$1095	por	dc	2.0 kg	20.3x17.8x10.2 cm
3-Gas Sampler (2)	AWC		200 ml/m	M/M	\$1315	por	ac	10.9 kg	39.2x33.7x21 cm
5-Gas Sampler (2)	AWC		200 ml/m	M/M	\$1125	por	ac	7.2 kg	30.5x32.4x19.7 cm
Model PV Sequential Sampler (2)	AWC		200 ml/m	M/M	\$2855	por	ac		
SS2000 (30)	Ech	/ 0-75 ppm		L/M		por	dc	1.5 kg	21.6x10.9x17.3 cm
Liquid Sorbent Badge (31)	D, G, IC	/6-148 ppm (8 hr)	0.5-5 ml/m	L/L	\$31/ea	per	p		
<b>ASBESTOS</b>									
MIE FAM-1 Fibrous Aerosol Monitor (19)	Ph	0.01 fibers/cm <sup>3</sup> / 0.01-30 fibers/cm <sup>3</sup>	1.5-2.5 l/m	M/M	\$14,250	por	ac/dc	11.4 kg	53x35x20 cm
BDX 74 Asbestos Pump (30)	I		1.5-4.5 l/m	L/L		per	dc	1 kg	10.2x11.4x6.1 cm
BDX 99 Respirable Dust Sampler (30)	I		1.7 l/m	L/L		per			
LV-1 (32)	F		15-35 l/m	L/M	\$630	por	ac/dc	2.7 kg	10.2x10.2x17.8 cm
VM-3 (32)	F		3-25 l/m	L/M	\$800	por	ac	5 kg	11.4x14.6x23.5 cm
ASB-II (3)	I	0.8 µm / >0.8 µm	11 l/m	L/L	\$500	por		13.6 kg	33x20.3x19 cm
<b>BIOLOGICAL AEROSOLS</b>									
Microbial Air Sampler (2)	I		28.3 l/m			por			
Viable Microbial Sampler (2)	I	0.65 µm /0.65-7.0 µm	28.3 l/m	L/L		por	ac/dc	7.7 kg	41.9x16.5x43.1 cm
Stainless Steel Syringe (7)	F			L/L	\$200-\$400/14	per	p		20-500 ml
<b>CADMIUM</b>									
BDX 99 Respirable Dust Sampler (30)	I	1.7 l/m		L/L		per			SAMP

(continued next page)

**Exhibit 6-2a. Commercially available indoor air monitoring equipment (continued).**

NAME (MFR. CODE)	METHOD	LDL/RANGE	SAMP RATE	T/M	PRICE	PER/ POR	POWER	WT.	DIMENSIONS
<b>CARBON DIOXIDE</b>									
Gastechtor (18)	Ech			L/M	\$670-\$1100	por	dc, both		
RI-411 (18)	NDIR	/ 0-9950 ppm		M/M	\$2100	por	dc		
RI-411 (5)	IRD	20 ppm / 0-9950 ppm		M/M	\$1995	por	ac/dc		25.4x19x11.4 cm
RI-550A (5)	NDIR	1% full scale / 0-20%	6 l/m	M/M	\$2495	por	ac	9.5 kg	22x19.8x32 cm
MEXA 211E Portable Gas Analyzer (21)	NDIR	/ 0-5%		M/M		por	ac	9.5 kg	22x22.5x52 cm
MEXA 321E Portable Gas Analyzer (21)	NDIR	/ 0-25%		M/M		por	ac	13 kg	33x22.5x52 cm
SS2000 (30)	Ech	0-10,000 ppm		L/M		por	dc	1.5 kg	21x10.9x17.3 cm
Model APBA-210 CO2 Monitor (21)	NDIR	/ 0-2000 ppm		M/M		por	ac/dc	6 kg	31.1x13x17 cm
Model APBA-200E CO2 Monitor (21)	NDIR	/ 0-2000 ppm	0-100 ml/m	M/M		por	ac	5 kg	18x32x9.1 cm
Gastech Model 4776 (18)	NDIR	/ 0-3000 ppm		L/M	\$2000	por	ac, dc		39.4x33.0x15.2 cm
<b>CARBON MONOXIDE</b>									
CO-82 (18)	Ech	/ 0-500 ppm		L/L	\$595	per	dc, p		
BSI 210 (12)	Ech	1 ppm / 0-1999 ppm		L/L	\$695	per	dc, p	0.3 kg	14x8.5x3.8 cm
Gastechtor (18)	Ech			L/M	\$670-\$1100	por	dc, both		
GX-82 (18)	Ech			L/M	\$1295	per	dc, p		
Interscan 5140 (22)	Ech	2.5 ppm / 0-1000 ppm		L/M	\$1145	per	dc, p	680 g	15.2x7.6x5.1 cm
Interscan CO 1140 (22)	Ech	1% full scale / 0-500 ppm	1.2 l/m	L/M	\$1675	por	dc	3.6 kg	18.4x15.2x2.9 cm
Interscan CO 4140 (22)	Ech	1% full scale / 0-500 ppm	1.2 l/m	L/M	\$1895	por	dc	2.0 kg	17.8x10.2x22.5 cm
Ecolyzer Model 2000 (12)	Ech	0.5 ppm / 0-600 ppm	700 ml/m	L/M	\$1900	por	ac/dc	4.5 kg	17.8x17.8x33 cm
GE CO Detector (20)	Ech	1 ppm / 0-1000 ppm	60 ml/m	L/L	\$1195	por	dc	290 g	7.5x13.5x3.6 cm
Dosimeter Model 3140 (22)	D	1% full scale / 0-500 ppm		L/M	\$1235	per	dc, p	680 g	15.2x7.6x5.1 cm
Model 4148 Compact Portable (22)	Ech	1% full scale / 0-50 ppm		L/M	\$1895	por	ac/dc	2.0 kg	17.8x10.2x22.5 cm
PAM Model 2140 (22)	Ech	1% full scale / 0-500 ppm		L/L	\$695	per	dc, p	680 g	16.5x7.6x5.1 cm
Model PV Sequential Sampler (2)	AWC		200 ml/m	M/M	\$2855	por	ac		
Carbon Monoxide Detector (14)	Ech	1 ppm / 0-500 ppm		L/M	\$725	per	dc, p	343 g	7.9x12.1x2.8 cm
Ecolyzer Model 211 (26)	Ech	1 ppm / 0-1999 ppm		L/M		per	dc	343 g	14.6x8.9x3.8 cm
Pure Air Monitor (4)	Ech			M/M	\$455	por	ac	2.7 kg	30.5x10.2x17.8 cm
Model 1148 Standard Portable (22)	Ech	1% full scale / 0-50 ppm		L/M	\$1895	por	ac/dc, p	3.6 kg	18.4x15.2x29.2 cm
RI-550A (5)	NDIR	1% full scale / 0-20%	6 l/m	M/M	\$2495	por	ac	9.5 kg	22x19.8x32 cm
Carbon Monoxide Indicator Badge (36)	Col	/ 10-500 ppm		L/L	\$2.25	per	p		
Carbon Monoxide Dosimeter, Model 3 (25)	D/Col			L/L		per	p	14.3 g	7.6x12.7x0.6 cm
Exotox (27)	Ech	1 ppm / 0-999 ppm		L/M		por	dc	0.9 kg	15.2x8.9x5.3 cm
MiniCO Indicator and Alarm model IV (25)	Ech	1 ppm / 0-500 ppm		L/L	\$562	per	dc		
MiniCO V (25)	Ech	/ 0-1999 ppm		L/L		per	dc, p		15.2x8.9x3.8 cm
Neotox Pocket CO Monitor (27)	Ech	1 ppm / 0-999 ppm		L/L		per	dc	150 g	2.8x6.1x10.2 cm
Portable CO Indicator, Model 70 (25)	Ech	2 ppm / 0-100 ppm		M/M	\$1472	por	dc	3.2 kg	21.6x16.5x8.9 cm
MEXA 321E Portable Gas Analyzer (21)	NDIR	/ 0-1000 ppm		M/M		por	ac	13 kg	33x22.5x52 cm

**Exhibit 6-2a. Commercially available indoor air monitoring equipment (continued).**

NAME (MFR. CODE)	METHOD	LDL/RANGE	SAMP RATE	T/M	PRICE	PER/ POR	POWER	WT.	DIMENSIONS
<b>CARBON MONOXIDE (continued)</b>									
Lamotte 7782 Carbon Monoxide Test Kit (34)	WC	10 ppm /		L/L	\$45	por	p		
MEXA 201E Portable Gas Analyzer (21)	NDIR	/ 0-1000 ppm		M/M		por	ac	9.5 kg	22x22.5x52 cm
Mini Monitor (30)	Ech	0-400 ppm		L/L		per	dc	200 g	7.7x2.4x11.8 cm
VaporGard Dosimeter Tube (25)	D/Col	specific to tube		L/L	\$24/10	per	p		
<b>CHLORINE</b>									
Model 1340 Standard Portable (22)	Ech	1% full scale / 0-10 ppm		L/M	\$2156	por	ac/dc	3.6 kg	18.4x15.2x29.2 cm
PAM Model 2340 (22)	Ech	1% full scale / 0-10 ppm		L/L	\$875	per	dc,p	680 g	16.5x7.6x5.1 cm
Model 4340 Compact Portable (22)	Ech	1% full scale / 0-10 ppm		L/M	\$2156	por	ac/dc	2.0 kg	17.8x10.2x22.5 cm
SS2000 (30)	Ech	/ 0-3 ppm		L/M		por	dc	1.5 kg	21.6x10.9x17.3 cm
<b>COMBUSTIBLE GAS</b>									
Scott S-101 (29)		/0-100%		L/M	\$483	por	dc	.51 kg	7.9x15.9x4.1 cm
Scott S-105A (with O <sub>2</sub> ) (29)		/0-100%; /0-25% O <sub>2</sub>		L/M	\$777	por	dc	.51 kg	7.9x15.9x4.1 cm
Gastech Protecht I & II (18)		/0-100%; /0-25% O <sub>2</sub>		L/M		por	dc		
<b>FORMALDEHYDE</b>									
TGM 555 (5)	AWC/Col	0.002 ppm / 0-5 ppm	0.5 l/m	M/M	\$5410	por	ac/dc	14 kg	51x41x18 cm
Formaldehyde Monitor 3750 (35)	D	0.8 ppm-hr / 0.8-72 ppm-hr	65.9 l/m	L/L	\$35	per	p		
PF-1 (1)	D	0.01 ppm / 0.01-1.0 ppm	4.1 ml/m	L/L	\$48/2	por	p		90x25 mm
Pro-Tek Formaldehyde Dosimeter (9)	D	1.6 ppm-hr / 1.6-54 ppm-hr		L/L	\$222/10	per	p	17.8 g	7.6x7.1x0.9 cm
ETS Formaldehyde Dosimeter (15)	DD	0.03 ppm / 0.03-1.0 ppm		L/L	\$24/2	por	p		
PRO-TEK Colorimetric Air Monitoring Badges (9)	D	1.6 ppm / 1.6-54 ppm		L/L		per	p	17.8 g	7.6x7.1x0.9 cm
Formaldemeter (24)	Ech	0.1 ppm / 0.1-99.9 ppm		L/M		per	dc	200 g	12x6.3x3 cm
Lamotte 3408 Formaldehyde-in-Air Test Kit (34)	Col	0.1 ppm / 0.1-1.0 ppm		L/L	\$38	por	p		
Lamotte 6695 Formaldehyde Test Kit (34)	WC	0.13 ppm /		L/L	\$40	por	p		
Liquid Sorbent Badge (31)	D, Col	0.02 ppm / 0.2-2 ppm	0.5-50 ml/m	L/L	\$30	per	p		
Passive Bubbler™ Sampler (31)	D, Col	0.1/0-1.5 ppm (8 hr, slowcap)	11.6 ml/m	L/L	\$36/5	per	p		7.0x2.05 cm
		0.5/0-5 ppm (15 min, fastcap)							
PF - 20 (1)	D, Col	/0.1-3ppm (8 hr)	16 cm <sup>3</sup> /m	L/L		per	p		
<b>HYDROCARBONS</b>									
Gastechtor (18)	Ech			L/M	\$670-1100	por	dc, both		
SP-203F (18)	Ech	/ low ppm		L/L	\$500	per			
MEXA 221E (21)	NDIR	/ 0-500 ppm		M/M		por	ac	9.5 kg	22x22.5x52 cm

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**Exhibit 6-2a. Commercially available indoor air monitoring equipment (continued).**

NAME (MFR. CODE)	METHOD	LDL/RANGE	SAMP RATE	T/M	PRICE	PER/ POR	POWER	WT.	DIMENSIONS
<b>HYDROGEN SULFIDE</b>									
Ecolyzer Model 2000 (12)	Ech	0.5 ppm / 0-600 ppm	700 ml/m	L/M	\$1900	por	ac/dc	4.5 kg	17.8x17.8x33 cm
Dosimeter Model 3170 (22)	D	1% full scale / 0-500 ppm		L/M	\$1270	per	dc,p	680 g	15.2x7.6x5.1 cm
Model 4170 Compact Portable (22)	Ech	1% full scale / 0-1 ppm		L/M	\$2064	por	ac/dc	2.0 kg	17.8x10.2x22.5 cm
PAM Model 2170 (22)	Ech	1% full scale / 0-100 ppm		L/L	\$765	per	dc,p	680 g	16.5x7.6x5.1 cm
Midget Air Sampler (2)	F		1 l/m	M/M	\$1095	por	dc	2.0 kg	20.3x17.8x10.2 cm
3-Gas Sampler (2)	Sa Tr		200 ml/m	M/M	\$1315	por	ac	10.9 kg	39.2x33.7x21 cm
5-Gas Sampler (2)	Sa Tr		200 ml/m	M/M	\$1125	por	ac	7.2 kg	30.5x32.4x19.7 cm
Model PV Sequential Sampler (2)	Sa Tr		200 ml/m	M/M	\$2855	por	ac		
TGM 555 (5)	AWC/Col	0.002 ppm / 0-5 ppm	0.5 l/m	M/M	\$5250	por	ac/dc	13.6 kg	50.8x40.6x17.8 cm
Ecolyzer Model 241 (26)	Ech	1 ppm/ 0-1000 ppm		L/M		per	dc	343 g	14.6x8.9x3.8 cm
Model 1170 Standard Portable (22)	Ech	1% full scale / 0-1 ppm		L/M	\$2064	por	ac/dc,p	3.6 kg	18.4x15.2x29.2 cm
Exotox (27)	Ech	1 ppm / 0-500 ppm		L/M		por	dc	0.9 kg	15.2x8.9x5.3 cm
Gold Film Hydrogen Sulfide Analyzer (23)	Ech	1 ppb / 1-500 ppb	150 ml/m	L/M	\$8500	por	ac/dc	3.6 kg	30.5x20.3x20.3 cm
Neotox Pocket H2S Monitor (27)	Ech	1 ppm / 0-999 ppm		L/L		per	dc	150 g	2.8x6.1x10.2 cm
Portable Indicator and Alarm, Model 361 (25)	Ech	/ 0-50 ppm	1.5 l/m	M/M	\$1685	por	dc	3.4 kg	17.8x25.4x9.5 cm
Mini Monitor (30)	Ech	/ 0-100 ppm		L/L		per	dc	200 g	7.6x2.4x11.8 cm
SS2000 (30)	Ech	/ 0-3- ppm		L/M		por	dc	1.5 kg	21.6x10.9x17.3 cm
<b>LEAD</b>									
BDX 99 Respirable Dust Sampler (30)	I		1.7 l/m	L/L		per			
<b>MERCURY</b>									
Model 411 Gold Film Mercury Vapor Analyzer(23)	Ech	0.001 mg/m <sup>3</sup> / 0.001-1.999 mg/m <sup>3</sup>	0-75 l/m	L/M	\$3750	por	ac/dc	2.3 kg	33.0x16.3 cm
Mercury Gas Monitoring Badge (31)	D, AA	0.002 mg/m <sup>3</sup> (8hr)/		L/L	\$22.50/10	per	p		
Mercury Vapor Badge 3600 (35)	D, AA	/0.005-0.20 mg/m <sup>3</sup>		L/L		per	p		
<b>NITROGEN DIOXIDE</b>									
TGM 555 NO2 Analyzer (5)	AWC/Col	0.005 ppm / 0-0.25 ppm	0.5 l/m	M/M	\$5340	por	ac/dc	14 kg	51x41x18 cm
CSI 1600 NOx Analyzer (6)	Ch	0.002 ppm / 0.002-5 ppm	500 ml/m	M/M	\$7950	por	ac	34 kg	43.2x27.7x68.6 cm
Air Check (1)	D	0.005 ppm / 0.005-10 ppm		L/L	\$48/2	por	p		
DuPont PRO-TEK Type C30 Dosimeter (9)	D	10 ppm-hr / 10-100 ppm-hr		L/L	\$259/10	per	p	16 g	7.6x7.1x0.9 cm
Toyo Roshi NO <sub>2</sub> Badge (26)	D/Ad	66 ppb-hr / 66-1066 ppb-hr		L/L	\$12	per	p	15 g	5x4x1 cm
MDA Palmes Tube (24)	D/S	1 ppm-hr / 1-20 ppm-hr	1 ml/m	L/L	\$8-10	per	p	14 g	8 cm x 1.3 cm dia.
Ecolyzer Model 2000 (12)	Ech	0.5 ppm / 0-600 ppm	700 ml/m	L/M	\$1900	por	ac/dc	4.5 kg	17.8x17.8x33 cm
Dosimeter Model 3150 (22)	D	1% full scale / 0-500 ppm		L/M	\$1425	per	dc,p	680 g	16.5x7.6x5.1 cm

**Exhibit 6-2a. Commercially available indoor air monitoring equipment (continued).**

NAME (MFR. CODE)	METHOD	LDL/RANGE	SAMP RATE	T/M	PRICE	PER/ POR	POWER	WT.	DIMENSIONS
<b>NITROGEN DIOXIDE (continued)</b>									
Model 1152 Standard Portable (22)	Ech	1% full scale / 0-10 ppm		L/M	\$2295	por	ac/dc	3.6 kg	18.4x15.2x29.2 cm
Model 4152 Compact Portable (22)	Ech	1% full scale / 0-10 ppm		L/M	\$2295	por	ac/dc	2.0 kg	17.8x10.2x22.5 cm
PAM Model 2150 (22)	Ech	1% full scale / 0-50 ppm		L/L	\$860	per	dc,p	680 g	16.5x7.6x5.1 cm
Midget Air Sampler (2)	F		0.1 l/m	M/M	\$1095	por	dc	2.0 kg	20.3x17.8x10.2 cm
3-Gas Sampler (2)	Sa Tr		200 ml/m	M/M	\$1315	por	ac	10.9 kg	39.2x33.7x21 cm
5-Gas Sampler (2)	Sa Tr		200 ml/m	M/M	\$1125	por	ac	7.15 kg	30.5x32.4x19.7 cm
VaporGard Dosimeter Tube (25)	D/Col	/ specific to tube		L/L	\$24/10	per	p		
Mini Monitor (30)	Ech	/ 0-10 ppm		L/L		por	dc	200 g	7.6x2.4x11.8 cm
<b>NITROGEN MONOXIDE</b>									
CSI 1600 NOx Analyzer (6)	Ch	0.002 ppm / 0.002-5.0 ppm	500 ml/m	M/M	\$7950	por	ac	34 kg	43.2x27.7x68.6 cm
Ecoalyzer Model 2000 (12)	Ech	0.5 ppm / 0-600 ppm	700 ml/m	L/M	\$1900	por	ac/dc	4.5 kg	17.8x17.8x33 cm
Dosimeter Model 3540 (22)	D	1% full scale / 0-500 ppm		L/M	\$1425	per	dc,p	680 g	15.2x7.6x5.1 cm
Model 1545 Standard Portable (22)	Ech	1% full scale / 0-50 ppm		L/M	\$2247	por	ac/dc	3.6 kg	18.4x15.2x29.2 cm
Model 4545 Compact Portable (22)	Ech	1% full scale / 0-50 ppm		L/M	\$2247	por	ac/dc	2.0 kg	17.8x10.2x22.5 cm
<b>NITROGEN OXIDES</b>									
CSI 1600 NOx Analyzer (6)	Ch	0.002 ppm / 0.002-5 ppm	500 ml/m	M/M	\$7950	por	ac	34 kg	43.2x27.7x68.6 cm
Toyo Roshi NO2 Badge (26)	D/S	66 ppb-hr / 66-1066 ppb-hr		L/L	\$12	per	p	15 g	5x4x1 cm
MDA Palmes Tube (24)	D/S	1 ppm-hr / 1-20 ppm-hr	1 ml/m	L/L	\$8-10	per	p	14 g	8 cm x 1.3 cm dia.
Ambient Air Sampler (2)	AWC		3 l/m	M/M	\$520-685	por	ac	6.4 kg	20.3x25.4x27.3 cm
Model PV Sequential Sampler (2)	AWC		200 ml/m	M/M	\$2855	por	ac		
TGM 555 (5)	AWC/Col	1% full scale / 0-0.25 ppm	0.5 l/m	M/M	\$5250	por	ac/dc	14 kg	51x41x18 cm
IES Model A100 (41)	AWC	/0-0.1 ppm; 0-100 ppm		M/M	\$7995	por	ac	18.6 kg	27.9x30.5x36.8 cm
AC 35 NO-NO <sub>x</sub> (40)	Ch	0.01 ppm/0-2 ppm		M/M		por	ac, dc	5.5 kg	40x30x13 cm
<b>ORGANICS</b>									
Gas Monitoring Badges (31)	D	varies	varies	L/L	\$48/25	per	p		
Charcoal Sampling Tubes (9)	S			L/L		por		50/100 mg	6x70 mm
PRO-TEK G-AA Air Monitoring Badges (9)	D	0.2 ppm-hr / 0.2-1300 ppm		L/L		per	p	7.7 g	7.7x0.8x1.4 cm
PRO-TEK G-BB Air Monitoring Badges (9)	D	0.4 ppm-hr / 0.4-4000 ppm		L/L		per	p	11.1 g	7.7x0.9x1.6 cm
Ambient Air Sampler (2)	AWC		3 l/m	M/M	\$520-685	por	ac	6.4 kg	20.3x25.4x27.3 cm
VaporGard Dosimeter Badges (25)	D			L/L	\$74	per	p		

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**Exhibit 6-2a. Commercially available indoor air monitoring equipment (continued).**

NAME (MFR. CODE)	METHOD	LDL/RANGE	SAMP RATE	T/M	PRICE	PER/ POR	POWER	WT.	DIMENSIONS
<b>ORGANICS (continued)</b>									
Organic Vapor Monitor, Series 3500 (35)	D	compound specific		L/L		per	p		
OVA-108 (17)	FI/GC	0.5 ppm / 1-10000 ppm	1 l/m	M/M		por	dc	5.5 kg	23x30x10 cm
OVA-128 (17)	FI/GC	0.2 ppm / 0-1000 ppm	1 l/m	L/M		por	dc	5.5 kg	23x30x10 cm
<b>OXYGEN</b>									
Gastechtor (18)	Ech			L/M	\$670-1100	por	dc, both		
GX-82 (18)	Ech			L/M	\$1295	per	dc,p		
OX-82 (18)	Ech	/ 0-50%		L/L	\$525	per	dc,p		
Model 3300 Oxygen Monitor (24)		/ 0-25% or 0-100%		M/M		por	dc		
Ecolyzer Model 260 (26)	Ech	0.1% / 0-30%		L/M		per	dc	343 g	14.6x8.9x3.8 cm
Personal O2 Monitor (14)	Ech	1% full scale / 0-100%		L/M	\$695	per	dc,p	343 g	7.9x12.1x2.8 cm
Portable Oxygen Analyzer (14)	Ech	1% full scale / 0-100%		L/M	\$2695	por	dc	6.4 kg	15.2x19x30.5 cm
Scott-Alert (29)		3% full scale / 0-100%		L/L	\$505	per	dc	514 g	7.9x15.7x4.1 cm
Exotox (27)	Ech	0.1% / 0-35%		L/M		por	dc	0.9 kg	15.2x8.9x5.3 cm
Neotox Pocket O2 Monitor (27)	Ech	0.1% / 0-35%		L/L		per	dc	150 g	2.8x6.1x10.2 cm
Portable Indicator & Alarm, Model 361 (25)	Ech	/ 0-25%	1.5 l/m	M/M	\$1685	por	dc	3.4 kg	17.8x25.4x9.5 cm
Mini Monitor (30)	Ech	/ 0-40%		L/L		per	dc	200 g	7.6x2.4x11.8 cm
<b>OZONE</b>									
CSI 2000 Portable Ozone Meter (6)	Ch	0.004 ppm / 0-1 ppm	700 ml/m	M/M	\$6750	por	dc	7.7 kg	20.3x17.8x45.7 cm
Ambient Air Sampler (2)	AWC		3 l/m	M/M	\$520-685	por	ac	6.4 kg	20.3x25.4x27.3 cm
<b>RADON AND PROGENY</b>									
Track Etch (33)	D	0.2 pCi/l / 0.2-2000 pCi/l		L/L	\$20-50	por	p		6.4 sq cm
Mini CON II (8)	GM	2.3 MeV / 0-5000 cpm		L/M	\$485	per	dc,p	454 g	6.7x11.8x2.5 cm
MiniCON-RAD II (8)	GM	2.3 MeV / 0-5000 cpm		L/M	\$550	per	dc,p	454 g	6.7x11.8x2.5 cm
Portable Survey Meter (8)	GM	/ 0-0.5 mR/hr		M/M	\$440	por	dc,p	1735 g	11.1x22.2x10.8 cm
RDA-2000 Radon/Radon Daughter Detector (11)	Sc	/ 0-99,999 cts	variable	M/M	\$4450	por	dc	8 kg	12.7x16.5x20 cm
LV-1 (32)	F		15-35 l/m	L/M	\$550	por	ac/dc	2.7 kg	10.2x10.2x17.8 cm
Model 442-A (28)	DD	/ 0-1000 cpm	28.3-453 l/m	M/M		por	ac	7.3 kg	27.9x40.6x15.9 cm
WLM-IA (10)	Ech		0.12-0.18 l/m	L/M	\$2950	por	dc	2.4 kg	14.6x11.8x20.3 cm
Model 05-420 AT EASE (39)	D	0.1 pCi/l / 0.1-999 pCi/l		L/L	\$449	por	p		
Model 05-418 Honeywell Professional (39)	D	0.1 pCi/l / 0.1-999 pCi/l		L/L	\$795	por	p		
E-Perm Introductory Kit (42)	D	<1 to 50 pCi/l (2-7 da)		L/L	\$2500	por	p	.12 kg	10.2x8.3 cm (chamber)
		/50 to 200 pCi/l (15-30 da)							
		<7pCi/l (up to 1 yr)							



**Exhibit 6-2a. Commercially available indoor air monitoring equipment (continued).**

NAME (MFR. CODE)	METHOD	LDL/RANGE	SAMP RATE	T/M	PRICE	PER/ POR	POWER	WT.	DIMENSIONS
<b>RESPIRABLES</b>									
TSI Piezobalance Model 3500 (37)	EP	0.001 mg/m <sup>3</sup> / 0.01-10 mg/m <sup>3</sup>	1 l/m	M/M	\$4400	por	ac/dc	4.5 kg	31x13x17 cm
Low-Pressure Impactor Model 20-900 (2)	I	0.08 µm / 0.08-1.0 µm	3 l/m	L/L		por			
Marple Personal Cascade Impactor Model 294 (2)	I	3.5 µm / 4 stages	2 l/m	L/L	\$775	per		170 g	7.2x5.7x4.0 cm
Marple Personal Cascade Impactor Model 296 (2)	I	0.6 µm / 6 stages	2 l/m	L/L	\$975	per		185 g	8.0x5.7x4.0 cm
Marple Personal Cascade Impactor Model 298 (2)	I	0.6 µm / 8 stages	2 l/m	L/L	\$1175	per		200 g	8.6x5.7x4.0 cm
Microbial Air Sampler (2)	I		28.3 l/m			por			
Particle Fractioning Sampler (2)	I	0.4 µm / 0.4-10.0 µm	28.3 l/m	L/L		por	ac/dc	8.3 kg	23.5x22.2x12.7 cm
PS-4 Particulate Sizing Impactors (19)	I	1.1 µm / 1.1-8.0 µm	2 l/m	L/L	\$960/4	por		130 g	8.8x4.8 cm dia.
Mie Miniram (19)	Ph	0.1 mg/m <sup>3</sup> / 0.1-100 mg/m <sup>3</sup>		L/M	\$2350	per	dc,p	0.4 kg	10x10x5 cm
Mie RAM-1 (19)	Ph	0.1 mg/m <sup>3</sup> / 0.01-200 mg/m <sup>3</sup>	1-3 l/m	L/M	\$6250	por	dc	4 kg	20x20x20 cm
BDX 30 (30)	I			L/L		per	dc	600 g	10.2x11.4x6.1 cm
BDX 99 Respirable Dust Sampler (30)	I		1.7 l/m	L/L		per			
P-5 Digital Dust Indicator (24)		0.001 mg/m <sup>3</sup> / 0.001-100 mg/m <sup>3</sup>		M/M		por	ac/dc		
Personal Dust Monitoring System (24)		0.1 mg/m <sup>3</sup> / 0.01-100 mg/m <sup>3</sup>		L/M		per	dc		
Stainless Steel Syringe (7)	F			L/L	\$200-\$400/14	per	p	20-500 ml	
May/R.E. Cascade Impactor (3)	G	0.5 µm / 0.5-32 µm	5 l/m	L/L	\$4995	por			12x8.2x8.7 cm
Portable Condensation Nuclei Monitor (13)	Ph	0.0025 µm /	30-70- ml/sec	M/M		por	dc	3.6 kg	12.7x17.8x40.6 cm
TEOM® Series 1200 (39)	Im	5 µg/m <sup>3</sup> (10 min ave)/ 15 µg/m <sup>3</sup> (2 min ave)/	0.5 - 5 l/m	M/M		por	ac	30g 12 kg	25x36x46 cm (sensor) 36x45x19 cm (computer)
<b>SULFUR DIOXIDE</b>									
Dosimeter Model 3240 (22)	D	1% full scale / 0-500 ppm		L/M	\$1425	per	dc,p	680 g	15.2x7.6x5.1 cm
Interscan 5240 Dosimeter (22)	Ech	0.5% full scale / 0-20 ppm		L/M	\$1145	per	dc,p	680 g	15.2x7.6x5.1 cm
Interscan SO2 1240 (22)	Ech	1% full scale / 0-10 ppm		L/M	\$1675	per	dc	3.6 kg	18.4x1.5x29 cm
Interscan SO2 4240 (22)	Ech	1% full scale / 0-10 ppm		L/M	\$1895	per	dc	2.0 kg	17.8x10.2x22.5 cm
Model 4240 Compact Portable (22)	Ech	1% full scale / 0-1 ppm		L/M	\$2211	por	ac/dc	2.0 kg	17.8x10.2x22.5 cm
PAM Model 2240 (22)	Ech	1% full scale / 0-50 ppm		L/L	\$860	per	dc,p	680 g	16.5x7.6x5.1 cm
Midget Air Sampler (2)	F		0.1 l/m	M/M	\$1095	por	dc	2.0 kg	20.3x17.8x10.2 cm
3-Gas Sampler (2)	AWC		200 ml/m	M/M	\$1325	por	ac	10.9 kg	39.2x33.7x21 cm
5-Gas Sampler (2)	AWC		200 ml/m	M/M	\$1125	por	ac	7.15 kg	30.5x32.4x19.7 cm
Ambient Air Sampler (2)	AWC		3 l/m	M/M	\$520-685	por	ac	6.4 kg	20.3x25.4x27.3 cm
Model PV Sequential Sampler (2)	AWC		200 ml/m	M/M	\$2855	por	ac		
VaporGard Dosimeter Tube (25)	D/Col	/ specific to tube		L/L	\$24/10	per	p		
Model 1240 Standard Portable (22)	Ech	1% full scale / 0-1 ppm		L/M	\$2210	por	ac/dc,p	3.6 kg	18.4x15.2x29.2 cm
Liquid Sorbent Badge (31)	D	0.1 ppm / 0.1-100 ppm	0.5-50 ml/m	L/L	\$30	per	p		

(continued next page)

**Exhibit 6-2a. Commercially available indoor air monitoring equipment (continued).**

NAME (MFR. CODE)	METHOD	LDL/RANGE	SAMP RATE	T/M	PRICE	PER/ POR	POWER	WT.	DIMENSIONS
<b>SULFUR DIOXIDE (continued)</b>									
TGM 555 (5)	AWC/Col	1% full scale / 0-0.25 ppm	0.5 l/m	M/M	\$5395	por	ac/dc	14 kg	51x41x18 cm
SS2000 (30)	Ech	/ 0-10 ppm		L/M		por	dc	1.5 kg	21.6x10.9x17.3 cm
Mini Monitor (30)	Ech	/ 0-20 ppm		L/L		per	dc	200 g	7.6x2.4x11.8 cm
<b>TOTAL SUSPENDED PARTICULATES</b>									
Status 2100 (16)	Ph	0.5 $\mu$ m / 0.5-5 $\mu$ m	23.3 ml/m	M/M	\$3950	por	ac	7.2 kg	15.2x25.4x35.6 cm
Status 5000 (16)	Ph	0.3 $\mu$ m / 0.3-5.0 $\mu$ m	28.3 ml/m	M/M	\$6950	por	ac	10.8 kg	11.4x29.2x41.9 cm
BDX 74 Asbestos Pump (30)	I		1.5-4.5 l/m	L/L		per	dc	1 kg	10.2x11.4x6.1 cm
PCD-1 Direct-Reading Dust Monitor (24)		0.001 mg/m <sup>3</sup> / 0.001-9.9 mg/m <sup>3</sup>		M/M		por			
LV-1 (32)	F		15-35 l/m	L/M	\$550	por	ac/dc	2.7 kg	10.2x10.2x17.8 cm
VM-3 (32)	F		3-25 l/m	L/M	\$680	por	ac	5 kg	11.4x14.6x23.5 cm
Series 12A Automatic Syringe Samplers (7)	WC			M/M	\$3000	por	dc	14.5 kg	53x30x20 cm
Midget Air Sampler (2)	Sa Tr		0.1 l/m	M/M	\$1095	por	dc	2.0 kg	20.3x17.8x10.2 cm

SOURCE: Ritchie and Deal (1988)

**Exhibit 6-2b. Identification codes for methods in Exhibit 6-2a.**

ABBREVIATION	DESCRIPTION OF METHOD
AA	<i>Atomic Absorption</i> —ionized molecules are deflected by a magnetic field according to their mass and charge
AWC	<i>Automated Wet Chemistry</i> —reagents are reacted with the contaminant to determine its presence or concentration; reagents are automatically introduced
Ch	<i>Chemiluminescence</i> —the intensity of light emitted from a chemical reaction between the contaminant and a reagent is directly related to the contaminant concentration
Col	<i>Colorimetry</i> —reagents are reacted with the contaminant; the presence or concentration of contaminant is based on a color change resulting from the chemical reaction
D	<i>Diffusion</i> —spontaneous transfer and mixing of contaminant based on molecular motion
DD	<i>Dry Deposition</i> —natural settling of particles due to gravity
Ech	<i>Electrochemical</i> —contaminant concentrations are based on the measurement of electrical changes caused by chemical reactions
EP	<i>Electrostatic Precipitation</i> —concentrations of particles are based on the use of an electrical field to charge and separate the particles
F	<i>Filtration</i> —physical separation of suspended matter from a gas stream
FI	<i>Flame Ionization</i> —concentrations are proportional to ion currents which are produced by contaminants which are introduced into a flame
G	<i>Gravimetric</i> —measurement by weight
GC	<i>Gas Chromatography</i> —concentrations are proportional to a signal that is generated as contaminant gas is separated into its components and measured by a detector
GM	<i>Geiger Mueller</i> —measurement of pulses resulting from the ionizing effect of radiation on an enclosed gas
I	<i>Impaction</i> —collection by forcing contact
IC	<i>Ion Chromatography</i> —sequential determination of anions or cations using ion exchange and conductivity, amperometric, or colorimetric detectors

(continued next page)

**Exhibit 6-2b. Identification codes for methods in Exhibit 6-2a (continued).**

ABBREVIATION	DESCRIPTION OF METHOD
Im	<i>Inertial mass</i> —direct determination by oscillating microbalance
IR	<i>Infrared Detection</i> —infrared radiation is passed through the sample, dispersed, and detected; concentration is proportional to the amount of radiation that is absorbed by the contaminant
NDIR	<i>Nondispersive Infrared Detection</i> —similar to IR except that a single band of infrared radiation is used
Ph	<i>Photometry</i> —measurement of light intensity
S	<i>Sorption</i> —adsorption, absorption, or both
Sc	<i>Scintillation</i> —measurement of flashes from radiation
SrTr	<i>Sampling Train</i> —for collection of sample only
WC	<i>Wet Chemistry</i> —reagents are manually introduced to the sample to determine the presence or concentration of a contaminant

**Exhibit 6-2c. Identification codes for manufacturers in Exhibit 6-2a.**

CODE	ADDRESS	CONTAMINANTS	CODE	ADDRESS	CONTAMINANTS
1	Air Quality Research, Inc. 901 Grayson Street Berkeley, CA 94710 (415-644-2097)	NO <sub>2</sub> , HCHO	4	Calibrated Instruments, Inc. 731 Saw Mill River Rd. Ardsley, NY 10502 (914-693-9232)	CO
2	Anderson Samplers 4215 Wendell Dr. Atlanta, GA 30336 (800-241-6898)	RSP, TSP, AER, BIO, AER, SO <sub>2</sub> , NO <sub>x</sub> , NO <sub>2</sub> , H <sub>2</sub> S, NH <sub>3</sub> , ORG, O <sub>3</sub> , CO	5	CEA Instruments, Inc. 16 Chestnut St., P.O. Box 303 Emerson, NJ 07630 (201-967-5660)	HCHO, NO <sub>2</sub> , SO <sub>2</sub> , H <sub>2</sub> S, CO, CO <sub>2</sub>
3	BGI, Inc. 58 Guinan St. Waltham, MA 02154 (617-891-9380)	AER, RSP, ASB	6	Columbia Scientific Industries 11950 Jollyville Rd. P.O. Box 9908 Austin, TX 78766 (800-531-5003)	O <sub>3</sub> , NO <sub>x</sub> , NO, NO <sub>2</sub>

**Exhibit 6-2c. Identification codes for manufacturers in Exhibit 6-2a (continued).**

CODE	ADDRESS	CONTAMINANTS	CODE	ADDRESS	CONTAMINANTS
7	Demaray Scientific Instruments 1122 Latah St. Pullman, WA 99163 (509-332-8577)	AER, BIO AER, SE RSP, TSP	16	Faley International Corp. P.O. Box 669 El Toro, CA 92630-0669 (714-837-1149)	TSP
8	Dosimeter Corporation P.O. Box 42377 Cincinnati, OH 45242	Rn	17	Foxboro Company 38 Niponset Avenue Foxboro, MA 07039 (714-837-1149)	ORG
9	DuPont Co., Inc. Barclay Mill Plaza Marshall Mill Bldg. Wilmington, DE 19898 (215-444-4188)	NO <sub>2</sub> , HCHO, ORG	18	Gastech P.O. Box 390726 Mountain View, CA 94039	CO, CO <sub>2</sub> , O <sub>2</sub> , HC
10	Eberline Instrument Corp. P.O. Box 2108 Sante Fe, NM 87501 (505-471-3232)	Rn, Prog	19	MIE, Inc. 213 Burlington Rd. Bedford, MA 01730 (617-275-5444)	RSP, ASB, AER
11	EDA Instruments, Inc. 5151 Ward Rd. Wheat Ridge, CO 80033 (303-422-9112)	Rn	20	General Electric 333 W. Seymour Ave. Cincinnati, OH 45216 (513-948-5065)	CO
12	Energetics Science Division Six Skyline Dr. Hawthorne, NJ 10532 (914-492-3010)	CO, NO <sub>2</sub> , NO, H <sub>2</sub> S	21	Horiba Instruments 1021 Duryen Ave. Irvine, CA 92714 (800-446-7422)	CO, CO <sub>2</sub> , HC
13	Environment/One Corp. 2773 Balltown Rd. Schenectady, NY 12309 (518-346-6161)	RSP	22	Interscan Corporation 21700 Nordhoff St. P.O. Box 2496 Chatsworth, CA 91311 (800-458-6153)	CO, NO <sub>2</sub> , H <sub>2</sub> S, SO <sub>2</sub> , NO, CO <sub>2</sub>
14	Environmental Tectonics Corp. County Line Industrial Park Southampton, PA 18966 (800-523-6079)	CO, CO <sub>2</sub>	23	Jerome Instrument Corp. P.O. Box 336 Jerome, AZ 86331 (800-952-2566)	H <sub>2</sub> S, Hg
15	Envirotech Services, Inc. 547 Park Ave. Prairie Du Sac, WI 53758 (608-643-4755)	HCHO	24	MDA Scientific, Inc. 405 Barclay Lincolnshire, IL 60069 (800-323-2000)	NO <sub>2</sub> , NO <sub>x</sub> , O <sub>3</sub> , SO <sub>2</sub> , O <sub>2</sub> , RSP, TSP, HCHO
			25	Mine Safety Appliances Co. 400 Penn Center Blvd. Pittsburgh, PA 15235 (800-672-2222)	ORG, CO, SO <sub>2</sub> , NO <sub>2</sub> , O <sub>2</sub> , H <sub>2</sub> S

*(continued next page)*

**Exhibit 6-2c. Identification codes for manufacturers in Exhibit 6-2a (continued).**

CODE	ADDRESS	CONTAMINANTS	CODE	ADDRESS	CONTAMINANTS
26	National Draeger, Inc. 101 Technology Drive Pittsburgh, PA 15275 (412-787-8383)	NO <sub>2</sub> , NO <sub>x</sub> , CO, H <sub>2</sub> S, O <sub>2</sub>	35	3M Corporation 220-7W, 3M Center St. Paul, MN 55144 (612-733-6234)	HCHO, ORG, Hg
27	Neotronics P.O. Box 370 411 Bradford St., N.W. Gainesville, GA 30503 (404-535-0600)	O <sub>2</sub> , CO, H <sub>2</sub> S	36	Tracor Atlas 9441 Baythorne Drive Houston, TX 77041 (713-462-6166)	CO
28	SAI Technology Co. 4060 Sorrento Valley Blvd. San Diego, CA 92121 (619-452-9983)	Rn	37	TSI P.O. Box 64394 St. Paul, MN 55164 (612-490-2888)	RSP
29	Scott Aviation Lancaster, NY 14086 (716-683-5100)	O <sub>2</sub>	38	Rupprecht & Parashnick Co., Inc. 8 Corporate Circle Albany, NY 12203 (518-452-0065)	TSP, RSP
30	Sensidyne, Inc. 12345 Starkey Rd., Suite E Largo, FL 33542 (813-530-3602)	CO, CO <sub>2</sub> , NO <sub>2</sub> , O <sub>2</sub> , SO <sub>2</sub> , Cl <sub>2</sub> , RSP, ASB, TSP	39	Nuclear Associates 100 Voice Road P. O. Box 349 Carle Place, NY 11514-0349 (516-741-6360)	Rn
31	SKC, Inc. RD1 #395 Valley View Rd. Eighty Four, PA 15330 (412-941-9701)	ORG, SO <sub>2</sub> , HCHO	40	Environment SA 111 Bd. Robespierre 78300 Poissy, France (1) 39.79.34.57	NO-NO <sub>x</sub>
32	Staplex Air Sampler Division 777 Fifth Ave. Brooklyn, NY 11232 (212-768-3333)	ASB, TSP, Rn	41	IES Systems Corp. 4432 N. Kedzie Ave. Chicago, IL 60625 (312-459-4655)	NO, NO <sub>2</sub> , NO <sub>x</sub> , SO <sub>2</sub> , HCHO
33	Terradex Corp. 460 N. Wiger Lane Walnut Creek, CA 94596 (415-938-2545)	Rn	42	Rad Elec. Inc. 5330 J. Spectrum Drive 270 Technology Park Frederick, MD 21701 (301-694-0011)	Rn, Prog
34	Thomas Scientific Vine St. at Third P.O. Box 779 Philadelphia, PA 19105 (609-467-2000)	HCHO, CO			

SOURCE: Ritchie and Deal (1988)

**Exhibit 6-3. Battery-powered personal air samplers.<sup>1</sup>**

MFG. CODE <sup>2</sup>	MODEL	FLOW RANGE	FLOW CONTROL ACCURACY	RUNNING TIME	PRICE	WEIGHT	DIMENSIONS
1	AFC 123	1.0-2.3 l/m	±5% of flow	8+hrs	\$425	454 g	11.8 x 13.2 x 7.9 cm
	AFC 400T	1.0-4.01 l/m	±5% of flow	4-8 hrs	\$1095	454 g	14.6 x 9.5 x 6.3 cm
2	BDX 30	0.8-3 l/m	±0.1 l/m of flow	8 hrs	\$420	595 g	10.2 x 6.3 x 11.4 cm
	BDX 34LF	0.025-0.225 l/m	±0.5% of flow	6 hrs	\$644	624 g	10.2 x 6.3 x 11.4 cm
	BDX 44	0.5-3 l/m	±0.1 l of flow	8 hrs	\$495	624 g	10.2 x 6.3 x 11.4 cm
	BDX 55HD	0.5-3 l/m	±5% of flow	8 hrs	\$550	850 g	12.7 x 6.3 x 11.4 cm
3	LV-1, LV-2	15-35 l/m	±5% of flow	line voltage	\$630	2.7 kg	10.2 x 10.2 x 17.8 cm
	BN, BNA	5-17 l/m		1 hr	\$895	5 kg	11.4 x 17.8 x 21.6 cm
	BS, BSA	5-17 l/m		2 hrs	\$995	5.5 kg	11.4 x 17.8 x 21.6 cm
4	MCS-15	3-15 l/m	±5% of flow	8 hrs-7 days	\$695	964 g	4.8 x 11.9 x 13 cm
	224-PCXR7	1-5 l/m		8 hrs	\$645	964 g	4.8 x 11.9 x 13 cm
	224-PCXR3 (and 43XR)	1-5 l/m		8 hrs	\$595 (\$445)	964 g	4.8 x 11.9 x 13 cm
	222-3; 222-4	0.02-0.08 l/m		4-8 hrs	\$425	283 g	13 x 6.4 x 3.3 cm
		0.05-0.20 l/m					
	Aircheck 50	0.75-3.0 l/m					
5	PAS-300011	0.005-3 l/m	±5% of flow	10-12 hrs	\$620	900 g	10.7 x 11.7 x 6.1 cm
	PAS-1000	0.005 2 l/m		4-8 hrs	\$420	283 g	7.6 x 10.2 x 3.6 cm

<sup>1</sup> Accessories such as calibration kits, filters, filter cassettes, impingers, sampling bags, and sorbent tubes are also included in the manufacturers' product lines.

## Manufacturers' Codes

Code	Manufacturer	Code	Manufacturer	Code	Manufacturer
1	BGI, Inc. 58 Guinan Street Waltham, MA 02154	3	Staplex <sup>®</sup> Air Sampler Division 777 Fifth Avenue Brooklyn, NY 11232-1695	4	SKC <sup>®</sup> 334 Valley View Road Eighty Four PA, 15330-9614
2	Sensidyne (formerly Bendix) 12345 Starkey Road Suite E Largo, FL 34643			5	Spectrex Corp <sup>®</sup> 3594 Haven Avenue Redwood City, CA 94063

**Exhibit 6-4. Properties of filters used in particulate sampling.**

FILTER	MATERIAL	PORE SIZE, μm	FILTER PERMEABILITY VELOCITY, cm/sec (ΔP = 1 cm Hg)	FILTER EFFICIENCY RANGE, % *
<b>A. Cellulose Fiber Filter</b>				
Whatman				
No. 1	Cellulose Fiber	-	6.1	49 - 99.96
No. 2		-	3.8	63 - 99.97
No. 3		-	2.9	89.3 - 99.98
No. 4		-	20.6	33 - 99.5
No. 5		-	0.86	93.1 - 99.99
No. 40		-	3.7	77 - 99.99
No. 41		-	16.9	43 - 99.5
No. 42		-	0.83	92.0 - 99.992
<b>B. Glass Fiber Filter</b>				
Gelman				
Type A	Glass Fiber	-	11.2	99.2 - >99.99
Type A/E		-	15.5	99.6 - >99.99
Spectrograde		-	15.8	99.5 - >99.99
Microquartz		-	14.1	98.5 - >99.99
MSA 1106B		-	15.8	99.5 - >99.99
Pallflex				
2500 QAO	Quartz Fiber	-	41.	84 - 99.9
E70/2075W		-	36.5	84 - 99.95
T60A20	Teflon Coated Glass Fiber	-	49.3	55 - 98.8
(another lot)		-	40.6	52 - 99.5
T60A25		-	36.5	65 - 99.3
TX40H12O		-	15.1	92.6 - 99.96
(another lot)		-	9.0	98.9 - >99.99
Reeve Angel 934AH (acid treated)	Glass Fiber	-	12.5	98.9 - >99.99
		-	20.	95.0 - 99.96
Whatman				
GF/A	Glass Fiber	-	14.5	99.0 - >99.99
GF/B		-	5.5	>99.99 - >99.99
GF/C		-	12.8	99.6 - >99.99
EPM 1000		-	13.9	99.0 - >99.99
<b>C. Plastic Fiber Filter</b>				
Delbag	Polystyrene			
Microsorban-98		-	13.4	98.2 - >99.99
<b>D. Membrane Filter</b>				
Millipore				
MF-VS	Cellulose acetate/nitrate	0.025	0.028	99.999 - >99.999
MF-VC		0.1	0.16	99.999 - >99.999



**Exhibit 6-4. Properties of filters used in particulate sampling (continued).**

FILTER	MATERIAL	PORE SIZE, μm	FILTER PERMEABILITY VELOCITY, cm/sec (ΔP = 1 cm Hg)	FILTER EFFICIENCY RANGE, % *
<i>Millipore (continued)</i>				
MF-PH		0.3	0.86	99.999 - >99.999
MF-HA		0.45	1.3	99.999 - >99.999
MF-AA		0.8	4.2	99.999 - >99.999
MF-RA		1.2	6.2	99.9 - >99.999
MF-SS		3.0	7.5	98.5 - >99.999
MF-SM		5.0	10.0	98.1 - >99.99
MF-SC		8.0	14.1	92.0 - >99.9
Polyvic-BD	Polyvinyl Chloride	0.6	0.86	99.94 - >99.99
Polyvic-VS		2.0	5.07	88 - >99.99
PVC-5		5.0	11.	96.7 - >99.99
Celotac-EG	Cellulose Acetate	0.2	0.31	>99.95 - >99.99
Celotac-EH		0.5	1.07	99.989 - >99.999
Celotac-EA		1.0	1.98	99.99 - >99.99
Mitex-LS	Teflon	5.0	4.94	84 - >99.99
Mitex-LC		10.0	7.4	62 - >99.99
Fluoropore	PTFE-polyethylene reinforced			
FG		0.2	1.31	>99.90 - >99.99
FH		0.5	2.32	>99.99 - >99.99
FA		0.1	7.3	>99.99 - >99.99
FS		3.0	23.5	98.2 - >99.98
Metrical				
GM-6	Cellulose acetate/nitrate	0.45	1.45	>99.8 - >99.99
VM-1	Polyvinyl chloride	5.0	51.0	49 - 98.8
DM-800	PVS/Acrylonitrile	0.8	2.7	99.96 - >99.99
Gelman Teflon	Teflon	5.0	56.8	85 - 99.90
Ghia				
S2 37PI 02	Teflon	1.0	12.9	>99.97 - >99.99
S2 37PJ 02		2.0	23.4	99.89 - >99.99
S2 37PK 02		3.0	24.2	92 - 98.98
S2 37PF 02		10.0		95.4 - >99.99
Zefluor-	Teflon			
P5PJ 037 50		2.0	32.5	94.6 - 99.96
P5PJ 037 50		3.0	31.6	88 - 99.9

(continued next page)

**Exhibit 6-4. Properties of filters used in particulate sampling (continued).**

FILTER	MATERIAL	PORE SIZE, μm	FILTER PERMEABILITY VELOCITY, cm/sec (ΔP = 1 cm Hg)	FILTER EFFICIENCY RANGE, % *
Chemplast				
75-F	Teflon Filter	1.5	3.	83 - 99.99
75-M		1.0	6.6	54 - >99.99
75-C		1.0	32	26 - 99.8
Selas Flotronics				
FM0.45	Silver	0.45	1.8	93.6 - 99.98
FM0.8		0.8	6.2	90 - 99.96
FM1.2		1.2	9.2	73 - 99.7
FM5.0		5.0	19.0	25 - 99.3
E. Nuclepore Filter				
Nuclepore				
N010	Polycarbonate	0.1	0.602	>99.9 - >99.9
N030		0.3	3.6	93.9 - >99.99
N040		0.4	2.9	78 - >99.99
N060		0.6	2.1	53 - 99.5
N100		1.0	8.8	28 - 98.1
N200		2.0	7.63	9 - 94.1
N300		3.0	12.	9 - 90.4
N500		5.0	30.7	6 - 90.7
N800		8.0	21.2	1 - 90.5
N1000		12.0	95.	1 - 46
N1200		10.0	161.1	1 - 66
F. Miscellaneous Filter				
MSA Personal Air Sampler		12		89 - 99.97

\*The range of filter efficiency value given generally corresponds to a particular diameter range of 0.035 to 1 Å, a pressure drop range of 1 to 30 cm Hg and a face velocity range of 1 to 100 cm/sec.

SOURCE: From *Air Sampling Instruments for Evaluation of Atmospheric Contaminants*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1983. Reproduced with permission.

**Exhibit 6-5. Some storage properties of gases in plastic bags.**

PLASTIC FILM	GAS OR VAPOR STORED	CONCENTRATION	REMARKS
Mylar	Olefins	20 to 400 ppm	5 to 10% loss in 24 hrs
	Formaldehyde	2 to 3 ppm	5% in 24 hrs in air mixture
	Formaldehyde	Irradiated car exhaust	5 to 10% loss in 2 hrs
	Ozone	70 ppm	10% loss in 5 hrs in synthetic air
	NO <sub>2</sub>	0.2 to 0.5 ppm	5% in 8 hrs in synthetic air
	SO <sub>2</sub>	0.5 to 5 ppm	Stable for 4 hrs in bags reconditioned with SO <sub>2</sub>
	Acrolein	Car exhaust	10% loss in 24 hrs
	Acrolein	0.1 to 10 ppm	Stable air mixture
	Aliphatic HC	0.1 to 130 ppm	10% loss for 3 days in air samples
	Toluene	200 ppm	Data given for conditioned and unconditioned bags for up to 288 hr storage
	Ethyl ether	200 ppm	
	Benzene	50 ppm	
	Methyl alcohol	200 ppm	
	Perchloroethylene	100 ppm	
	Trichloroethylene	100 ppm	
	O <sub>2</sub> deficient atmosphere	10%	
	Methyl ethyl ketone	200 ppm	
	Amyl Acetate	100 ppm	
	Acetone	200 ppm	
	Xylene	100 ppm	
	Benzene	25 ppm	2% loss after 5 days; 20% loss after 13 days
Mylar and Teflon	Sulfur Dioxide	0.5 to 1.55 ppm	Data given for conditioned and unconditioned bags for 72 hr storage
	Nitrogen dioxide	0.5 to 1.5 ppm	
	Ozone	0.5 to 1.5 ppm	
	Hydrocarbons	7 to 20 ppm	
Mylar, Aluminized, Mylar Saran, Scotchpak & Aluminized Scotchpak	Mixtures containing aliphatic & aromatic hydrocarbons, aldehydes, ketones, olefins, sulfur dioxide & nitrogen dioxide	Ranges of approx. 50 ppm to 100 ppm	Storage data given for periods varying from 16 to 65 hrs for different combinations of components in different plastic containers
Aluminized Scotchpak	Carbon monoxide	1 to 100 ppm in expired air	Stable several days
Kel-F	Nitrogen dioxide	1 ppm	Stable for 120 hrs
Polyvinyl	Carbon monoxide	1 to 100 ppm	Storage variable with source of supply
Saran	Chlorinated hydrocarbons	200 ppm	Expired air and synthetic air standards
FFP-Teflon	Hydrocarbons	Irradiated car exhaust	Stable for several hrs
Tedlar	Hydrocarbons	Irradiated car exhaust	Stable for several hrs

SOURCE: From American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1983. *Air Sampling Instruments for Evaluation of Atmospheric Contaminants*. Used with permission.

**Exhibit 6-6. Limitations of selected solid absorbents.**

ABSORBENT	LIMITATIONS
Charcoal	high surface area causes artifact formation during sampling high background contamination if using thermal desorption high affinity for water high catalytic activity incomplete sample recovery impurities in solvent extraction may be high solvent extraction causes dilution of sample
Silica gel	limited use in humid areas thermal breakdown if using thermal desorption solvent extraction causes dilution of sample
XAD-2	thermal stability questionable compounds below C <sub>7</sub> lost/breakthrough extensive
Tenax <sup>R</sup>	poor desorption of highly polar compounds possibly retains oxygen which leads to sample oxidation limited to some volatile compounds high benzene background low breakthrough volume for some organics
Carbon molecular sieve	holds onto very volatile compounds solvent extraction desorption efficiency decreases with b.p. > 100 °C

SOURCE: U.S. EPA (1989)

**Exhibit 6-7. Sources for testing and calibration procedures applicable to indoor air quality sampling.**

Air Pollution Control Association (APCA)  
Box 2861  
Pittsburgh, PA 15230  
(412-232-3444)

American Conference of Governmental Industrial Hygienists (ACGIH)  
6500 Glenway Avenue, Building D-7  
Cincinnati, OH 45211  
(513-661-7881)

American Industrial Hygiene Association (AIHA)  
475 Wolf Ledges Parkway  
Akron, OH 44311  
(216-762-7294)

American National Standards Institute, Inc. (ANSI)  
1430 Broadway  
New York, NY 10018  
(212-354-3300)

American Public Health Association (APHA)  
1015 15th Street, NW  
Washington, DC 20005  
(202-789-5600)

American Society for Testing and Materials (ASTM)  
Committee D-22 on Sampling and Analysis of Atmospheres  
1916 Race Street  
Philadelphia, PA 19103  
(215-299-5400)

National Institute for Occupational Safety and Health (NIOSH)  
Centers for Disease Control  
Robert A. Taft Laboratories, MS-R2  
4676 Columbia Parkway  
Cincinnati, OH 45226  
(513-533-8236)

U.S. Environmental Protection Agency (EPA)  
Environmental Monitoring Systems Laboratory  
Methods Standardization Branch  
Quality Assurance Division (MD-77)  
Research Triangle Park, NC 27711  
(919-541-2622)

**Exhibit 6-8. National Institute of Standards and Technology (NIST) \* Standard Reference Materials (SRMs) for the calibration of instruments and procedures utilized in air quality analysis.**

SRM ID	DESCRIPTION	COMPONENT	CONCENTRATION
Calibration Gases			
1670	Carbon dioxide in air	CO <sub>2</sub>	330 ppm
1671	Carbon dioxide in air	CO <sub>2</sub>	340 ppm
1672	Carbon dioxide in air	CO <sub>2</sub>	350 ppm
2633	Carbon dioxide in nitrogen	CO <sub>2</sub>	400 ppm
2634	Carbon dioxide in nitrogen	CO <sub>2</sub>	800 ppm
2619a	Carbon dioxide in nitrogen	CO <sub>2</sub>	0.5 mole %
2620a	Carbon dioxide in nitrogen	CO <sub>2</sub>	1.0 mole %
2621a	Carbon dioxide in nitrogen	CO <sub>2</sub>	1.5 mole %
2622a	Carbon dioxide in nitrogen	CO <sub>2</sub>	2.0 mole %
2612a	Carbon monoxide in air	CO	10 ppm
2613a	Carbon monoxide in air	CO	20 ppm
2614a	Carbon monoxide in air	CO	45 ppm
1677c	Carbon monoxide in nitrogen	CO	10 ppm
2635a	Carbon monoxide in nitrogen	CO	25 ppm
1678c	Carbon monoxide in nitrogen	CO	50 ppm
1679c	Carbon monoxide in nitrogen	CO	100 ppm
1658a	Methane in air	CH <sub>4</sub>	1 ppm
1659a	Methane in air	CH <sub>4</sub>	10 ppm
2627a	Nitric oxide in nitrogen	NO	5 ppm
2628a	Nitric oxide in nitrogen	NO	10 ppm
2629a	Nitric oxide in nitrogen	NO	20 ppm
1683b	Nitric oxide in nitrogen	NO	50 ppm
1684b	Nitric oxide in nitrogen	NO	100 ppm
2654	Nitrogen dioxide in air	NO <sub>2</sub>	500 ppm
2657	Oxygen in nitrogen	O <sub>2</sub>	2 mole %
2658	Oxygen in nitrogen	O <sub>2</sub>	10 mole %
2659	Oxygen in nitrogen IN PREP	O <sub>2</sub>	21 mole %

**Exhibit 6-8. National Institute of Standards and Technology (NIST) \* Standard Reference Materials (SRMs) for the calibration of instruments and procedures utilized in air quality analysis (continued).**

SRM ID	DESCRIPTION	COMPONENT	CONCENTRATION
1693a	Sulfur dioxide in nitrogen	SO <sub>2</sub>	50 ppm
1694a	Sulfur dioxide in nitrogen	SO <sub>2</sub>	100 ppm
Permeation Devices			
1625	Sulfur dioxide 10 cm tube	2.8 µg/min	0.107 ppm - 1.07 ppm
1626	Sulfur dioxide 5 cm tube	1.4 µg/min	0.0535 ppm -0.535 ppm
1627	Sulfur dioxide 2 cm tube	0.56 µg/min	0.0214 ppm -0.214 ppm
1629a	Nitrogen dioxide 10 cm tube	1.0 µg/min	0.05 ppm-0.5 ppm
Analyzed Liquids and Solids			
1579	Powdered lead base paint, 35 g	Pb	11.87 %
Sulfur in Fossil Fuels			
1616	Sulfur in kerosene	S	
Materials on Filter Media			
2676c	Metals on filter media (conc in µg/filter)	Cd	<0.01 - 10.09
		Pb	<0.01 - 29.81
		Mn	<0.01 - 19.85
		Zn	<0.01 - 99.29
2677	Beryllium and arsenic (conc in µg/filter)	As	<0.002 - 10.5
		Be	<0.001 - 1.03
Asbestos			
1876a	Chrysotile asbestos	As	37 fibers/ 0.01 mm <sup>2</sup>

\* Formerly the National Bureau of Standards (NBS)

SOURCE: Seward (1988)

## 6.2. ACCURACY, PRECISION, AND RELATED TERMS

Measured data can provide an estimate of the true value of a parameter which can be thought of as the average or center of an interval. In order to interpret a measurement, it is necessary to understand the variability associated with the measured data, and the overall quality of the data.

Accuracy and precision are two measures of data quality that allow us to identify the center point or average and the variability of a measurement. Exhibit 6-9 illustrates these two concepts.

Accuracy is a measure of how close the measured values are, on average, to the true value. The concept of accuracy can be easily understood by visualizing a dart board; the most accurate player is the one whose shots are scattered evenly around the bull's eye. A less accurate player may, for example, tend to hit one side of the board more frequently. In Exhibit 6-9 the most accurate measurements are shown in Exhibits 6-9b and 6-9c; in these two figures, the true value and the measured value coincide. Accuracy can be described mathematically as follows:

$$A = \frac{(X_m - X_t)(100)}{X_t}$$

where,

A = accuracy in percent;  
 $X_m$  = measured value; and  
 $X_t$  = true value.

Precision describes the variation or scatter among the results; it is a measure of the uncertainty of the average—it is not related to the true value. Again, visualizing the dart board, the most precise player is the one who consistently places the darts in the same place, even if they are not near the bull's eye. In Exhibit 6-9, the most precise measurements are shown in Exhibits 6-9a and 6-9b; in these two figures the measured values are closely clustered around the true value. Figure 6-9c shows measurements that are both precise and accurate. The

standard deviation,  $s$ , or the variance,  $s^2$ , provide a good estimate of uncertainty of the average measurement. The standard deviation for a sample of measurements can be calculated from:

$$S = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2}$$

where,

$s$  = standard deviation;

$n$  = total number of measurements;

$X_i$  =  $i$ th measurement of  $X$  measurements;

and

$\bar{X}$  = arithmetic mean of  $n$  measurements.

In many cases, accuracy and precision can be obtained with the other method and equipment specifications. If measurements are performed in the laboratory, the laboratory will evaluate accuracy and precision through the use of standard reference materials as part of its quality assurance program.

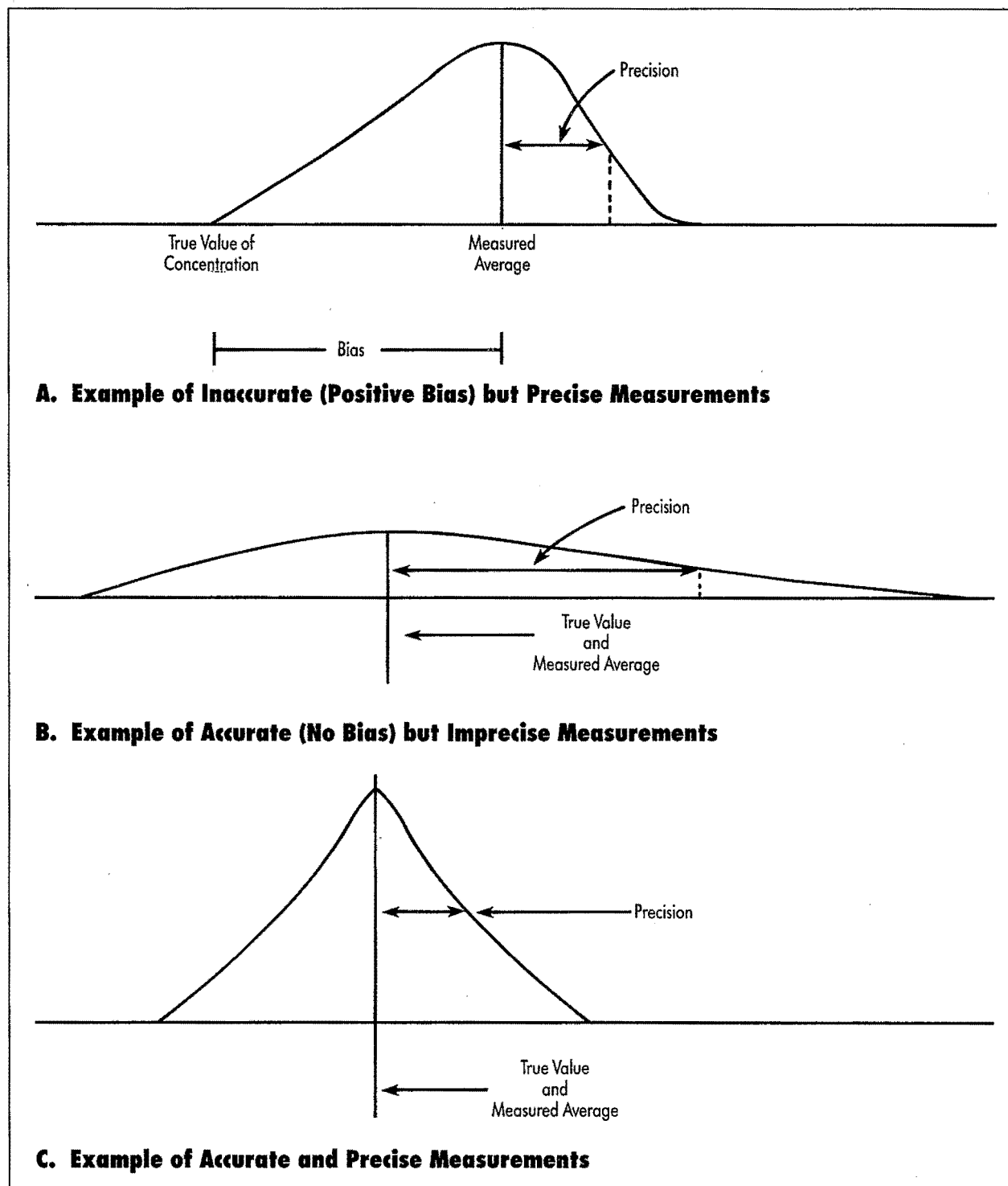
Ideally, the sampling or analytical method that is employed by the investigator will be both accurate and precise. However, it is possible for a method to have high precision but low accuracy because of improperly calibrated equipment or inaccurate measurement/dilution techniques. Alternatively, a method can be accurate but imprecise because of low instrument sensitivity or factors beyond the investigator's control.

**Bias (B)** is a term that describes the ratio of the measured value to the true value:

$$B = \frac{X_m}{X_t},$$

**Reproducibility** describes the extent to which a measurement method yields the same response to the same quantity of contaminant. It is similar to



**Exhibit 6-9. Precision and accuracy.**

SOURCE: U.S. EPA (1975)

precision, but it is a function of the instrument that is used rather than the entire measurement process, and it is evaluated over a long period of time.

**Sensitivity** is a measure of the accuracy of the output signal of an instrument, usually expressed as the ratio of the full-scale output of the instrument to the full-scale input value. An instrument with high sensitivity reproduces every fluctuation, regardless of size, that is received as an input signal. For example, a very sensitive thermometer may reflect a  $\pm 0.01$  °C change in temperature, but a less sensitive one may only reflect changes of  $\pm 2.0$  °C.

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### 6.3. REPRESENTATIVE SAMPLING

Any sampling program, survey work, or research problem should have a study design which is contained in the protocol. The study design addresses such questions as what contaminants and equipment to use, the length of the sampling time, the sampling locations, and the sample size.

A major objective of the study design is to ensure that a representative sample is collected. This generally implies a random sample of a sufficient size that will allow conclusions to be drawn about the data. Not all investigations will require the collection of many samples. Some indoor investigations may involve the collection of only one or just a few samples. Even if only a few samples are collected, the investigator must still be alert to the basic principles of collecting representative samples.

#### Probability Sampling

Valid conclusions can be drawn only if all portions of a population have a known probability of being selected during sampling. Where elements of the population have a higher probability of selection than others, the selected sample elements must be weighted to compensate for this difference during statistical computations. This means that some type of probability sampling plan must be used to ensure that the sample is representative of the population being measured.

The selection of a probability sample can be accomplished in several ways. In one method (used for asbestos sampling) the area or volume to be sampled is reproduced on paper and divided into numbered units. The units to be sampled are selected from a table of random numbers which can be found in most books on statistics. Random numbers can also be generated by computer programs. If random sampling is employed, care must be taken to ensure that samples are collected at the specified locations or times. In large survey work, random sampling can be costly.

An alternative to random sampling is systematic sampling in which samples are collected at regular intervals both in time and space. This sampling scheme may be more cost effective and easier to accomplish, but bias can enter into the sample selection if there is a pattern in the data which is correlated with the structure of the sampling frame.

Another approach is to stratify the sample (either in time or in space) if the population under study is known or suspected of being stratified in some way. This approach has the advantage of resulting in better precision than random sampling (and it may be more cost effective). The population is divided into strata (parts) that are as uniform as possible in the component of interest. Each stratum is sampled independently, and the average standard deviation is calculated. The strata do not have to be equal in size.

Before any large scale investigation, survey, or research is undertaken, it is important to get advice from someone who is knowledgeable in statistical sampling. Considerable time, expense, and embarrassment can be saved by ensuring that the job is done correctly the first time.

#### Determining Sample Size

Deciding on the proper sample size for a given project can be a difficult decision because of the usual trade-offs between budget constraints and the ideal situation. Starting points for the selection of a

sample size are the overall objectives of the monitoring, and the availability of equipment for sampling and laboratory analyses.

Within these two constraints, the selection of sample size depends on many factors including:

- contaminant(s) to be monitored;
- length of time each contaminant is to be sampled (instantaneous sample, 24-hour, 3-month, and so forth);
- type of structure, geographic area; and
- time when sampling occurs (season, day of week, time of day).

The number of samples to be measured depends on the accuracy desired in the data as well as the expected variance in the data. When measured data are arranged according to frequency, some data may fit a symmetrical or normal distribution which is defined by the mean or standard deviation. The mean is found by dividing the sum of the individual observations by the number of observations. In many instances, the frequency distributions tend to be nonsymmetrical or skewed in one direction. These data can be represented by a geometric mean which is defined as the  $n$ th root of the product of  $n$  values:

$$\bar{X}_g = \left[ \prod_{i=1}^n X_i \right]^{1/n}$$

where,

$\bar{X}_g$  = geometric mean, and  
 $X_i$  = individual data values.

The geometric mean can also be defined as the antilog of the arithmetic mean of the logarithms of the data values. Either common logarithms ( $\log_{10}$ ) or natural logarithms ( $\log_e$ ) can be used to calculate the geometric mean. When the data are distributed according to the lognormal frequency distribution, the geometric standard deviation,  $s_g$ , is used as a measure of dispersion instead of the standard deviation,  $s$ . The geometric standard deviation is

defined as the antilog of the standard deviation of the logarithms of the measurements. It is computed as for the arithmetic standard deviation, after transforming each value to its corresponding log value.

The sample size necessary to achieve a given precision (for example, being 95% confident that the true value is plus or minus some amount) can be approximated using the following equation:

$$n = \frac{t^2 s^2}{d^2}$$

where,

$t$  = the number of standard deviations that account for the desired confidence level (area under the normal curve); for example, 2.14 standard deviations account for 95% of the area under a normal curve

$s$  = standard deviation of the variable to be estimated; and

$d$  = the margin of error that is acceptable.

In this calculation, a preliminary estimate of the standard deviation is required. The expected average may also be desirable for deciding what margin of error will be acceptable.

When the required information is not available for calculating the sample size, the expected levels can be estimated based on professional judgment and experience, or a pilot program (small-scale sampling program) can be used to gather preliminary data which are then used to refine the sample size calculations as well as the overall protocol. It is important to avoid making the sample so small that the estimate is too inaccurate to be useful, but because of cost, a sample that is too large should be avoided. Since the determination of sample size can be complicated (for example, nonnormal distributions, stratified sampling), the investigator is cautioned to consult with a statistician to be sure that the proper sample size will be collected in a cost efficient manner.

### Example Calculation

Assume that the average value of a contaminant (normally distributed) is to be estimated within  $\pm 10\%$  of its true value under a given set of environmental conditions with a confidence of 95%. From previous studies, it is known that the standard deviation,  $s$ , is 0.20. The required sample size, 18, is estimated as follows:

$$n = \frac{(2.14^2)(0.20^2)}{.10^2}$$

$$= 18.$$

The effect of the acceptable error can be evaluated by comparing the above results to those if a margin of error of 20% is acceptable as follows:

$$n = \frac{(2.14^2)(0.20^2)}{.20^2}$$

$$= 5.$$

In this example, accepting a greater margin of error means that fewer samples must be collected. Whether or not this is a good decision depends on the consequences of accepting a greater margin of error.

## 6.4. CALIBRATION

Calibration methods and quality assurance procedures for equipment and laboratory methods are specified in several references (Taylor, 1987; Katz, 1977; and U.S. EPA, 1975, 1977, 1980, and 1989).

Direct reading instruments must be calibrated and audited on a routine basis if they remain at a fixed site. An audit is simply a check on the calibration using one or two calibration points plus zero. Field monitors which are routinely moved from site to site should be calibrated before use at a new site (on-site) and the calibration should be checked at the

end of the sampling period. The calibration curve should be developed over the concentration range of interest and should consist of zero plus 3 to 4 points using standard calibration materials.

Exhibit 6-10 provides an example of a calibration data sheet. This form can also be used for audits. If the before and after calibrations differ significantly from previously identified values ( $\pm 5\%$  is a useful guideline if a value is not specified in the procedure), the data should not be used, and the contaminant should be resampled.

Indirect reading methods must also be calibrated. This may involve calibration of flowmeters followed by laboratory analysis some time after collection. If so, the laboratory will have its own procedures for calibrating equipment used to analyze the collected contaminant. Some samplers such as passive diffusion samplers are calibrated by the manufacturer—these calibrations can be checked by the investigator who has the appropriate facilities, but these checks are not routinely done.

## AIRFLOW MEASURING DEVICES

### Types of Airflow Measuring Devices

The concentration of a contaminant that is collected (by filter, absorber, adsorber, direct reading instrument) depends on the volume of air sampled:

$$\text{Concentration} = \frac{\text{mass of pollutant}}{\text{volume of air sampled.}}$$

The volume of air sampled, in turn, depends on the flowrate, and it is the flowrate which must be calibrated in both active and passive direct reading and indirect reading samplers:

$$\text{Volume} = \text{flowrate} \times \text{time.}$$

Flowrates can be measured by several different types of devices (Exhibit 6-11):

- a) volume meters that measure the total volume of gas over some period of time;
- b) rate meters that measure the time rate of flow through them—the flowrate is measured through some property of the gas;
- c) variable area meters that measure the rate of flow through a changing cross-sectional area; and
- d) velocity meters that measure the linear velocity of a gas through a duct.

Widely used devices for measuring flowrates in indoor applications are rotameters, orifice meters, and mass flow meters.

### Rotameters

The rotameter is a device that consists of a float that is free to move up and down in a vertically graduated, tapered tube (made of glass, metal, or plastic) which is larger at the top than at the bottom. As the float moves up and down, a variable ring or annulus is created between the outer diameter of the float and the inner wall of the tube. As air flows upward the float rises until the pressure drop across the annular area between the float and the wall of the tube is just sufficient to support it. The height of the float is noted at the point of maximum diameter (by convention) and this position on the vertical scale is compared to a calibration chart to obtain the flowrate.

The rotameter is the most commonly used device in the laboratory and in commercial instruments. Rotameters can be easily calibrated using a bubble meter; accuracies are  $\pm 5\%$  using the calibration curve supplied by the manufacturer, but accuracies of  $\pm 1.0\%$  to  $2\%$  can be achieved when rotameters are calibrated in the sampling system as they will be used (Wilson *et al.*, 1983).

The vacuum pump and rotameter may be combined into one unit as in personal sampling pumps. Since

rotameters are very sensitive to pressure changes, they must be calibrated in place with the sampling system exactly as it will be used during field operation. Also, periodic cleaning of rotameters is essential since performance is affected by the accumulation of moisture and dust.

### Orifice Meters

The orifice meter may be noncritical or critical. Both types can be easily calibrated using a soap-bubble meter. A noncritical orifice can consist of a thin plate having one circular hole that is inserted into a pipe. The pressure drop upstream and downstream of the orifice can be related to the time rate of flow. Flowrates from a few ml/min to 50 ml/min can be measured (Wilson *et al.*, 1983).

The term critical orifice designates an orifice in which the pressure drop across the orifice is increased until the downstream pressure is equal to about 0.53 times the upstream pressure. As long as this ratio remains constant, the flowrate remains constant for a given upstream pressure and temperature, regardless of the pressure drop.

Critical orifices can easily be fashioned from hypodermic syringe needles by trimming the plastic end and inserting the needle into the airflow stream. A 22 gauge hypodermic needle 25 mm long results in a flowrate of about 1 l/min for a 30 minute sampling time; a 23 gauge needle 16 mm long results in a flowrate of about 0.5 l/min. Only one calibration point is needed for a critical orifice, and accuracies of  $\pm 2\%$  can be expected (Wilson *et al.*, 1983). Once critical orifices are calibrated, they are relatively insensitive to pressure changes and can maintain constant flow for a long time, provided they do not plug.

### Mass Flow Meters

The mass flow meter is a device that works on the principle that when a gas passes over a heated surface, heat is transferred from this surface to the gas. The velocity of the gas is measured by the

amount of current required to keep the surface at a constant temperature. The term mass flow rate arises because the amount of heat transferred depends on the mass and velocity of the gas. Mass flow meters are increasingly used in monitoring instruments. The mass flow meter must be calibrated with the same gas which will be measured, because different gases have different thermal properties. Flows do not need to be corrected for temperature and pressure, and the soap-bubble meter can be used to calibrate the meters.

**174****Calibration of Airflow Measuring Devices**

Airflow measuring devices can be calibrated using primary, secondary, or intermediate standards. Primary standards are those for which the volume can be determined by measuring the internal physical dimensions alone. Accuracies of  $\pm 0.30\%$  can be reached. Intermediate standards are those that are calibrated against primary standards; 1% to 2% accuracies can be achieved. Secondary standards are those that are calibrated against primary or secondary standards; accuracies of less than 5% can be achieved (Wilson *et al.*, 1983).

The flowrates of active samplers are typically calibrated in the laboratory or in the field by the investigator before the sampling devices are used, but the flowrates of passive samplers are calibrated by the manufacturer.

Flowrates that are specified by the methods should be used. Increasing the flowrate to increase sensitivity may result in sample loss or decrease the collection efficiency. Always consult with a knowledgeable person before changing any parameters in a method.

Flowrates for indoor air measurements must be low enough not to affect air movement and air exchange. Personal sampling pumps operate at flowrates up to 4 l/min for 8 hours and are powered by internal batteries. Batteries must be fully charged before sampling begins or data could be lost if the pump quits before the sampling period is finished.

Standard methods will specify flow rates both as a range and acceptable percent change during a given sampling period. The flowrate must be measured both before and after sampling to ensure that the pump was operating properly during the entire sampling period. This will also prevent a faulty pump from being used for subsequent sampling efforts. Routine calibration of the flowmeter is a must.

It is important to perform the calibration with the sampling system in place exactly as it will be used during operation (that is, impingers should be filled with solution, filters should be loaded onto cassettes, and so forth).

Flowmeters should be calibrated over several points (4 to 5); however, devices with a fixed flow (critical orifice) would be calibrated at a single point. A sample calibration data form for the calibration of rotameters is given in Exhibit 6-12.

**Soap-Bubble Meter**

The most commonly used devices to calibrate flowrate measurements for indoor environments are the soap-bubble meter and the wet test meter. A soap-bubble meter is one of the simplest and most basic primary standards; it is also relatively inexpensive (less than \$100 for the meter) and easy to use. It is nothing more than a cylindrical tube that has graduated markings to identify volume. Inverted burets are commonly used as soap-bubble meters, but they can only be used to calibrate vacuum pumps. In order to calibrate positive pressure flows, the soap-bubble meter must be used.

The soap-bubble meter must itself be calibrated before it can be used to calibrate flows from pumps. This is done by the manufacturer. The calibration can be checked by filling the tube with water and measuring the liquid from the top graduation to the bottom graduation. A temperature correction must be applied. The soap-bubble meter should only be used to measure volumes between gradations that have been calibrated. In an average laboratory

setting the soap-bubble meter is accurate to about  $\pm 1\%$ ; accuracy decreases for flows greater than 1 l/min or less than 1 ml/min. The calibration and use of bubble meters are discussed in an article by Levy (1964).

The set up for calibrating under vacuum and pressure conditions is shown in Exhibit 6-13 for the soap-bubble meter and an inverted buret. The calibration procedure using either device begins by wetting the inside of the tube with a soap solution. Commercial surfactant products such as "Snoop" or dishwashing soaps such as "Ivory" work well. Some experimentation is needed to get the right proportion of soap to water. Next, a bubble is formed by either touching the tip of the buret to the soap solution (Exhibit 6-13c) or by squeezing the rubber bulb until the soap solution is raised above the gas inlet (Exhibit 6-13 a,b).

The bubble is moved up the tube by either a vacuum at the top or a slight positive pressure at the bottom of the tube. The volumetric flow rate can be calculated by measuring the time (with a stopwatch) it takes the bubble to move through a given volume:

$$\text{Flowrate} = V_{\text{meas}} / \text{time}.$$

Because of the potential variability in measuring the time, each flowrate should be measured five times. The average time should be used in the calculation of the flowrate. Before the flowrate is calculated, the measured volume must be corrected. First, a pressure and temperature correction must be applied if the room conditions are different from standard atmospheric conditions:

$$V_{\text{STP}} = V_{\text{meas}} (P_{\text{atm}} / 760 \text{ mm Hg}) (298^\circ\text{K} / T_{\text{atm}}).$$

where,

$$V_{\text{STP}} = \text{volume at STP};$$

$$V_{\text{meas}} = \text{measured volume};$$

$$P_{\text{atm}} = \text{atmospheric pressure (mm Hg)};$$

$$T_{\text{atm}} = \text{atmospheric temperature (}^\circ\text{K)}.$$

Second, the volume must be corrected for water content of the air. If the gas behind the bubble has a relative humidity greater than 50%, the error is small; if the gas is dry, the error can be large and must be corrected:

$$V_{\text{corr}} = V_{\text{STP}} [(P_{\text{atm}} - P_w) / P_{\text{atm}}]$$

where,

$$V_{\text{corr}} = \text{volume (STP) corrected for water vapor, and}$$

$$P_w = \text{vapor pressure of water at room temperature (mm Hg); can be found in a handbook of chemistry.}$$

## Wet Test Meter

The wet test meter is an intermediate standard that must be calibrated against a primary standard before it can be used. It operates much like a waterwheel. The meter consists of a series of inverted traps that are mounted radially around a shaft that rotates. The traps are partially immersed in water, and gas that enters the meter fills the traps which causes the shaft to rotate. The volume of gas that enters and exits the meter is registered by rotating index pointers.

The meter is prepared by first leveling and then filling it to the proper level with water. The water should be allowed to equilibrate until it is the same temperature as the surrounding air. Gas is passed through the meter for several hours to saturate the water with the gas. Once the meter water level is set and the meter is equilibrated, it is ready to use. Enough gas is drawn through the system to move the drum, and each point is measured several times. Wet test meters should not be used with gases (such as sulfur dioxide) which produce a corrosive solution with water. Temperature and pressure corrections must be made.

**Exhibit 6-10. Example calibration or audit form for a direct reading carbon monoxide or carbon dioxide monitor.**

\_\_\_\_\_ Audit

\_\_\_\_\_ Calibration      Operational Period \_\_\_\_\_ to \_\_\_\_\_

Site # \_\_\_\_\_      Instrument \_\_\_\_\_

Location \_\_\_\_\_      Serial # \_\_\_\_\_

Date \_\_\_\_\_      Range Setting \_\_\_\_\_

Operator \_\_\_\_\_      Zero Setting \_\_\_\_\_

Span Setting \_\_\_\_\_

Cylinder #	Standard Conc.	Response % Chart	Measured Conc.	% Diff.	Remarks

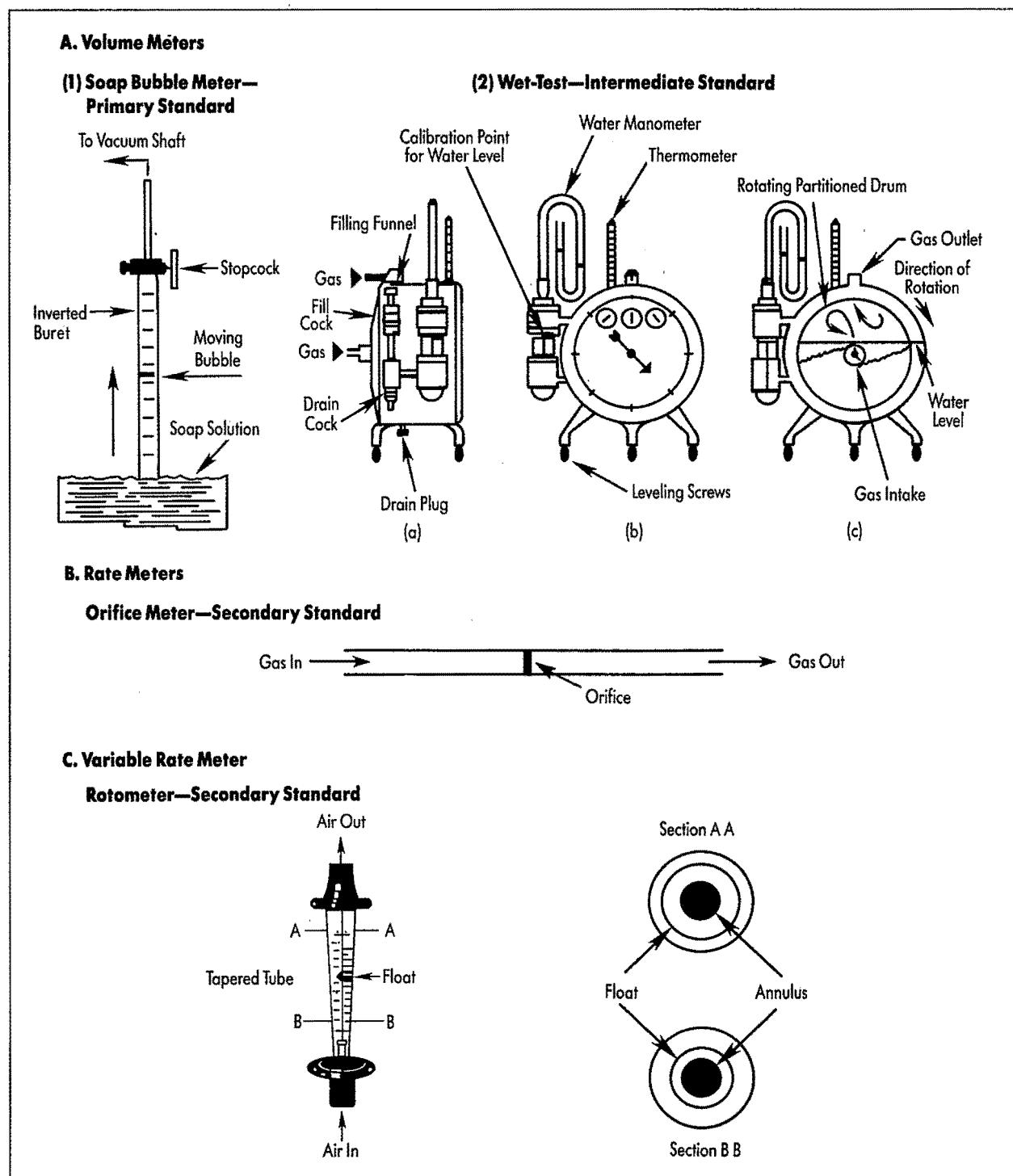
To determine recorder response when setting span during calibration:  
 (cylinder concentration/.5) + baseline = % chart (100% of scale = 50 ppm)

Measured concentration = (Response % chart - baseline) (.5)

% Difference =  $\frac{\text{Measured concentration} - \text{Standard concentration}}{\text{Standard Concentration}} \times 100$

SOURCE: U.S. EPA (1977)



**Exhibit 6-11. Different types of airflow meters.**

**Exhibit 6-12. Sample rotameter calibration form.**

Rotameter serial number \_\_\_\_\_ Calibrated with \_\_\_\_\_

Location \_\_\_\_\_ Atmospheric temperature ( $T_{\text{atm}}$ ) \_\_\_\_\_ °C + 273 = \_\_\_\_\_ °KAtmospheric pressure ( $P_{\text{atm}}$ ), mm Hg \_\_\_\_\_ Vapor pressure of H<sub>2</sub>O ( $P_w$ ), mm Hg \_\_\_\_\_

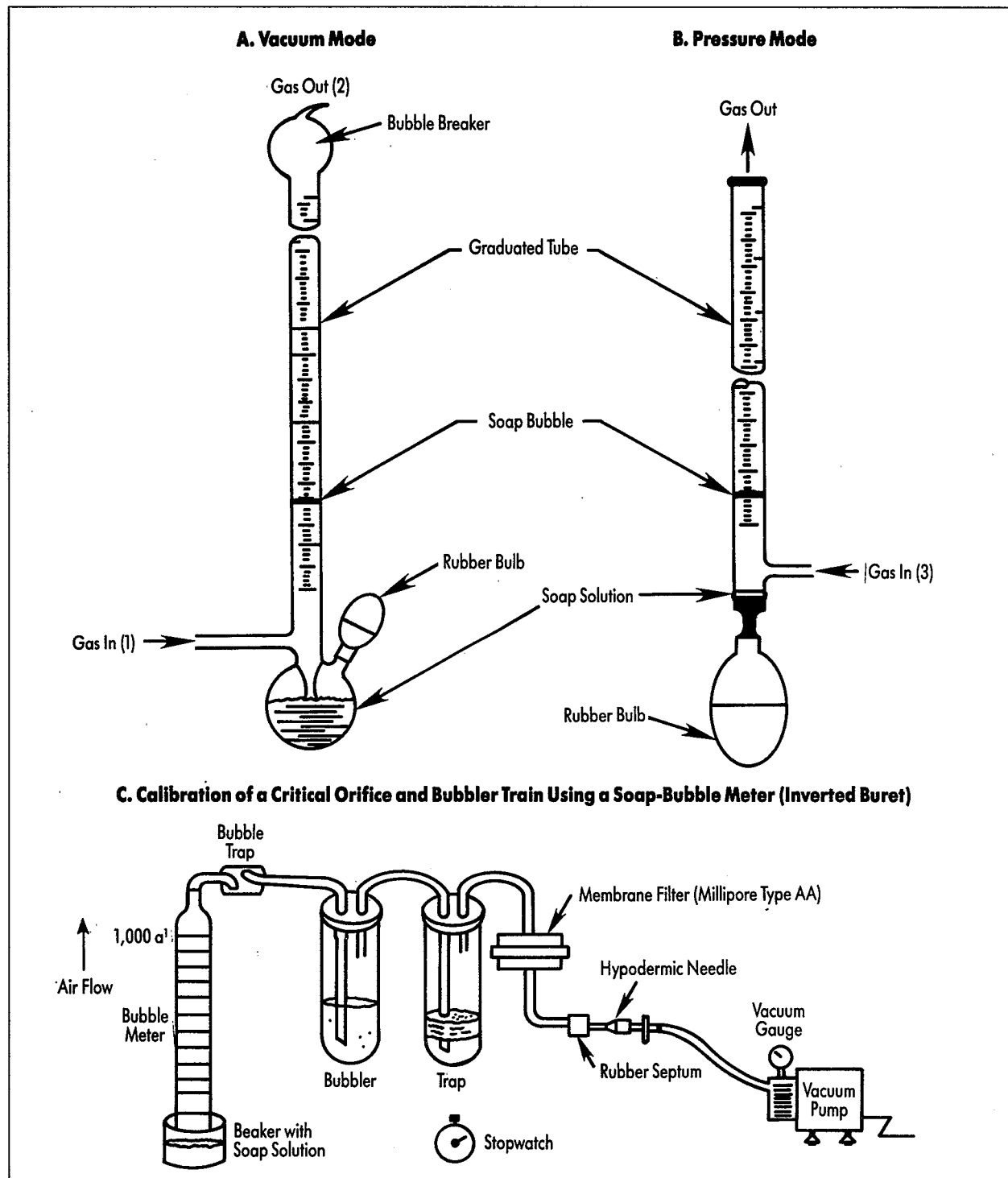
Calibrated by \_\_\_\_\_ Date \_\_\_\_\_

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Test point	Rotameter reading units	Bubble displacement time, min	Average time ( $\tau$ ), min	Volume displaced, ( $V_{\text{meas}}$ ) ml	Volume at STP ( $V_{\text{STP}}$ ) <sup>a</sup> , ml	Flowrate, $Q_{\text{STP}} = \frac{V_{\text{STP}}}{t}$ ml/min	Remarks
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

$$^a V_{\text{STP}} = V_{\text{meas}} \left( \frac{P_{\text{atm}} - P_w}{P_{\text{STP}}} \right) \left( \frac{T_{\text{STP}}}{T_{\text{atm}}} \right)$$

SOURCE: U.S. EPA (1977)

**Exhibit 6-13. Calibration using the soap-bubble meter.**SOURCE: Wilson *et al.* (1983)

Wet test meters are not for field use. They are bulky, heavy and require special environmental conditions; therefore, they are seldom used outside the laboratory. They do have a high accuracy ( $\leq 0.5\%$ ) and can be used to calibrate flowrates in the range of 0.5 to 20 l/min (Lioy, 1983).

## SECTION 6.5. PASSIVE SAMPLERS

**R**ecent technological advances have resulted in the development of a variety of small, lightweight devices that can be worn by an individual to measure exposures over varying periods of time. These sampling devices include both active and passive monitors. Passive monitors have expanded the ability of the investigator to collect data unobtrusively and at a reasonable cost per sample. Results are expressed as the measured concentration during a given period of time (ppm-hr); the time period for sampling should be included in the reprint of results.

General descriptions of some types of passive samplers are given below; further discussion of passive samplers can be found in Wallace and Ott (1982) and Berlin *et al.* (1987). Characteristics of specific samplers are given in Exhibit 6-2a.

### Sorbent Badges

Sorbent badges contain liquid or solid sorbents in a reusable badge housing. These are widely used in the workplace to collect both organic and inorganic contaminants, and some of these may be appropriate for indoor air measurements. Sorbent badges can be attached to an individual's clothing to approximate the breathing zone.

**Liquid sorbent badges:** Liquid sorbent badges consist of a liquid-filled chamber which has a bound-liquid membrane on the sampling face. Contaminated air diffuses through a diffusion barrier at a previously determined rate and comes into contact with the bound-liquid membrane. Sorbent badges can be obtained with a collecting medium capacity of 5 ml to 25 ml and flowrates

from 0.5 to 50 ml/min. A variety of analytical methods can be used to analyze the contaminant-containing liquid including direct injection into a GC, GC with purge and trap techniques, specific ion electrodes, and colorimetric methods. Badges can be reused if they are properly cleaned and refilled (refill kits can be purchased). The cost is about \$30-\$45 for each badge, and refill kits can be purchased for about \$30 for 10 kits. Not all of the potential applications have been verified with validation studies.

**Solid sorbent badges:** Sorbent badges with solid sorbents also rely on diffusion to transport contaminants at a constant sampling rate into the sorbent. These samplers can be purchased with a backup sorbent which is located behind the primary sorbent. Since sorbents have a finite capacity, the use of a backup sorbent or two sorbents in parallel, but at different sampling rates, is a recommended practice. After the sample has been collected, the sorbent capsule is removed, placed into a container, sealed, and transported to the laboratory. Both the primary and backup sorbents are analyzed. Analysis can be accomplished by a variety of methods as noted under liquid sorbents. Charcoal, silica gel, XAD-2, and other sorbents can be purchased. Typical costs are about \$10-\$15 for the reusable capsule holder and about \$2 for each sorbent capsule.

**Sorbent filters and metallic grids:** A variety of sorbent devices are available for sampling gases. These devices are configured as both tubes and badges. One example is the Palmes tube (or similar device), which has been widely used to sample nitrogen dioxide indoors. It is a small acrylic tube (1.27 cm outside diameter, 0.95 cm inside diameter, and 7.1 cm long) which has three stainless steel grids stacked and held into place by a cap at one end of the sampler. The grids are precoated with triethanolamine (TEA). The bottom end of the tube is open to the air and allows the nitrogen dioxide to diffuse upward to the TEA coated grids. After exposure the open end of the tube is capped and the sampler is sent to the laboratory for analysis. The

Palmer tube has also been used to sample sulfur dioxide and carbon monoxide.

### Color Badges

Color badges, which provide immediate results, are also available. These badges are similar to colorimetric detector tubes. The badges consist of a sampling tube that contains a chemical which reacts with a specific contaminant to produce a color change. The length of the color stain and the sampling time are used to determine concentrations. In general, color badges are not sensitive enough for indoor air monitoring.

#### Passive Bubbler

Another potentially versatile passive monitor is the Passive Bubbler™. It consists of a glass vial sealed with a Teflon<sup>®</sup>-faced Knudsen diffusion disk and cap. The disk can be reused up to three times, but a new disk for each sample is recommended to minimize sampling errors. A sorbing solution is placed into the vial and the vial is clipped to the clothing of a potentially exposed person or placed on a stand to collect an area sample.

The Knudsen diffusion disk controls the rate of sampling, which is accurate over a range of air velocities from 25 fpm to 250 fpm without correction. The sampling rate of the bubbler can be determined by comparison with a reference method or by using a test atmosphere (Miksch, 1989a,b). After the sample is collected the disk and septum cap are removed and replaced by a solid Teflon-lined cap. The collected sample can be analyzed by GC, HPLC, ion specific electrodes, colorimetry, or other methods.

## SECTION 6.6 AIR EXCHANGE RATES

Measurements of air exchange rates may be needed for some types of modeling studies or to evaluate the effectiveness of control strategies. Several tracer gas techniques, either short-term or long-term, can be used for measuring infiltration in

residential and commercial buildings. Tracer gas techniques and instrumentation for studying building air exchanges are reviewed by Persily (1988) and Dietz (1988).

A commonly used method is referred to as the tracer-gas decay method. In this procedure a known concentration of a gas such as sulfur hexafluoride or nitrous oxide is injected into a space and the decrease in the concentration of the gas, which is referred to as the decay of the gas, is measured over time. The concentration of the tracer gas is assumed to be negligible outside of the structure, and the rate of dilution of the tracer gas is proportional to the rate at which outside air enters the structure.

A portable, nonintrusive passive system based on the tracer-gas decay method has been developed at Brookhaven National Laboratory (Dietz, *et al.*, 1986). This method is available commercially through the National Association of Home Builders (NAHB) National Research Center, 400 Prince Georges Center Boulevard, Upper Marlboro, MD 20772-8731.

The NAHB method, which is called the Air Infiltration Measurement System (AIMS), uses perfluorocarbon tracers (PFTs) to measure infiltration for periods of a few days to 6 months (Song and Fan, 1989). The system uses a source emitter which releases PFT gas at a rate of 1 to  $4 \times 10^{-8}$  l/min. A uniform concentration is established within 5 to 6 hours. The receiver is a capillary adsorption tube (CAT) which contains a small amount of activated ambersorb to capture the perfluorocarbons. Air enters the receiver by diffusion at a constant rate of 0.2 l/day. Since the rate of emission is temperature dependent, air temperatures should be measured, and the emitter and receivers must be placed carefully. After exposure, the adsorption tube is analyzed by a gas chromatograph using an electron capture detector. The cost is about \$50 per 500 ft<sup>2</sup> of floor area or \$50 per sampler tube. Multizone analysis typically costs \$60 per 500 ft<sup>2</sup> of area or \$60 per sampling tube.

Tracer-gas decay methods are relatively accurate, but they do have shortcomings. First, they are unable to provide much information about the location of air leaks in a structure, and second, short-term tests cannot determine infiltration under weather conditions different from those present at the time of the test. EPA has developed standard methods for both the PFT-CAT system and the sulfur hexafluoride procedure (U.S. EPA, 1989).

Air exchange rates can be measured indirectly by estimating the effective leakage area of the structure. The effective leakage area is equivalent to the sum of the areas of all the openings in the building shell through which air is able to pass. The effective leakage area can then be used in an infiltration model to estimate the uncontrolled air exchange rates of the structure. These models are outlined in Diamond and Grimsrud (1984).

The fan pressurization method uses a variable-speed fan, which is mounted on a door which connects to the outside, to move large volumes of air into or out of a structure. The fan is used to pressurize and depressurize the structure. The flow of air through the fan is determined at a given pressure differential and fan speed by comparing measurements to a calibration curve. A pressure versus flow curve is determined by taking measurements at several fixed pressure differentials, for example, from 10 pascals to 70 pascals, at 10 pascal intervals. These data are then used in a mathematical equation to determine the effective leakage area of the structure. Additional overviews of these methods can be found in Wadden and Scheff (1983) and Diamond and Grimsrud (1984).

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## SECTION 7. STANDARDS AND GUIDELINES FOR VENTILATION AND HEALTH EFFECTS

This section contains tabulated information on available standards and guidelines. Exhibit 7-1 provides quantitative information on both public health and occupational concentration limits for various chemical contaminants. Exhibits 7-2 and 7-3, which are taken from ASHRAE Standard 62-1989, provide outdoor air requirements for various indoor spaces. Exhibit 7-4 provides ventilation requirements for residential structures which are contained in the current Uniform Building Code; these requirements may be changed pursuant to the issuance of ASHRAE Standard 62-1989. Exhibit 7-5 summarizes acceptable seasonal ranges of temperature and humidity from ASHRAE Standard 55-81.

Unit 2, lesson 7 of the *Learning Module* should be consulted for explanations and guidance on the use of these standards.

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**Exhibit 7-1. Air quality standards and guidelines for selected contaminants.**

STANDARD OR GUIDELINE (m = mg/m <sup>3</sup> ; μ = μg/m <sup>3</sup> )									
SUBSTANCE	AVERAGING TIME	PUBLIC HEALTH				OCCUPATIONAL			COMMENTS
		EPA	WHO	ASHRAE	CANADA	OSHA	NIOSH	ACGIH	
Acetaldehyde	8 hr					180m		180m	
	15 min					270m		270m	
Acetone	8 hr					1800m		1780m	
	15 min					2400m		2380m	
Acrolein	8 hr					250μ		230μ	
	15 min					800μ		690μ	
Acrylonitrile+	8 hr ceiling		*			4340μ 21700μ	2170μ 21700μ	4340μ	OSHA standard is given in 1910.1045
Aldehyde (total)	1 hr				R<1				R = sum (ci/Ci) ci = measured concentration over a 5 min. period Ci = 120μ formaldehyde 50μ acrolein 9000μ acetaldehyde
Ammonia	8 hr							17m	NIOSH ceiling is set for 5 minute exposure.
	15 min ceiling					27m	34.8m	24m	
Arsenic+	8 hr ceiling		*			500μ	2μ	200μ	OSHA standard is for organic compounds. ACGIH TWA is set for soluble compounds. NIOSH ceiling is set for 15 minute exposure.
Asbestos+	annual		*			0.2f/cc			OSHA standard is given in 1910.1001. NIOSH level for fibers over 5 um length. ACGIH levels (TWA) are amosite 0.5f/cc chrysotile 2.0f/cc crocidolite 0.2f/cc other 2.0f/cc f/cc = fibers per cubic cm
	8 hr ceiling					0.1f/cc	0.1f/cc		
Benzene+	8 hr		*			3.1m	0.32m	32m	NIOSH ceiling is set for 15 minute exposure. OSHA standard applies to industry exempt from 1910.1028.
	ceiling					7.8m	3.2m		

**Exhibit 7-1. Air quality standards and guidelines for selected contaminants (continued).**

SUBSTANCE	AVERAGING TIME	STANDARD OR GUIDELINE (m = mg/m³; µ = µg/m³)							COMMENTS
		PUBLIC HEALTH				OCCUPATIONAL			
		EPA	WHO	ASHRAE	CANADA	OSHA	NIOSH	ACGIH	
Beryllium+	8 hr ceiling					2µ 5µ	0.5µ	2µ	
Cadmium fume+	annual 8 hr ceiling		.01-.02			100µ 300µ		50µ	WHO guidelines are annual: <1-5 ng/m³ (rural areas) 10-20 ng/m³ (urban areas) OSHA standard is 100 (TWA) for cadmium fume, and 200 (TWA) for cadmium dust. ACGIH proposed TWA is 10. NIOSH recommends reducing exposure to lowest feasible level. In process of rulemaking for OSHA standard.
Calcium oxide (lime)	8 hr					5m		2m	
Carbon dioxide	continuous long term 10 hr 8 hr 15 min 10 min			1800m 1800m	6300m		18000m 54000m	9000m 54000m	ASHRAE guideline is not considered to be a health risk, but a surrogate for ventilation 1000 ppm=1800m.
Carbon disulfide	24 hr 10 hr 8 hr 30 min 15 min		.10m   .02m			12 m 100m 36m	3m  30m	31m	WHO guideline of .02m is based on sensory effects.
Carbon monoxide	8 hr 1 hr 30 min 15 min maximum	10m 40m	10m 30m 60m 100m	10m 40m	12.6m 28.6m	40m   229m	40m   229m	57m   458m	WHO CO guidelines are designed to protect nonsmokers and prevent COHb levels exceeding 2.3 -3%.
Chlordane+	8 hr continuous 30 min			.005m		0.5m		0.5m 2m	

(continued next page)

**Exhibit 7-1. Air quality standards and guidelines for selected contaminants (continued).**

		STANDARD OR GUIDELINE (m = mg/m³; µ = µg/m³)							
SUBSTANCE	AVERAGING TIME	PUBLIC HEALTH				OCCUPATIONAL			COMMENTS
		EPA	WHO	ASHRAE	CANADA	OSHA	NIOSH	ACGIH	
Chlorine	8 hr 15 min ceiling					1.5m 3m		1.5m 3.0m	NIOSH 15 minute limit is a ceiling limit.
							1.45m		
Chloroform+	8 hr					9.78m		49m	
Chlorpyrifos	8 hr 15 min					0.2m		0.2m (0.6m)	ACGIH proposes to delete the 15 min limit.
Chromium (II and III)	annual 10 hr 8 hr 15 min		*				0.001m		NIOSH 10 hr limit is for carcinogenic chromium; other chromium compounds have a 0.025m 10 hr limit. ACGIH limit for Cr (VI) is 0.05m for water soluble and certain water insoluble compounds.
						0.5m		0.5m	
							0.05m		
Cresol	10 hr 8 hr						10m		
						22m		22m	
Diazinon	8 hr					0.1m		0.1m	
Dichlorvos (DDVP)	8 hr					1m		0.9m	
p-Dichlorobenzene	8 hr 15 min					450m 675 m		451m 661m	
1,2-dichloroethane+ (ethylene dichloride)	24 hr 8 hr ceiling		0.7m			4m 8m	4m 8m	40m	
di-(2-ethyl hexyl) phthalate (DEHP)+	8 hr 15 min					5m 10m		5m 10m	
Ethyl acetate	8 hr					1400m		1440m	
Ethyl benzene	8 hr 15 min					435m 545m		434m 543m	
Ethyl ether	8 hr 15 min					1200m 1500m		1210m 1520m	

# Exhibit 7-1. Air quality standards and guidelines for selected contaminants (continued).

SUBSTANCE	AVERAGING TIME	STANDARD OR GUIDELINE (m = mg/m <sup>3</sup> ; μ = μg/m <sup>3</sup> )							COMMENTS
		PUBLIC HEALTH				OCCUPATIONAL			
		EPA	WHO	ASHRAE	CANADA	OSHA	NIOSH	ACGIH	
Ethylene dichloride+	8 hr 15 min					4m 8m		40m	
Formaldehyde+ (see aldehydes)	8 hr 30 min 15 min ceiling		.1m			1.2m  2.5m	 0.12m	1.2m 2.5m	ACGIH proposed ceiling limit is 0.45m. WHO level set to avoid complaints from sensitive people exposed in non-industrial indoor settings. NIOSH level reflects lowest reliably quantifiable concentration. OSHA standard is given in 1910.1048. 1.2m = 1 ppm
Heptachlor+	8 hr					0.5m		0.5m	
Hydrochloric acid (hydrogen chloride)	ceiling					7m		7.5m	
Hydrogen sulfide	24 hr 8 hr 30 min 15 min ceiling		.15m  .007m			14m 21m	 15m	14m 21m	WHO guideline of .007m is based on sensory effects. NIOSH ceiling set for 10 minute exposure.
Lead+	annual 3 month 10 hr 8 hr	1.5μ	.5-1μ	1.5μ		50μ	<100μ	150μ	OSHA standard is given in 1910.1025. NIOSH limit set so workers' blood lead remains <60 g/100g blood. ACGIH limit is for inorganic dusts and fumes. WHO limit is based on the assumption that this limit will result in blood lead levels <0.2 μg/ml for 98% of the population.
Malathion	8 hr					10m	15m	10m	
Manganese	annual 8 hr 15 min		.001m			1m 3m		1m 3m	WHO: short-term guideline desirable; but lack of data to set short-term limits. ACGIH limit is for fumes; the 8 hr TWA for dust is 5m.

(continued next page)

**Exhibit 7-1. Air quality standards and guidelines for selected contaminants (continued).**

SUBSTANCE	AVERAGING TIME	STANDARD OR GUIDELINE (m = mg/m³; µ = µg/m³)							COMMENTS
		PUBLIC HEALTH				OCCUPATIONAL			
		EPA	WHO	ASHRAE	CANADA	OSHA	NIOSH	ACGIH	
Mercury	annual 8 hr		1µ			50µ	50µ	50µ	ACGIH and OSHA standard of 50 is for non-alkyl vapor, but limits are 10µ (TWA) and 30µ (STEL) for alkyl compounds. WHO guideline is for indoor air.
Methylene chloride+ (Dichloromethane)	24 hr 8 hr ceiling		3m			173.8m 350m		174m	NIOSH recommends reducing exposure to lowest feasible limit. OSHA standard is in rulemaking.
Methyl alcohol	10 hr 8 hr 15 min						262m 260m 310m	262m 262m 328m	
Methyl ethyl ketone	8 hr 15 min					590m 885m		590m 885m	
Methyl isobutyl ketone	8 hr 15 min					205m 300m		205m 308m	
Microbial/biological contaminants									No formal guidelines/standards; ACGIH guidelines state that fungi concentrations less than 100 CFUs/m³ are not of concern.
Nickel+	annual 10 hr 8 hr		*				0.015m		ACGIH proposed TWA is 0.05m for soluble compounds and the metal. OSHA and ACGIH standards are for soluble compounds.
Nitrogen dioxide	long term annual 24 hr 8 hr 1 hr 15 min	100µ		100µ	100µ				
			150µ					5600µ	
			400µ		480µ	1800µ	1800µ	9400µ	

**Exhibit 7-1. Air quality standards and guidelines for selected contaminants (continued).**

SUBSTANCE	AVERAGING TIME	STANDARD OR GUIDELINE (m = mg/m <sup>3</sup> ; μ = μg/m <sup>3</sup> )							COMMENTS
		PUBLIC HEALTH				OCCUPATIONAL			
		EPA	WHO	ASHRAE	CANADA	OSHA	NIOSH	ACGIH	
Nitrogen monoxide (Nitric oxide)	10 hr 8 hr						30m	31m	
Ozone	continuous 8 hr 1 hr 15 min			100μ 100-200μ 150-200μ					ASHRAE standard is for indoor sources only.
		235μ		235μ	240μ	200μ 600μ		200μ	
Particulates (PM-10)	annual 24 hr 8 hr	50μ 150μ		50μ 150μ					OSHA standard is for total dust, not otherwise classified.
						15000μ		10000μ	
Particulates (PM-2.5)	long term 8 hr 1 hr				40μ 100μ				OSHA standard is for respirable fraction, not otherwise classified.
						5000μ			
Pentachlorophenol	8 hr					0.5m		0.5m	
Petroleum distillates (naphtha)	8 hr					1600m		1370m	
Phenol	10 hr 8 hr 15 min						20m 19m 60m	19m	
Polynuclear aromatic hydrocarbons+ (carcinogenic fraction)									ACGIH and OSHA standard for coal tar pitch volatiles as benzene solubles is 0.2m (TWA).
Propylene dichloride	8 hr 15 min					350m 510m		347m 509m	
Pyrethrum	8 hr					5m		5m	

(continued next page)

**Exhibit 7-1. Air quality standards and guidelines for selected contaminants (continued).**

SUBSTANCE	AVERAGING TIME	STANDARD OR GUIDELINE (m = mg/m <sup>3</sup> ; μ = μg/m <sup>3</sup> )							COMMENTS
		PUBLIC HEALTH				OCCUPATIONAL			
		EPA	WHO	ASHRAE	CANADA	OSHA	NIOSH	ACGIH	
Radon	annual	4 pCi/l	2.7 pCi/l	4 pCi/l	21.6 pCi/l				EPA recommends undertaking mitigation in homes with levels above 4pCi/l. WHO guideline is for new construction; remedial action should be taken without delay at >10.8 pCi/l.
Styrene+	24 hr		.80m				213m		WHO 30 minute guideline is based on odor direction.
	10 hr								
	8 hr					215m		213m	
	30 min		.07m						
	15 min					425m		426m	
	ceiling						426m		
Sulfur dioxide	long term				50μ				
	annual	80μ		80μ					
	24 hr	365μ		365μ					
	10 hr						1300μ		
	8 hr					5000μ		5200μ	
	1 hr		350μ						
	15 min					10000μ		13000μ	
	10 min		500μ						
	5 min				1000μ				
Sulfuric acid	10 hr						1m		WHO: more data needed; however, repeated exposure at or above 0.1 mg/m3 is cause for concern.
	8 hr					1m		1m	
	15 min							3m	
Tetrachloroethylene+ (perchloroethylene)	24 hr		5m						NIOSH recommends minimizing workplace exposure and limiting number of exposed workers. WHO guideline of 8m is based on sensory effects.
	8 hr					170m		339m	
	30 min		8m						
	15 min							1368m	
Toluene	24 hr		7.5m						WHO guideline of 1m is based on sensory effects.
	8 hr					375m	375m	377m	
	30 min		1m						
	15 min					560m		565m	
	10 min						750m		



**Exhibit 7-1. Air quality standards and guidelines for selected contaminants (continued).**

STANDARD OR GUIDELINE (m = mg/m³; µ = µg/m³)									
SUBSTANCE	AVERAGING TIME	EPA	PUBLIC HEALTH		CANADA	OCCUPATIONAL			COMMENTS
			WHO	ASHRAE		OSHA	NIOSH	ACGIH	
Trichloroethylene+	24 hr		1m						
	10 hr						134m		
	8 hr					270m		269m	
	15 min					1080m		1070m	
1,1,1-Trichloroethane	8 hr					1900m		1910m	
	15 min					2450m		2460m	
Vanadium	24 hr		1µ						OSHA and ACGIH limits are for vanadium respirable dust or fumes. NIOSH 10 hr limit set for metallic vanadium and vanadium carbide.
	10 hr							1000µ	
	8 hr					50µ			
	15 min						50µ	50µ	
Vinyl acetate	8 hr					30m		35m	NIOSH recommends lowest reliable detectable level.
	15 min					60m		70m	
Vinyl chloride+	annual		*						OSHA standard is given in 1910.1017. NIOSH recommends limiting exposure to lowest reliably detectable level.
	8 hr					1.5m		13m	
	15 min					7.6m			
Water vapor (relative humidity)				20-60%	30-80% summer 30-55% winter				
Xylene (o, m, p-isomers)	8 hr					435m	434m	434m	
	15 min					655m		651m	
	10 min						868m		
Zinc	10 hr						5000µ		NIOSH limits are for zinc oxide. OSHA and ACGIH limits are for zinc oxide total dust. Limit for respirable fraction is 5000µ.
	8 hr					10000µ		10000µ	
	15 min						15000µ		

<sup>1</sup> SOURCE: Adapted from U.S. EPA, (1989)

(continued next page)

**Exhibit 7-1. Air quality standards and guidelines for selected contaminants. (continued)****Notes**

Reported values were converted where necessary so that all values for the same chemical are in the same units to facilitate comparisons. Canadian standards distinguish between short term or long term exposures. Short term exposures are listed as 1 hr exposures in this table.

**Abbreviations**

ACGIH	American Conference of Governmental Industrial Hygienists
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
EPA	Environmental Protection Agency
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
WHO	World Health Organization

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U.S. DOL. 1989. "Occupational safety and health standards." *CFR, Title 29, Part 1910*.

U.S. EPA. 1989. "National primary and secondary air quality standards." *CFR, Title 40, Part 50, Section 50.1-50.12*.

WHO. 1987. *Air Quality Guidelines for Europe*. WHO: European Series No. 23, Copenhagen, Denmark.

\* WHO does not establish guidelines for these substances; instead, the agency publishes risk factors for each substance to indicate potential human health risks per unit of exposure.

+ Substance identified as a suspected or confirmed human carcinogen.

Conversion of Units: To convert mg/m<sup>3</sup> to ppm, use the following formula:

$$\text{ppm} = \frac{(24.45)(\text{mg/m}^3)}{(\text{gram molecular weight of the substance})}$$

**Exhibit 7-2. Outdoor air requirements for ventilation of commercial facilities  
(offices, stores, shops, hotels, sports facilities).**

OUTDOOR AIR REQUIREMENTS <sup>1</sup>						COMMENTS
APPLICATION	ESTIMATED MAX OCCUPANCY P/1000 ft <sup>2</sup> or 100m <sup>2</sup>	cfm/ person	l/s/ person	cfm/ ft <sup>2</sup>	l/s/ m <sup>2</sup>	
<b>Dry Cleaners, Laundries</b>						Dry cleaning processes may require more air.
Commercial laundry	10	25	13			
Commercial dry cleaner	30	30	15			
Storage, pick-up	30	35	18			
Coin-op laundries	20	15	8			
Coin-op dry cleaner	20	15	8			
<b>Food &amp; Beverage Service</b>						Supplementary smoke removal equipment may be required. Make-up air for hood exhaust may require more ventilating air. The sum of the outdoor and transfer air of acceptable quality from adjacent spaces shall be sufficient to provide an exhaust rate of not less than 1.5 cfm/ft <sup>2</sup> (7.5 l/s/m <sup>2</sup> ).
Dining room	70	20	10			
Cafeteria fast food	100	20	10			
Bars, cocktail lounge	100	30	15			
Kitchens (cooking)	20	15	8			
<b>Garages, Repair Service Stations</b>						Distribution among people must consider worker location and concentration of running engines; stands where engines are run must incorporate systems for positive engine exhaust withdrawal. Contaminant sensors may be used to control ventilation.
Enclosed parking garage				1.50	7.50	
Auto repair rooms				1.50	7.50	
<b>Hotels, Motels, Resorts</b>						See also food and beverage services, merchandising, barber and beauty shops, garages.
<b>Dormitories</b>						
Dormitory sleeping area	20	15	8			
Bedrooms cfm/room		30	15			
Living room cfm/room		30	15			
Baths cfm/room		35	18			Independent of room size; installed capacity for intermittent use.
Lobbies	30	15	8			
Conference rooms	50	20	10			Supplementary smoke removal equipment may be required.
Assembly rooms	120	15	8			
Gambling casinos	120	30	15			

(continued next page)

**Exhibit 7-2. Outdoor air requirements for ventilation of commercial facilities  
(offices, stores, shops, hotels, sports facilities) (continued).**

OUTDOOR AIR REQUIREMENTS <sup>1</sup>						
APPLICATION	ESTIMATED MAX OCCUPANCY P/1000 ft <sup>2</sup> or 100m <sup>2</sup>	cfm/ person	l/s/ person	cfm/ ft <sup>2</sup>	l/s/ m <sup>2</sup>	COMMENTS
<b>Offices</b>						
Office space	7	20	10			Some office equipment may require local exhaust. Supplementary smoke removal equipment may be required.
Reception areas	60	15	8			
Telecommunication centers & data entry areas	60	20	10			
Conference rooms	50	20	10			
<b>Public Spaces</b>						
Corridors & utilities				0.5	2.5	Mechanical exhaust with no recirculation is recommended.
Public restrooms cfm/wc or urinal		50	25			
Locker & dressing rooms				0.5	2.5	Normally supplied by transfer air. Local mechanical exhaust with no recirculation is recommended.
Smoking lounge	70	60	30			
<b>Retail Stores, Sales Floors &amp; Show Room Floors</b>						
Basement and street	30			0.30	1.50	Normally supplied by transfer air. Local mechanical exhaust with no recirculation is recommended.
Upper floors	20			0.20	1.00	
Storage rooms	15			0.15	0.75	
Dressing rooms				0.20	1.00	
Malls and arcades	20			0.20	1.00	
Shipping and receiving	10			0.15	0.75	
Warehouses	5			0.05	0.25	
Elevators				1.00	5.00	
Smoking lounge	70	60	30			
<b>Specialty Shops</b>						
Barber	25	15	8			Ventilation to optimize plant growth may dictate requirements.
Beauty	25	25	13			
Reducing salons	20	15	8			
Florists	8	15	8			
Clothiers, furniture				0.30	1.50	
Hardware, drugs, fabric	8	15	8			
Supermarkets	8	15	8			
Pet shops				1.00	5.00	

**Exhibit 7-2. Outdoor air requirements for ventilation of commercial facilities  
(offices, stores, shops, hotels, sports facilities) (continued).**

OUTDOOR AIR REQUIREMENTS <sup>1</sup>						
APPLICATION	ESTIMATED MAX OCCUPANCY P/1000 ft <sup>2</sup> or 100m <sup>2</sup>	cfm/ person	l/s/ person	cfm/ ft <sup>2</sup>	l/s/ m <sup>2</sup>	COMMENTS
<b>Sports &amp; Amusement</b>						
Spectator areas	150	15	8			When internal combustion engines are operated for maintenance of playing surfaces, increased ventilation rates may be required.
Game room	70	25	13			
Ice arena (playing area)				0.50	2.50	Higher values may be required for humidity control.
Swimming pools (pool & deck area)				0.50	2.50	
Playing floors (gymnasium)	30	20	10			
Ballrooms and discos	100	25	13			
Bowling alleys (seating areas)	70	25	13			
<b>Theaters</b>						
Ticket booths	60	20	10			Special ventilation will be needed to eliminate special stage effect (e.g., dry ice vapors, mists, etc.).
Lobbies	150	20	10			
Auditorium	150	15	8			
Stages, studios	70	15	8			
<b>Transportation</b>						
Waiting rooms	100	15	8			Ventilation within vehicles may require special consideration.
Platforms	100	15	8			
Vehicles	150	15	8			
<b>Workrooms</b>						
Meat processing	10	15	8			Spaces maintained at low temperatures (-10°F to +50°F, or -23°C to +10°C) are not covered by these requirements unless the occupancy is continuous. Ventilation from adjoining sources is permissible. When the occupancy is intermittent, infiltration will normally exceed the ventilation requirement.
Photo studios	10	15	8			
Darkrooms	10			0.50	2.50	
Pharmacy	20	15	8			
Bank vaults	5	15	8			Installed equipment must incorporate positive exhaust and control (as required) of undesirable contaminants, (toxic or otherwise).
Duplicating printing				0.50	2.50	

(continued next page)

**Exhibit 7-2. Outdoor air requirements for ventilation of commercial facilities  
(offices, stores, shops, hotels, sports facilities) (continued).**

OUTDOOR AIR REQUIREMENTS <sup>1</sup>						
APPLICATION	ESTIMATED MAX OCCUPANCY P/1000 ft <sup>2</sup> or 100m <sup>2</sup>	cfm/ person	l/s/ person	cfm/ ft <sup>2</sup>	l/s/ m <sup>2</sup>	COMMENTS
INSTITUTIONAL FACILITIES						
Education						
Classroom	50	15	8			
Laboratories	30	20	10			Special contaminant control systems may be required for processes or functions including laboratory animal occupancy.
Training shop	30	20	10			
Music rooms	50	15	8			
Libraries	20	15	8			
Locker rooms				0.50	2.50	
Corridors				0.10	0.50	
Auditoriums	150	15	8			Normally supplied by transfer air. Local mechanical exhaust with no recirculation is recommended.
Smoking lounges	70	60	30			
Hospitals, Nursing & Convalescent Homes						
Patient rooms	10	25	13			Special requirements or codes and pressure relationships may determine minimum ventilation rates and filter efficiency.
Medical procedure	20	15	8			
Operating rooms	20	30	15			Procedures generating contaminants may require higher rates.
Recovery and ICU	20	15	8			
Autopsy rooms				0.50	2.50	Air shall not be recirculated in other spaces.
Physical therapy	20	15	8			
Correctional Facilities						
Cells	20	20	10			
Dining halls	100	15	8			
Guard stations	40	15	8			

<sup>1</sup> The outdoor air is assumed to be acceptable.

SOURCE: Reprinted with permission ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*, published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

**Exhibit 7-3. Outdoor air requirements for ventilation of residential facilities (private dwellings, single, multiple).**

APPLICATION	OUTDOOR AIR REQUIREMENTS	COMMENTS
Living areas	0.35 air changes per hour but not less than 15 cfm (7.5 l/s) per person	For calculating the air changes per hour, the volume of the living areas shall include all areas within the conditioned space. The ventilation is normally satisfied by infiltration and natural ventilation. Dwellings with tight enclosures may require supplemental ventilation supply for fuel burning appliances. Occupant loading shall be based on the number of bedrooms as follows: first bedroom, two persons; each additional bedroom, one person. Where higher densities are known, they shall be used.
Kitchens	100 cfm (50 l/s) intermittent -or- 25 cfm (12 l/s) continuous -or- Openable windows	Installed mechanical exhaust capacity.
Baths, toilets	50 cfm (25 l/s) intermittent -or- 25 cfm (12 l/s) continuous -or- Openable windows	Installed mechanical exhaust capacity.
Garages: Separate for each dwelling unit	100 cfm (50 l/s) per car	Normally satisfied by infiltration or natural ventilation.
Common for several units	1.5 cfm/ft <sup>2</sup> (7.5 l/s/m <sup>2</sup> )	See enclosed parking garages, Exhibit 7-2.

**SOURCE:** Reprinted with permission from ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*, published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

**Exhibit 7-4. Uniform Building Code ventilation requirements.**

OCCUPANCY TYPE	VENTILATION REQUIREMENTS
<b>Group A, Assembly Group E, Educational</b>	
general area ventilation	<p>openable exterior openings with an area not less than 1/20 of total floor space</p> <p>-or-</p> <p>a mechanical system that supplies a minimum of 5 cfm/outside air/person with a total circulated of not less than 15 cfm/person at all times of occupancy</p>
toilet rooms	<p>fully openable exterior windows at least 3 ft<sup>2</sup> in area for each room; or a vertical duct not less than 100 in<sup>2</sup> in area for the first toilet facility, with 50 additional in<sup>2</sup> for each additional facility</p> <p>-or-</p> <p>mechanically operated exhaust system capable of providing a complete change of air every 15 min; exhaust must be connected directly to the outside and the point of discharge shall be at least 5 ft from any openable windows</p>
<b>Group B, Business</b>	
general area ventilation	same as for Group A, unless Class I, II, or III-A liquids (flammable or combustible) are used in a portion or all of the building; the use of these materials requires exhaust ventilation sufficient to provide 6 ach
toilet rooms	same as for Group A
parking garages (other than open)	ventilation shall be provided capable of exhausting a minimum of 1.5 cfm per ft <sup>2</sup> of gross floor area
	<p>-or-</p> <p>an approved alternate method that can exhaust a minimum of 14,000 cfm for each operating vehicle; automatic CO sensing devices may be employed to modulate the ventilation system to maintain a maximum average CO concentration of 50 ppm during any 8-hr period, with a maximum concentration of 200 ppm for a period not exceeding 1 hr; connecting waiting rooms, office, ticket booth, etc. shall be supplied with conditioned air under positive pressure</p>
<b>Group H, Educational</b>	
general area ventilation and toilet rooms	same as for Group A; when recirculation of air is not permitted, the ventilation system shall be capable of providing not less than 15 cfm of outside air per occupant to the general area
rooms containing hazardous materials	mechanical ventilation system as required by fire and mechanical codes; must have a manual shutoff control for ventilation equipment; control must be outside the room adjacent to the principal access door



Exhibit 7-4. Uniform Building Code ventilation requirements (continued).

OCCUPANCY TYPE	VENTILATION REQUIREMENTS
Group H, Educational (continued)	
garages for the repair of vehicles operating under their own power	<p>a mechanical ventilation system capable of exhausting a minimum of 1 cfm/ft<sup>2</sup> of floor area; each stall must have an exhaust pipe extension which, if over 10 ft long, must exhaust 300 cfm</p> <p>connecting offices and waiting rooms shall be supplied with conditioned air under positive pressure</p>
fabrication areas	<p>mechanical ventilation, which may include recirculated air, shall be provided throughout the fabrication area at the rate of not less than 1 cfm/ft<sup>2</sup> of floor area</p> <p>the exhaust air duct system of one fabrication area shall not connect to another duct system outside that fabrication area within the building</p> <p>at least one manually operated remote control switch that will shut down the fabrication area ventilation system shall be installed at an approved location outside the fabrication area</p>
service corridors and storage of hazardous production material	<p>mechanical ventilation shall be provided at not less than 1 cfm/ft<sup>2</sup> of floor area or not less than 6 ach/hr, whichever is greater</p>
Group R, Hotels, Apartment Houses, Dwellings, and Lodging Houses	
general area ventilation	<p>habitable rooms shall be provided with natural ventilation by means of openable exterior openings with an area not less than 1/20 of the floor area of such rooms with a minimum of 5 ft<sup>2</sup></p> <p>-or-</p> <p>mechanical ventilation shall be provided at a rate of 2 ach in all habitable rooms and in public corridors; 1/5 of the air supply shall be taken from the outside</p>
toilet rooms, bathrooms, laundry rooms, and similar rooms	<p>natural ventilation shall be provided by means of openable exterior openings with an area not less than 1/20 of the floor area of such rooms with a minimum of 1.5 ft<sup>2</sup></p> <p>-or-</p> <p>mechanical ventilation shall be provided at 5 ach/hr; the system must be connected directly to the outside; the point of discharge of the exhaust shall be at least 5 ft from a mechanically ventilating intake</p>

SOURCE: International Conference of Building Officials (ICBO). 1988. *Uniform Building Code*. ICBO: Whittier, CA.

**Exhibit 7-5. Acceptable ranges of temperature and humidity during summer and winter.<sup>1</sup>**

RELATIVE HUMIDITY	WINTER	SUMMER
30%	68.5°F-76.0°F	74.0°F-80.0°F
40%	68.5°F-75.5°F	73.5°F-79.5°F
50% <sup>a</sup>	68.5°F-74.5°F	73.0°F-79.0°F

<sup>1</sup>Applies for persons clothed in typical summer and winter clothing, at light, mainly sedentary activity.

<sup>a</sup>Humidities greater than 50% are considered unacceptable because of the potential for microbial growth.

SOURCE: ASHRAE (1981)

## REFERENCES

American Conference of Governmental and Industrial Hygienists (ACGIH). *Threshold Limit Values and Biological Exposure Indices for 1989-1990*. ACGIH: Cincinnati, OH.

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## **SECTION 8. INVESTIGATION TECHNIQUES**

Section 8 provides a discussion of general and specific investigation techniques for combustion sources, pesticides, microorganisms, formaldehyde, and other volatile organic compounds.

Section 8.1 contains two exhibits which can be used in their current form or adapted to field investigations. Exhibit 8-1 is a health effects questionnaire and Exhibit 8-2 is a general residential building inspection form.

Sections 8.2, 8.3, and 8.4 provide specific guidance for residential investigation techniques, sampling methods, interpretation of data, and mitigation advice for individual contaminant categories.

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## 8.1. GENERAL INVESTIGATION TECHNIQUES FOR RESIDENCES

General techniques for investigating indoor air quality problems in residences are provided in Lesson 8 of the *Learning Module*. This section also contains examples of indoor air quality survey forms which can be used to assist in the collection of information. Exhibit 8-1 is a sample health symptom questionnaire form. Exhibit 8-2 is a general residential building inspection form. Each of these forms are freestanding, and each may be used directly by the investigator. Alternatively, the forms may be used as models and modified to meet the needs of the particular investigator or situation.

For individuals seeking private sector diagnostic or mitigation services, a useful resource is a survey of

indoor air quality diagnostic and mitigation firms published by EPA's Indoor Air Division (U.S. EPA, 1989). This report provides a listing of firms that are involved in either mitigation or diagnostics, and it summarizes the services they offer by the type of buildings serviced, the types of evaluation, monitoring, and mitigation services, and the areas of expertise for personnel in the firm. It should be noted that EPA does not imply approval, recommendation, endorsement, or accreditation of the listed firms. Copies can be obtained for a fee from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. (The NTIS report number is PB 90-130469.)

**Exhibit 8-1. Indoor air quality health effects form.**

NOTE: This form contains example questions that apply to residential and nonresidential investigations—it can be modified for either application.

Investigator \_\_\_\_\_ Date \_\_\_\_\_

Client's Name \_\_\_\_\_

Address \_\_\_\_\_

**206****A. Demographics**

1. Male \_\_\_\_\_ Female \_\_\_\_\_ Age \_\_\_\_\_

2. What is your occupation?

3. Have you had a change in occupation or position since the onset of your symptoms?

yes      no

**B. Work Environment**

1. How many hours per week do you work?

2. Does your job require you to photocopy?

yes      no

3. Do you frequently use a video display terminal?

yes      no

4. Are there old or deteriorating books in your primary work area?

yes              no

5. Have there been any water leaks on ceilings, pipes, or walls in your primary work area during the last six months?

yes      no

6. To your knowledge, are you exposed to any hazardous substances (chemicals, dusts, solvents, gases, minerals) during the course of your working day?

If yes, please describe:

**Exhibit 8-1. Indoor air quality health effects form (continued).**

7. Check as many of the following conditions that describe your work area:

- ☐ temperature too cold  
☐ temperature too hot  
☐ temperature just right  
☐ air too dry  
☐ air too moist  
☐ humidity just right  
☐ air too stuffy  
☐ air too smoky  
☐ too noisy  
☐ too quiet  
☐ frequent unpleasant odors

**C. Personal Habits**

1. Do you smoke tobacco products?

yes      no

If yes,  
how much at home? \_\_\_\_\_

how much at work? \_\_\_\_\_

2. Do you wear contact lenses?

yes      no

If yes,  
how many hours at home? \_\_\_\_\_

how many hours at work? \_\_\_\_\_

3. Do you regularly drink coffee, tea, colas, or eat chocolate?

yes      no

If yes,  
how much? \_\_\_\_\_

**D. Are you currently taking any prescribed medicines?**

yes      no

**E. Do you have any of the following?**

migraine      yes      no

heart problems      yes      no

allergies/  
allergic reactions      yes      no

asthma      yes      no

**F. Check the times when you are most aware of your symptoms**

\_\_\_\_ Winter      \_\_\_\_ Mornings      \_\_\_\_ At home

\_\_\_\_ Summer      \_\_\_\_ Evenings      \_\_\_\_ At work

\_\_\_\_ Spring      \_\_\_\_ At night      \_\_\_\_ Other place

\_\_\_\_ Fall      \_\_\_\_ Weekdays      \_\_\_\_ Weekends

(continued next page)

**Exhibit 8-1. Indoor air quality health effects form (continued).**

G. At home, do your symptoms get better or worse when you (*check as many as apply*):

	Better	Worse	Don't Know
Open the windows? (home or office?)	_____	_____	_____
Turn on the air conditioner?	_____	_____	_____
Turn on the furnace?	_____	_____	_____
Use a humidifier?	_____	_____	_____
Use a dehumidifier?	_____	_____	_____
Sleep overnight elsewhere?	_____	_____	_____
Go away for the weekend?	_____	_____	_____
Go away for a week?	_____	_____	_____
Go to school, work, or stay at home? (circle one)	_____	_____	_____

H. Have you seen a physician for your symptoms?

yes                  no

I. Have any of the following events been associated with onset of symptoms or occurred within the last six months?

1. Redecorating	yes	no
2. Home repairs	yes	no
3. Energy conservation	yes	no
4. New furniture	yes	no
5. New vehicle	yes	no
6. Use of unvented space heater in a recreational vehicle	yes	no
7. New clothing	yes	no
8. New job	yes	no
9. New office/office renovations	yes	no
10. Pest control activities	yes	no
11. Working on crafts or hobbies that involve chemicals, dusts, or heat	yes	no



**Exhibit 8-1. Indoor air quality health effects form (continued).****J. Symptom Survey**

Please place a check mark next to each symptom which you have or are experiencing. Indicate the severity and frequency of each symptom:

Mild = noticeable, but no change in routine necessary  
 Moderate = some change in normal routine necessary  
 Severe = unable to maintain a normal routine  
 Occasionally = less than one time per week  
 Sometimes = one time per week  
 Frequently = more than one time per week

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SYMPTOM	SEVERITY			FREQUENCY		
	Mild	Moderate	Severe	Occasionally	Sometimes	Frequently
Eye irritation, burning	_____	_____	_____	_____	_____	_____
Dry or sore throat	_____	_____	_____	_____	_____	_____
Skin irritation, dryness, or scaling	_____	_____	_____	_____	_____	_____
Skin rash	_____	_____	_____	_____	_____	_____
Tightness in the chest	_____	_____	_____	_____	_____	_____
Runny nose	_____	_____	_____	_____	_____	_____
Asthma (exacerbation of)	_____	_____	_____	_____	_____	_____
Cough	_____	_____	_____	_____	_____	_____
Wheezing or other breathing problems	_____	_____	_____	_____	_____	_____
Chest pain	_____	_____	_____	_____	_____	_____
Changes in the rate and depth of breathing	_____	_____	_____	_____	_____	_____
Changes in pulse rate	_____	_____	_____	_____	_____	_____
Visual disturbances	_____	_____	_____	_____	_____	_____
Dizziness	_____	_____	_____	_____	_____	_____
Fatigue	_____	_____	_____	_____	_____	_____
Depression	_____	_____	_____	_____	_____	_____

*(continued next page)*

**Exhibit 8-1. Indoor air quality health effects form (continued).**

SYMPTOM	SEVERITY			FREQUENCY		
	Mild	Moderate	Severe	Occasionally	Sometimes	Frequently
Clumsiness						
Drowsiness						
Headache						
Fever						
Repeated throat infections						
Sinus irritation or infection						
Muscular pains						
Change in heart rhythm						
Tingling or numbness in extremities						
Muscle twitching/ convulsions						
Nausea or vomiting						
Abdominal pain						
Diarrhea						
Loss of appetite						
Cold/flu symptoms						
Cold extremities						
Difficulty in sleeping						
Irritability						
Backache/neckache						
Eyestrain						

**Exhibit 8-2. Indoor air quality residential inspection form.**

	<b>Indoor Measurements</b>
Date and time of inspection _____	Relative humidity (%) _____
Name of client _____	Temperature (°F) _____
Home address _____	Radon (pCi/l or WL, if tested) _____
Telephone (home) _____ (work) _____	Date of test _____
Inspector _____	Carbon monoxide (ppm) _____
Presence of odor on entering home? If so, describe.	Other: _____

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Client's description of the problem (health effects, odor, event).

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**SYSTEMS INVENTORY**

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Items applicable to newer homes (< 5 yrs) are indicated with "N", those for recent (< 3 yrs) renovations "R," older homes "O;" if there is no designation the item applies to all homes.

**A. Residence Background Information**

## 1. Type of home:

Conventional \_\_\_\_

Mobile \_\_\_\_ Pre-fab \_\_\_\_ Apartment \_\_\_\_

Single-story \_\_\_\_ Multi-story \_\_\_\_

Attached garage \_\_\_\_

2. Date of construction/  
manufacture \_\_\_\_\_3. Manufacturer (if manufactured)  
\_\_\_\_\_

4. Approximate size \_\_\_\_\_

5. Move-in date \_\_\_\_\_

*(continued next page)*

**Exhibit 8-2. Indoor air quality residential inspection form (continued).****B. The Site**

1. Attach sketch of house/surrounding obstacles with orientation to north.
2. Check for air pollution and noise sources.
3. Check for low spots and poorly drained clay soil.
4. Check for trash, food, harborage.
5. Check for proximity to agricultural fields.

**C. The Building Materials**

1. Type of construction:  
Brick \_\_\_\_ Stone \_\_\_\_ Concrete \_\_\_\_  
Wood \_\_\_\_ Earth \_\_\_\_ Other \_\_\_\_
2. Roofing materials (N/R): Are there asphalt materials close to doors or operable windows?  
  
Condition: Are there leaks, damaged shingles, and corroded flashings which may lead to dampness in the attic?

3. Exterior finish (N/R): Is there preservative treated wood (creosote—black and tarry; pentachlorophenol—greenish)?

Condition: Is there evidence of moisture damage (rot, mildew, warping, blistering paint)?

4. Interior materials (N/R): Is there interior grade plywood, simulated wood wallboard, or vinyl finish wallboard?

Condition: Is there evidence of moisture damage?

5. Interior finish: (O) Is there lead-based paint? (If so, caution about removal by sanding; hazards to children.)

(N/R) Is there new (within 1 month) paint?

6. Type of insulation:

None \_\_\_\_ UFFI \_\_\_\_ Fiberglass \_\_\_\_

Cellulose \_\_\_\_ Other \_\_\_\_

If UFFI, date of installation:

**Exhibit 8-2. Indoor air quality residential inspection form (continued).****D. Heating/Cooling Systems****1. Primary heating System:**Gas ☐ LP ☐ Wood ☐ Oil ☐Electric ☐ Kerosene ☐Other ☐**Distribution System:**Forced-air ☐ Gravity ☐Other ☐**2. Secondary heating System:**Wood-burning stove ☐Coal-burning stove ☐Fireplace ☐Unvented space heater ☐ Btu ☐Other ☐**3. Cooling system:**Central air ☐ Window ☐Water cooler ☐ None ☐**E. Inspection of Heating/Cooling Systems**

1. Check all appliances for proper installation, damage.
2. Check venting system for proper separation of appliances; damage to flues and ducts; maintenance of all systems; clearance and condition of chimneys; combustion air supply to each unit; and safety hazards.

3. Central furnaces should be checked for condition of filters; registers and ducting should be checked for accumulation of dust/dirt/fiber glass/moisture; inlets and cold air return should be clear of obstructions. Interior furnace rooms must have adequate air intakes to allow for proper draft air for chimney.

4. Fireplaces and wood stoves should be checked for creosote buildup; type of wood/fuel; clearance of chimney; presence of unlined masonry chimney; procedures for loading/cleaning.

5. Unvented heaters should be evaluated for proper size; ventilation during use; operation of heater unattended; proper fuel and fueling practices.

6. Check for the presence of asbestos pipe covering, insulation, and other materials containing asbestos. Are any friable?

**NOTES:***(continued next page)*

**Exhibit 8-2. Indoor air quality residential inspection form (continued).****F. Ventilation Systems**

1. Mechanical ventilation (check those that are present):

\_\_\_ Supply air fans. Check for short circuiting ventilation and inadequate exit paths.

\_\_\_ Exhaust fans. Check for backdrafting and adequate supply air; ratings (at least 100 cfm for bathrooms, 200 cfm for standard cook-stove, 400+ cfm for draft stoves).

\_\_\_ Fresh air connection on central forced-air systems. Check for uncontaminated outside air supply.

\_\_\_ Heat recovery ventilator. Check for type of matrix, condensate removal, inlet and outlet location, condensaton problems.

NOTES:

2. Air Cleaning/Conditioning Devices (Check those that are present. Is the equipment sized properly?) Determine condition and maintenance.

\_\_\_ Filters (fiberglass, fabric, electronic, plastic)

\_\_\_ Chemical adsorption devices (activated charcoal, alumina)

\_\_\_ Room air cleaners

\_\_\_ Dehumidifiers

\_\_\_ Humidifiers Type \_\_\_\_\_  
(Note the presence of slime and crusting.)

NOTES:

**G. Utilities**

1. Water supply. City \_\_\_ Well \_\_\_

2. Sewage removal. City \_\_\_ Septic \_\_\_

**H. Cooking Appliances**

Gas \_\_\_ Electric \_\_\_ Other \_\_\_\_\_

**Exhibit 8-2. Indoor air quality residential inspection form (continued).****I. Chemical Usage (Indicate aerosols with "a").**  
Note ventilation practices.

1. List cleaning products:

2. List pesticides:

3. List personal care products:

4. List chemicals used in hobbies/crafts:

**J. Foundation Inspection**

1. Type: concrete \_\_\_ brick \_\_\_ wood \_\_\_

poured concrete \_\_\_ creek rock \_\_\_

2. Condition:

**K. Crawl Space Inspection (note condition)**

1. Floor material: dirt \_\_\_ pea gravel \_\_\_

plastic over dirt or gravel \_\_\_

2. Vents: Total number \_\_\_

Number opened \_\_\_

3. Standing water:

At time of inspection: yes \_\_\_ no \_\_\_

Reported by occupant: yes \_\_\_ no \_\_\_

4. Sump: yes \_\_\_ no \_\_\_

**L. Basement Inspection (note condition)**

1. Damp: yes \_\_\_ no \_\_\_

2. Cracks: In walls—yes \_\_\_ no \_\_\_

In floor —yes \_\_\_ no \_\_\_

3. Floor drain/sump: yes \_\_\_ no \_\_\_

Sealed drain/sump: yes \_\_\_ no \_\_\_

4. Wall surfaces (construction):

concrete \_\_\_ drywall \_\_\_ plaster \_\_\_

5. Wall covering: paneling \_\_\_ paint \_\_\_

wallpaper \_\_\_ none \_\_\_

6. Floor surface (construction):

concrete \_\_\_ dirt \_\_\_

particleboard sub-floor \_\_\_

7. Floor covering: carpet \_\_\_ vinyl \_\_\_

paint \_\_\_ none \_\_\_

*(continued next page)*

**Exhibit 8-2. Indoor air quality residential inspection form (continued).**

M. Have any of the following occurred during the last year?

1. Energy conservation measures:

2. Renovations:

3. New furniture:

4. Interior redecorating:

NOTES:



## 8.2. INVESTIGATION TECHNIQUES FOR COMBUSTION SOURCES

Guidance for the investigation of indoor air quality heating and cooling problems can be found in the CABO One and Two Family Dwelling Code (CABO, 1989), the ASHRAE handbook (ASHRAE, 1989), and books on superinsulated design (Lenchek *et al.*, 1987; Mann, 1989). The Canada Mortgage and Housing Corporation (CMHC, 1988a; 1988b) has several publications on combustion systems that are useful. In addition, the standards of the National Fire Protection Association (NFPA) and the American National Standards Institute (ANSI) should be consulted for the installation of specific appliances. Some of these standards include NFPA 31 for oil-burning equipment, NFPA 54 for gas appliances and gas piping (NFPA, 1988a), and NFPA 211 for chimneys, fireplaces, and venting (NFPA, 1988b). Local codes should always be consulted for specific requirements. Section 5 of the *Reference Manual* also provides additional information on the types of heating systems and air distribution systems.

A complete discussion of the different types of heating system appliances which could be encountered during residential investigations is beyond the scope of this section; however, basic information is provided for a limited number of vented and unvented systems. The investigator should become familiar with the design and correct operation of both vented and unvented heating systems and accessories which may be encountered in the geographical area served by the investigator.

The inspection provides a good opportunity to educate the residents about contaminants from combustion sources and the safe use of combustion appliances. Public education efforts can be assisted by the Consumer Product Safety Commission which has several useful publications on the selection and use of combustion appliances which can be obtained free of charge. Some of these are also written in Spanish.

## EMERGENCY SITUATIONS

High carbon monoxide concentrations and leaking fuel are potential emergency situations which may be encountered. The investigator should be prepared to handle potential emergencies over the telephone and in the field.

During a telephone contact, clients who complain about a fuel odor should be instructed to eliminate any sources of flame and contact the fuel supplier immediately. All potential sources of flame or sparking should be avoided; this includes using telephones in the home. Clients should be instructed to call the gas company from an outside telephone. These situations must be treated as an emergency because the investigator cannot determine the nature and degree of the hazard.

If the investigator is conducting an inspection and a fuel odor is detected, the degree of hazard can be evaluated with a combustible gas meter. In the case of a small, slow leak, all sources of flame should be extinguished, windows should be opened, and the fuel company should be called from an outside telephone. The residence should be evacuated if the leak appears serious (for example, caused by a broken supply pipe) or as a general safety precaution if the degree of hazard cannot be ascertained. If the fuel company discovers a leak, the service will be disconnected until the repairs are made to prevent the possibility of fire or other hazards. If monitoring equipment is not available, the situation must be treated as an emergency.

Elevated carbon monoxide concentrations (evaluate based on guidelines and length of exposure) from leaking furnaces and other sources should also be treated as a potential emergency. If sources are suspected and the individual appears groggy, disoriented, or has reddish-colored skin, emergency action should be taken. The individual should be taken outside of the building immediately (or instructed to leave in case of a telephone contact). If the contact is by telephone, emergency assistance

should be requested because the individual may be too disoriented to follow commands.

The investigator should also be alert to the possibility of chronic carbon monoxide poisoning, particularly in children. A health care evaluation should be obtained as soon as possible if chronic exposure is suspected.

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### BACKGROUND INFORMATION FOR INVESTIGATING COMBUSTION SOURCES

#### *Useful Definitions*

**Chimney and Flue:** A chimney is a masonry or concrete channel which extends above the roof and carries combustion gases away from the appliance to the outside air. The chimney may be lined with a pipe (fireclay or other approved material), called the flue or chimney flue, which carries the combustion gases from the appliance to the outside air. The flue connector is that portion of the ducting that connects the appliance to the chimney. The flue collar is that portion of the appliance designed for the attachment of a draft hood, vent connector, or venting system.

**Vent:** Vent is a term that refers to a passageway (pipe or duct) that conveys flue gases (or plumbing gases) from appliances (or vent connectors) to the outside atmosphere. The vent connector is the pipe or duct which connects a gas-burning appliance to a vent or chimney. In woodstove installations, the vent connector may also be called the stovepipe.

**Draft:** Draft refers to the flow of gases through the chimney, flue, or vent caused by pressure differences. Draft may be natural (caused by temperature or pressure differences) or mechanical.

**Volume Damper:** A volume damper is any device which when installed will slow or direct the airflow in any duct, or the products of combustion in any heat-producing equipment, vent connectors, vents, or chimneys.

**Draft Regulator:** A draft regulator is a device which maintains a desired draft in the appliance by automatically reducing the draft. Draft regulators are generally used to maintain combustion stability on appliances that require negative static draft at the appliance flue gas outlet. These devices bleed air into the chimney automatically when pressure decreases (Section 5, Exhibit 5-1).

**Vent Damper:** A vent damper (also called automatic vent damper device) is a device in the venting system, in the outlet or downstream of the appliance draft hood of a fuel-burning appliance, which automatically opens the venting system when the appliance is in operation and automatically closes the venting system when the appliance is in a standby or off condition. These devices control the draft and can reduce energy consumption and improve the seasonal efficiency of gas- and oil-burning appliances, and they can be manually operated, mechanically activated, electrically operated, or thermally actuated, depending on the system.

**Draft Hood or Backdraft Diverter:** The draft hood or backdraft diverter (Exhibit 8-3) is a device built into an appliance, or part of a vent connector from an appliance. The draft hood ensures that the natural-draft furnace operates safely (without generating carbon monoxide) if the chimney is blocked, if there is a downdraft, or if there is an excessive updraft. The draft hood neutralizes the effect of stack action of the chimney or gas vent while the appliance is operating, and it allows gases to escape easily from the appliance if there is no draft, backdraft, or stoppage beyond the draft hood. In general, inlet and outlet flue pipe sizes of the draft hood should be the same as that of the appliance outlet connection. Spillage can result if combustion air is not adequate for a gas appliance with a draft hood.

**Plenum:** A plenum is a compartment or chamber to which one or more ducts are connected and which forms part of the air distribution system.

## Combustion Air

It is important for an appliance to have sufficient air for fuel combustion, draft hood dilution, and ventilation of the enclosure for the appliance; this air is called combustion air. It is not the same as circulating air which is air that moves into and out of a conditioned space by means of a circulating system. In construction that is not energy efficient, combustion air is normally supplied by infiltration. If there is insufficient combustion air, incomplete combustion and backdrafting will result. To determine the required combustion air, the air requirements for exhaust fans, kitchen vents, clothes dryers, fireplaces, and other combustion appliances must be considered.

In energy efficient homes, inadequate combustion air can be a significant problem which can be solved in several ways. In new construction, appliances that have sealed combustion units can be used, or the appliance can be located in an unheated and unsealed room (typically, exterior to the house). In existing construction, the appliance can be connected to a combustion air intake, providing the unit is designed for such a remedy. A relatively easy solution (but not an energy efficient one) is to crack open windows on the floor where the appliance is operating. This is a potential solution for infrequently used fireplaces that may be subject to backdrafting when fires are low or smoldering.

If woodburning stoves and furnaces do not have a sealed air intake, they should have a 3-inch diameter (minimum) outdoor-air inlet, ducted close to the air control of the appliance. A sealed damper or gasketed door that will not leak air when the stove or furnace is not in use is also needed. Combustion air requirements from the CABO code are given in Exhibit 8-4 for residential fuel-burning equipment.

## Supply and Return Ducts

Ducts carrying supply air into the building from the outside or from evaporative coolers should be

constructed of galvanized steel or corrosion-resistant metal. Although sheet metal is the preferred material for both supply and return air ducts, alternatives are permitted under most codes. Flexible material (fiberglass sandwiched between plastic) is also used. Another technique is to use the spaces between studs in walls or floor joists to form an air channel by nailing sheet metal or fiberboard over the openings (called open joist ducts). When these spaces are used to create ducts, the duct space should be sealed from unused portions by tight-fitting stops of sheet metal or wood. Gypsum products should not be exposed in ducts serving evaporative coolers. Although these approaches are permitted in some codes, they can allow the release of organics such as formaldehyde into the living space as hot supply air comes into contact with floor joists, subflooring, or plastic.

An underfloor space can be used as a supply plenum providing the entire ground surface is covered with a vapor retarder having a maximum permeability of 1 perm and all loose combustible scrap material is removed. In addition, fuel gas lines and plumbing waste cleanouts should not be located within the space. Foil-coated fiberboard is also used to create ducts in floor joists--this practice should be discouraged in crawl spaces because of the possibility of moisture damage to the fiberboard which would create a substrate for microbial growth. In addition, any openings in ducts can allow termiticides to enter the living space.

All ductwork installed in an attic should be insulated to prevent condensation. All metal supply ductwork installed in a ventilated crawl space or other nonconditioned area should also be insulated. When ducts used for cooling are insulated, the insulation should be covered with a vapor retarder having a maximum permeance of 0.05 perm or aluminum foil having a minimum thickness of 2 mils. Exterior ducts must be protected by an approved weatherproofed vapor retarder.

## Venting of Appliances

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There are two basic types of problems related to venting of appliances which can result in the release of contaminants indoors. Backdrafting is the flow of combustion gases back into the house as a result of outside air being drawn into the flue or chimney. Flue gas spillage (or spillout) is the flow of combustion gases back into the house as a result of a blockage in the flue or chimney or because flue gases do not have sufficient velocity to clear the backdraft diverter of the combustion appliance.

There are many causes of these problems including defective or unsafe equipment; improper installation of combustion appliances; blocked chimneys or flues; inadequate combustion air; and downdrafts in chimneys or flues. Depressurization caused by operating too many appliances that exhaust air out of the house (fans, fireplaces, and so forth) can be a significant cause of backdrafting and spillage in new energy-efficient construction.

Useful publications about combustion spillage and backdrafting can be obtained from the Canada Mortgage and Housing Corporation (682 Montreal Road, Ottawa, Ontario K1A 0P7) which has done extensive research in this area.

The CMHC (1988b) has published a manual that describes a series of procedures for testing the performance of a residential chimney system. These tests are used to identify houses in which spillage of combustion gases from fireplaces, natural-draft oil and gas furnaces, and hot water heaters. The manual includes five test procedures which are described in detail and are complete with checklists and report forms. The tests include house and venting systems tests (described as follows) which are designed to detect the susceptibility of the chimney system to spillage caused by the combined operation of fans, fireplaces, and any other exhausts. Furnace and flue tests are included which are designed to detect spillage caused by a leaky heat exchanger, weak chimney draft due to leaks or constrictions within the flue, or maintenance

problems that can be detected through careful inspection of the system.

The venting system pre-test consists of making a visual inspection and simple calculations which include estimating the exhaust flow and leakage area which are combined into a maximum house depressurization estimate which is compared to a house depressurization limit (HDL). If the estimated maximum depressurization is larger than the HDL, more detailed testing is needed. If it is smaller, the system is alright, and no further testing is needed. The test requires 10 to 15 minutes.

The venting system test is a detailed test that can be used to test the effect of fans and fireplace operation on the chimney serving the furnace and the hot water appliance, and it can also be used to evaluate the effect of fans and furnace operation on the chimney serving a fireplace. This test also includes a procedure for determining spillage under depressurization. The test requires about 40 to 80 minutes to complete.

### Vents

Appliances which require venting must be vented to the outside. Vents should be installed with an upward slope to maintain the velocity of the escaping gases, prevent moisture, and reduce the chances of backdrafting. Even if the vent slopes upward, it is possible for hot gases to flow downward (or horizontally) under some conditions. Vents that slope downward should be corrected. Too many and/or sharp elbows or bends in the vent will prevent it from drawing properly. A general rule of thumb is to have no more than two 90° elbows; ideally elbows should be limited to 45° which will result in an upward slant of about 45°.

The vent vertical length should be at least 5 feet above the highest vent collar for gravity-type systems with the exception of venting systems which are integral to the appliance or Type BW vents (vented wall appliances).

To prevent contamination of indoor air, direct vents (vents in sealed systems) should be at least 9 to 12 inches from any door, window, or gravity air inlet. The bottom of the vent terminal and air intake should be at least 12 inches above grade. In addition to these requirements, the venting system should end at least 3 feet above forced air inlets located within 10 feet (CABO, 1989; NFPA, 1988a).

The horizontal run of a gravity vent (circulation of air by gravity) and its connector should not be more than 75% of the vertical height of the venting system measured from the appliance outlet, and the rise of the connector should not be less 1/4 in/ft of length measured from the appliance vent collar to the vent.

Two or more appliances (oil or gas fuel only) may be connected to gravity-type venting systems providing they have the required safety controls and listed safety shutoff devices. The appliances should typically be located on the same story of the building, the connectors should be offset (should not enter directly opposite one another), and the venting area should be no less than the area of the largest vent connector plus 50% of the areas of the additional vent connectors.

## Chimneys

Appliances can be vented with unlined masonry chimneys, metal pipe, or factory-built chimneys. Whichever is used, it must be installed and maintained according to local and national building codes. A masonry chimney should be checked to make sure the mortar is intact between the bricks or stones. Metal chimneys should be checked for rust damage or spaces between the joints. These checks should be made both inside and outside (a flashlight and mirror are useful; smoke can also be used). Clients should be instructed to seal any openings which would allow combustion gases to seep back into the dwelling.

The chimney must be sized properly to prevent spillage and condensation problems. The correct size can be determined in several ways. In the case of venting a solid fuel burning appliances, the cross-sectional area of the flue should not be less than the cross-sectional area of the appliance flue collar, or more than 3 times the cross-sectional area of the appliance flue collar (NFPA, 1988b).

In the case of sizing a single gas-burning appliance, the effective areas of the vent connector and the chimney flue should not be less than the area of the appliance flue collar or draft hood outlet. A chimney that is connected to more than one gas-burning appliance is sized properly if the effective area of the chimney flue is not less than the area of the largest vent connector plus 50% of the area of additional flue collars or draft hood outlets (NFPA, 1988a).

*Avoiding Backdrafts on Chimneys:* Chimneys should extend above the roof to avoid possible downdrafts into the chimney in windy weather and to prevent overheating of the roof from the hot flue gases. Local codes specify required clearances. A general guideline is that the residential chimney should extend at least 3 feet above the highest point where it passes through the roof of a building and at least two feet higher than any portion of the roof within a horizontal distance of 10 feet (Exhibit 8-5). Another potential problem is overhanging tree limbs which can result in significant downdrafts.

The chimney should be properly capped to prevent rain water from entering (Exhibit 8-6). The chimney should also be checked (at least yearly) to prevent the buildup of soot and debris which could cause improper functioning. Birds' nests, in particular, can cause blockage.

Chimney connections must be checked to ensure that backdrafts and other problems will not result (Exhibit 8-7). A gas or an oil furnace should *not* be connected to a chimney that serves a separate appliance that burns solid fuel because the draft to the furnace may be significantly reduced. No two

appliances should enter the chimney in the same location at the same level; rather, they should be staggered along the vertical shaft. This prevents fumes from blowing across the chimney rather than up and out the other appliance. Another problem associated with shared chimneys is the possible release of sparks or burning creosote from an open wood-burning appliance into the room.

It should be noted that exterior chimneys are more likely to have problems with backdrafting than interior chimneys because the gases are quickly cooled and draft is lost.

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### INSPECTION OF COMBUSTION APPLIANCES

The main fuels for central heating appliances in the U.S. are natural gas (97% methane), liquid petroleum gas or LPG (propane, butane, or a combination of these), fuel oil, or electricity. In addition to these fuels, wood and coal are also used for central heating.

All of these appliances (except electricity) can become sources of indoor air contaminants including carbon monoxide, carbon dioxide, nitrogen oxides, inhalable particulates, and in the case of fuel oil, kerosene, coal, and sulfur dioxide. Improper installation and maintenance are most often the causes of fires and the release of contaminants into the living space.

On routine investigations, the evaluation begins with a visual inspection of the appliance. The use of a standard form is recommended (Exhibit 8-8 is an abbreviated form). The following types of questions should be answered:

- Does the appliance work? If not, is the equipment faulty or is there insufficient fuel. If the fuel correct for the equipment?
- Is the appliance vented properly? Is there any obvious damage to the appliance or venting system?
- Is there sufficient combustion and circulating air?
- Is the appliance maintained and operated properly?

Fuel-fired heating appliances should be inspected and cleaned on an annual basis. Regular inspection and maintenance will improve efficiency and prevent problems. In some cases regular inspection and maintenance can be performed by the homeowner who carefully follows the manufacturer's instructions; in other cases, a professional will be required. During the visual evaluation, the investigator can usually determine if a service call by a professional is needed.

The following general guidelines for vented appliances include checks that the investigator can make and general recommendations which can be given to the client. These guidelines only provide an introduction to this important area, and the investigator should become familiar with local codes for specific requirements.

#### Central Forced-Air Fuel-Fired Furnaces

A properly installed central heating system will not result in safety or indoor air quality problems. The evaluation should determine if the unit is properly installed and operated so that harmful contaminants are not emitted indoors. The unit should also be checked for other safety hazards.

One of the first clues that can be obtained in an investigation is the presence of any smoke, odor, black dust, or ash. If any of these exist, the cause should be determined. Next, the location of the appliance should be noted. Warm-air fuel-fired furnaces should not be installed under stairways, in a room used as a bedroom or bathroom, in a closet, or in any small space with access only through a bedroom or bathroom. These installation requirements, however, do not apply to direct vent furnaces or enclosed furnaces.

**Natural Gas Appliances:** Appendix G of the National Fuel Gas Code contains tables for sizing venting equipment serving appliances equipped with draft hoods and appliances listed for use with Type B vents (Category I furnaces). These tables indicate the maximum appliance input rating for different vent sizes.

It should be noted that the Tables in Appendix G can result in flue gas condensation in some installations. This is most likely to occur in new mid-efficiency furnaces that have fan-assisted combustion systems rather than draft hoods. Like the draft hood appliances, the fan-assisted furnaces still rely on the buoyancy of the hot combustion gases to vent the flue gases. However, since these appliances operate with reduced dilution air, the vent gas volume is reduced for a given input and smaller vents can therefore be used. The flue gases in this instance will have a higher dew point temperature which increases the potential for condensate formation. This, in turn, increases the corrosion of the vent materials. The 1988 version of the National Fuel Gas Code does not address this problem (it will in updated versions), but expanded tables have been developed by the Gas Research Institute and these can be consulted to ensure that vents are properly sized (tables can be obtained from any gas utility).

The investigator should make the following observations for gas-fired appliances:

- 1) Check the position and condition of the blower doors; doors that have been removed or which are ajar can allow contaminants from the burner chamber to enter the living space. This problem must be fixed immediately.
- 2) Examine the furnace filters. This is accomplished by disconnecting the power and removing the blower access door or filter assembly door. Clients should be instructed to replace soiled disposable filters with filters of the same size every four to six weeks during the heating season or according to the manufacturer's instructions. Filters that are not disposable should be cleaned (by vacuuming or washing with detergent according to the manufacturer's instructions) twice a month during periods of heavy use and once a month during other times.
- 3) Examine the burn chamber for the accumulation of lint and the heat exchangers for soot and rust. If any of these are present, the furnace should be cleaned so that the fuel will burn properly.
- 4) Check the flame in the burn chamber to determine if combustion is optimum. Natural gas furnaces should not have yellow tipped flames; LP units may have some light yellow tipping of the outer mantle, but the inner mantle should be bright blue. A service call is needed if yellow tipping exists.
- 5) Check the combustion air inlet and air openings in the casing of the furnace for any obstructions which could reduce airflow. The combustion chamber opening side should not be less than 6 inches for fuel-burning appliances.
- 6) Check the venting system for evidence of corrosion, leaks, and proper sizing. Problems should be corrected.
- 7) Check heat inlet registers and cold air returns to ensure that they are free and clear of carpets, furniture, and other obstructions. Any obstructions should be removed.
- 8) Check the cooling coil condensate drain of air-conditioning units if negative air is created inside the furnace or if the drain is connected directly to the structure's sewer system. Condensate should be discharged outside of the building. Condensate

drained to the sewer system must be drained through an observable airbreak. If the drain is not draining freely, it should be cleaned. The outside condensing unit should have a clearance of 3 inches above grade; manufacturer's clearances for proper airflow should be strictly observed.

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**Oil-Fired Appliances:** Oil furnaces are similar to gas furnaces in size, shape, and function; they are available as upflow, downflow, horizontal, and low-boy configurations for ducted systems. However, the heat exchanger, burner, and combustion control system are different. Oil-fired forced-air ducted systems are usually forced-draft furnaces and equipped with pressure-atomizing burners. The hot flue products flow through the inside of the heat exchanger into the chimney; conditioned air flows over the outside of the heat exchanger and into the air supply plenum. A barometric draft regulator is used in lieu of a draft hood. The checks for an oil-fired furnace are similar to those for the gas-fired system.

Oil-fired furnaces must also be checked for proper location of the fuel tank and sizing of the tanks (Section 5, Exhibit 5-1). If tanks are located inside the building the tanks should be evaluated for proper separation from boilers, furnaces, stoves, or exposed flames. Tanks must be vented to the outside. Sufficient combustion air must enter the furnace room; a general rule of thumb is to provide 15 in<sup>2</sup> of opening for each gallon of oil burned per hour.

Any odors, particulates, or staining in the furnace room suggest problems. The burner jets should be checked for cleaning. The blower compartment door should be tight. Filters and burner fan should be checked to determine if they need cleaning. The barometric damper should be checked for lubrication and the need for balancing. The air supply should be evaluated for adequacy and the unit should be evaluated for clearance from combustibles. In addition to these checks, the guidance listed under flues and chimneys also applies.

**Coal-Fired Appliances:** Coal-fired appliances are still used in some areas; these appliances include boilers, furnaces, and space heaters (resemble pot-bellied stoves). Coal should be burned only in those appliances specifically designed for coal. These units should be carefully checked for condition and possible leaks through the venting system.

Coal-fired furnaces and boilers must be sized properly for the particular supply of coal; improperly sized furnace grates and flues can result in excessive coal gas. Owners of coal-fired appliances should be questioned about procedures used to fire the unit. Sufficient time must be allowed to pass before damping to prevent the release of excessive coal gas; this is most likely to be a problem at night or other periods when full draft is not needed. Proper ventilation is needed to provide adequate combustion air and prevent heat buildup.

### Wood-Burning Stoves

Because of rising fuel costs, many people are turning to wood as their main or supplementary fuel. Fireplaces, with or without an insert, and various types of freestanding stoves are the most common wood-burning appliances; the term "stoves" will be used to refer to these devices. If wood appliances are used, they should be approved or listed and the NFPA or local code installation guidelines should be followed.

Conventional stoves have a single combustion chamber which is not airtight; these stoves have a low efficiency compared to airtight stoves which have a secondary chamber for combustion unburned gases from the primary chamber. Simpler stoves typically have a damper in the chimney to control the flow of air through or over the fire. More complicated stoves have a thermostat-controlled damper which controls the draft.

Improperly installed, maintained, or operated wood-burning appliances can create serious indoor air quality and safety hazards. The investigator should evaluate each stove and installation for proper



installation, condition, venting to the outside, proper clearance to all combustible materials, proper fuel supplies, and fire stoking techniques. The investigator should initially look for evidence of smoke, soot, or creosote in the living spaces; flues should be evaluated for evidence of leakage. The cause of any of these problems should be determined and corrected.

**Installation:** Proper installation is the key to the safe usage of a wood-burning stove (Exhibit 8-9). The stove should be located away from all combustible materials. NFPA 211 recommends a clearance of 36 inches at the ceiling, back, and sides from combustibles. The use of a fireproof barrier can reduce the required clearances, but local codes should be consulted for specifics.

The floor on which the stove is placed should also be protected (except concrete, clay tile, or ceramic). The condition of any asbestos floor protection should be noted; if the material is not intact or cannot be repaired, it should be removed. The stove should not be placed on carpeting or any other type of combustible surface. Combustible floors should be protected by a sheet of noncombustible material under the stove; the sheet should extend out from the stove 18 inches in all directions.

Wood and oil or wood and gas appliances should *not* be served by the same flue or chimney because of the possibility of insufficient draft for safe combustion in each appliance (Exhibit 8-7).

Stovepipe refers to the single-wall metal piping that is used to connect the appliance to the chimney; stovepipe should not be used as a chimney. It should not be routed through a ceiling, closet, alcove, or concealed space. When it must pass through interior combustible material, a ventilated thimble must be used.

The chimney for a stove (also oil appliances, domestic-type incinerators, and solid fuel-burning) should be of the right material and sized correctly (see

NFPA, 1988B for guidance). In residential installations, single-walled metal flues should not be used; flues must be double- or triple-lined. To prevent backdrafts, the chimney should not have a flue area more than twice the size of the stovepipe. Exhibit 8-10 provides suggested flue sizes for residential wood-burning appliances in the absence of manufacturer's instructions. Guidelines for the clearance of a stove chimney at the rooftop are identical to those for central heating appliances. These clearance guidelines should be followed to prevent downdrafts in windy weather and to prevent roof fires caused by hot flue gases.

Unlined masonry chimneys should not be used. Factory built chimneys should be labeled as "Class A," "All-Fuel," or "Solid Fuel." Metal thinner than 28 gauge should not be used as a chimney because it can rust or corrode easily, and it is not a good insulator which means that combustion gases will condense in the flue and increase creosote formation.

The stovepipe connection should be as short and straight as possible to minimize creosote buildup and maximize draft. Lengths up to about 8 feet are typical, and the horizontal portion should be less than 3/4 of the vertical part of the pipe and should rise a minimum of 1/4 inch per foot (ASHRAE, 1988; CABO, 1989). Smoke leaks typically occur if the stovepipe joint does not overlap properly; the crimped end should be pointing down toward the stove.

Long stovepipes increase heat output, but also result in more creosote accumulation and less draft. If the stovepipe is too small for an attached stove, smoke will spill out, or the stove will not be able to get hot enough because it does not get enough air. If the stovepipe is too large, decreased draft and increased creosote can result.

The connection of the stovepipe to the chimney should be examined to be sure that it is secure and does not leak creosote or gases. The stovepipe shouldn't move more than 1-2 inches horizontally.

NFPA requires that horizontal runs slope up from the stove. This upward slope maintains draft and prevents creosote drip.

*Operation and maintenance:* Stovepipes and chimneys should be checked frequently for creosote buildup. Black stains on the exterior of a chimney, flue, or stovepipe may indicate creosote buildup or water damage. Creosote has an unpleasant, acrid odor. It may be pooled on the floor, or it may appear as bubbles, flakes, curls, or as a dry or tacky shiny glaze on the inside of flues, stovepipes, or chimneys. After it dries, creosote is flammable. As a general rule, cleaning is needed when creosote and soot are more than 1/4 inch thick.

Creosote can be minimized by proper installation and operation of the stove. One of the best ways to minimize creosote formation is to use the correct type of fuel. Seasoned hardwood is recommended over softwoods because hardwoods burn hotter and result in less creosote formation. Resinous woods burn quickly, and they can be used in small amounts for starting fires. However, they should not be used as the primary wood because of creosote and smoke formation. Recommended moisture content ranges between 15% and 25%. "Green" or wet wood is likely to result in smoke and creosote problems.

As a safety precaution, wood should be stored at least 36 inches away from the stove. No more than 25 pounds of wood should be stored inside the dwelling at any time. Treated wood, railroad ties, plastics, charcoal, metal, tires, trash, and other nonwood materials must not be burned in stoves because they emit harmful contaminants when they burn.

Wood-burning furnaces and boilers may also be used in residential heating systems; some of these furnaces are multi-fuel furnaces which have a gas or oil burner which provides heat if the fire goes out or becomes low. Wood-burning boilers and furnaces require more care and maintenance than furnaces which are fueled by gas or oil only. Indoor air quality problems for wood appliances can result

from stoking operations, creosote deposits and plugging of the chimney, or draft problems. Local codes should be consulted for the legality of these appliances and specific requirements.

## Space Heaters

### Vented Gas Space Heaters

Many older homes use large gas-fired room heaters to heat the entire living space. Vented heaters which are not properly installed or maintained can release carbon monoxide, carbon dioxide, and nitrogen oxides into the living space. These appliances are usually vented through the chimney and should be installed in the same way as a fuel-fired central heating system.

The investigator should check the vent installation and clearance from the vent to any combustible walls. There should be 12 to 18 inches of clearance. The condition of exposed ducting should be evaluated. Joints should be examined to be sure that screws are present and tight. Any deteriorated or loose joints are likely sources of leaks. Vented heaters do not burn as efficiently as a central heating system, and these flues should be cleaned 2-3 times during the heating season.

Safety features which the investigator can identify are certification of the appliance by the American Gas Association Laboratory. Vented gas space heaters manufactured after June 1, 1984 are required to have a thermal shut-off device that will activate when the heater is not being vented properly.

### Unvented Kerosene or Gas Space Heaters

Unvented fuel-fired space heaters that use kerosene or gas are of serious concern to public health officials. An important marketing tool used to sell these devices is a fuel efficiency that is almost 100%, compared to 60% for most residential furnaces or 80% to 90% for high efficiency furnaces.

When unvented space heaters burn, the heat generated by the burning fuel is released directly into the living space, but the byproducts of combustion are also released. Burns from hot surfaces and fire hazards are additional concerns when unvented heaters are used.

Fire hazards are of great concern when unvented heaters are used. Each appliance should be inspected for obvious damage, improper burner settings, improper fuels and storage of fuels, distance to combustibles, absence of fuel shut-off devices in the event of tip-over or flare-up, and other fire safety hazards.

The combustion byproducts of unvented space heaters contain many potentially harmful contaminants such as carbon monoxide, nitrogen oxides, and carbon dioxide in the case of gas heaters; sulfur dioxide, aldehydes, polycyclic aromatic hydrocarbons, and acid aerosols are additional potential contaminants from kerosene heaters.

Emissions from kerosene heaters depend on a several factors including maintenance of the unit, flame setting, age of the heater, Btu rating of the heater in relation to the space to be heated, type of kerosene, and type of heater. Emissions from unvented gas heaters also depend on age and maintenance of the unit, Btu rating, and other factors.

The concentrations of these contaminants can be reduced, but not eliminated, by using heaters in well-ventilated areas. Most manufacturers recommend opening the door to the room with a kerosene heater to provide air exchange with the rest of the house. This practice does not provide sufficient ventilation air.

Adequate ventilation must be provided by bringing fresh outdoor air into the living space. This can be accomplished by opening a window(s). A general rule of thumb is to open a standard sized window 4 in<sup>2</sup> for every 1000 Btu of heater capacity. Using this general rule, an 11,000 Btu heater would require a window opening of about 2 inches.

Additional areas of concern and safety tips for unvented gas and kerosene heaters are given in Exhibits 8-11 and 8-12.

## Household Appliances

### Gas-fired Ranges

Gas-fired ranges should not be used as a source of heat during cold weather. The use of gas-fired ranges and ovens as a source of heat could result in the buildup of potentially fatal concentrations of carbon monoxide, and this practice also poses safety and fire hazards. Additional contaminants that are released by gas-fired ranges include carbon dioxide and oxides of nitrogen.

Local building codes should be consulted for specific installation requirements. In general, the back and sides of gas ranges are required to have a clearance of 6 inches to combustible materials. The vertical clearance should be at least 30 inches, but this is allowed to be reduced to 24 inches if the combustible material is protected by a fireproof material.

Vents serving range hoods should not terminate in an attic, crawl space, or any area inside the building. Most ranges that are vented to the outside require a ventilation rate of about 100 cfm; updraft or downdraft ranges require higher rates (around 400 cfm for some models) that vary depending on the particular model. The fan ratings can be found on identification plates on the hood. Many newer single and double family homes and apartment buildings have recirculating hoods rather than range hoods that vent to the outside.

Pilot lights must be adjusted properly so that the burners will burn efficiently, and gas will be prevented from escaping if the pilot light goes out.

### Gas-fired Hot Water Heaters

Proper venting of hot water heaters is also important to prevent combustion-related contaminants from entering the living space. The vent should be

maintained in a safe condition, and installation should follow the same guidelines as for a central heating system. The water heater should be located as close as possible to the chimney. It should *not* be located in bathrooms or bedrooms, closets, or confined spaces opening to the bedroom or bathroom.

If a water heater is located in a garage, it should be installed at least 18 inches above the ground. This clearance is required to prevent explosions which could occur if gasoline or other flammable volatile liquids are spilled onto the floor in proximity to the heater.

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### Gas-fired Clothes Dryers

Gas-fired clothes dryers can release nitrogen oxides, carbon dioxide, and carbon monoxide if they are not vented properly. Clothes dryers should be vented directly to the outside and not through a chimney, flue, gas vent, or vent connector (or to the attic or crawlspace). The duct should not be joined with screws or anything else that would project into the duct and trap lint because removal efficiency will be reduced.

Devices which can be attached to the dryer vent to allow heat to come back into the house should not be used with gas-fired clothes dryers because they allow passage of the combustion-related contaminants back into the living space. They also increase the humidity level in the home.

### Other Combustion Sources

There are other sources of combustion products in homes such as candles, lamps, and certain hobbies such as soldering, wood burning, and interior combustion engines. These sources can release a variety of gases and particulates. Emissions from these sources have not been characterized adequately. The investigator should be alert to these

sources and ensure that adequate ventilation is present when they are used.

### Fire Safety

Every home should have a fire detector and extinguisher, but this is especially important in homes that utilize wood-burning stoves. An extinguisher and detector is recommended in the room with the stove. Other detectors should be placed strategically based on guidance from the local fire department.

## MEASURING COMBUSTION-RELATED CONTAMINANTS

### Instrumentation

Most investigations of combustion-related complaints will require a carbon monoxide monitor and a combustible gas meter. A carbon dioxide monitor may also be useful, but it should not be purchased in lieu of the carbon monoxide monitor or combustible gas meter. Instruments for field inspections should be portable, lightweight, rugged, battery-operated, easily read, and convenient to use.

The combustible gas meter measures the concentration of a flammable gas or vapor in the air, and the results are indicated as a percentage of the lower explosive limit (LEL). The LEL is the minimum concentration of the gas or vapor in air which will propagate the flame if an ignition source is present. The upper explosive limit (UEL) is the concentration above which ignition will not occur. The flammable range is between the UEL and the LEL.

The combustible gas meter usually does not specify what gas is present, it just warns of a potentially dangerous situation with an audible sound or flashing light. The meter is not accurate for low concentrations, and it must be calibrated to the gas of interest. The zero and calibration checks should

be performed at the location where sampling will occur because the response of the instrument is affected by temperature.

Combustible gas meters are available for area sampling or can be configured with a probe for testing point sources such as gas pipes. Regardless of the type of meter, it should be intrinsically safe. These instruments are easy to use and require minimal training. The cost ranges from about \$700 to over \$1000.

Combination oxygen and combustible gas meters are available which can detect oxygen deficiencies and combustible gases in a single unit. The oxygen content of the air is normally 21%; 16% oxygen is the minimum needed to support life, and air with less than 19.5% oxygen is considered deficient.

Although there are several methods which can be used to measure both carbon monoxide and carbon dioxide, nondispersive infrared spectrophotometry (NDIR) is probably the method of choice for several reasons. Current generation NDIR instruments are: 1) insensitive to variations in flow rates and room temperature, 2) require no wet chemicals, 3) sensitive over a wide concentration range, 4) quick responding, 5) small and portable, and 6) require minimal training to operate.

The concentration of carbon monoxide is usually recorded in ppm while carbon dioxide is given in percent. Both instruments should be calibrated routinely using zero and multi-point calibration gases in the range of concentrations to be measured. If measurements are conducted in the range of 0 to 10 ppm, a single point calibration outside of the sampling range may not be adequate.

Carbon monoxide, carbon dioxide, and combustible gas meters can handle most situations involving combustion-related appliances. But there are occasions when concentrations of other gases are needed. A variety of active and passive monitors are available to test for specific contaminants such as

sulfur dioxide and nitrogen oxides if this information is necessary.

Most active samplers are not convenient for routine residential investigations of sulfur dioxide and nitrogen dioxide levels, but active bubbler methods which were developed for ambient air sampling can be used to collect 1 hour or 24 hour samples. These can be built at a nominal cost (about \$150 for each sampler). Sample collection is relatively uncomplicated, but a laboratory is required for analysis of the samples by colorimetric methods.

Portable electrochemical samplers can also be purchased for about \$1500 to \$3000. Passive samplers (at about \$30 each) are another potentially useful alternative, but they cannot be reused, and they do require laboratory analysis which is usually included in the cost of the sampler.

Indoor sampling methods are also available for organic particulates from fuel combustion and compounds found in cigarette smoke. Further information on equipment and methods for these contaminants is contained in Lesson 6 of the *Learning Module*, Section 6 of the *Reference Manual*, and EPA's Compendium of Methods for Indoor Air Quality (U.S. EPA, 1989).

It may also be necessary to monitor levels of carboxyhemoglobin in cases of acute exposures or when low-level chronic exposures are suspected. These analyses require a blood sample to be drawn by a health care provider.

### Measurement Locations

The combustible gas meter should be operating before entering the residence. Readings are taken upon entry. If safe levels are measured, the investigator proceeds to the room with the appliance and measures levels next to the appliance. If unsafe levels are measured (guidelines are given below), the residence should be evacuated and the gas company should be notified.

When fuel leaks are suspected during the course of a routine investigation, readings should be taken adjacent to the appliance and at any points where leaks might occur. If leaks are detected, the gas company should be notified; a qualified contractor will be needed to correct problems.

If fuel leaks are not suspected, carbon monoxide and other contaminants are usually measured in the general living area at breathing height or close to the floor if infants are present. Measurements can also be taken adjacent to the appliance or heat registers. Regardless of the location, measurements should be made during routine investigations after combustion appliances have been operating for at least one hour.

### Interpretation of Combustion-Related Contaminant Data

#### Combustible Gas

Combustible gas meters must be calibrated to the specific gas of interest. A meter calibrated to natural gas should not be used for investigations involving liquified propane, butane, or a mixture of these compounds (liquified petroleum gas, LPG) because the lower explosive limits for these compounds are lower than for natural gas (methane). General guidelines which can be used are given by EPA (U.S. EPA, 1990) for hazardous materials investigations:

- greater than or equal to 25% of LEL—evacuate immediately; explosion hazard!
- 10% to 25% of LEL—proceed with extreme caution,
- less than 10% of LEL—lower hazard, proceed cautiously with investigation.

#### Carbon Monoxide

Indoor levels of carbon monoxide (CO) vary considerably depending on the sources that are present and

consumer use patterns. Concentrations of 1 ppm to 2 ppm can result indoors from using a normally operating gas-fired central furnace; concentrations considerably over 100 ppm have been measured in homes with faulty furnaces. Levels of 35 ppm to 120 ppm have been measured after 4 burners on gas stoves were operating for 20 minutes (Sterling and Sterling, 1979). Kerosene heaters can result in concentrations from several parts per million to over 20 ppm (U.S. CPSC, 1983). Traynor *et al.* (1983) measured concentrations ranging from 1.9 ppm to 89.4 ppm in a test house (1150 ft<sup>2</sup>) heated by unvented gas heaters.

Since the potential effects of measured concentrations of CO depend on the % COHb in the blood, the WHO recommends a carboxyhemoglobin level of 2.5% - 3% for the protection of the general population, including sensitive groups (WHO, 1987). The WHO's air concentration guidelines to protect these levels include: a maximum permitted exposure of 100 mg/m<sup>3</sup> (about 87 ppm) for periods less than 15 min.; and time-weighted average exposures of 50 ppm (60 mg/m<sup>3</sup>) for 30 minutes, 25 ppm (30 mg/m<sup>3</sup>) for 1 hour, and 10 ppm (10 mg/m<sup>3</sup>) for 8 hours.

The U.S. EPA ambient standard and the Canadian indoor exposure guidelines for CO are similar. EPA's standards are 9 ppm for 8 hours and 35 ppm for 1 hour; Canada's guidelines are < 11 ppm for 8 hour exposures and < 25 ppm for 1 hour exposures.

It should be noted that these guidelines may not provide sufficient protection for individuals who are chronically ill with heart and/or lung problems.

#### Nitric Oxide

Nitric oxide will be present whenever combustion products are emitted directly into the living space. Undersized and oversized kerosene heaters have resulted in nitric oxide concentrations of 0.21 ppm and 0.43 ppm, respectively, when burned for a 4 hour period in a townhome (Ritchie and Oatman, 1983). Concentrations as high as 0.94 ppm were

measured when a convective kerosene heater was operated in a room with the door opened 1 inch (Ritchie and Arnold, 1984). Concentrations of 0.00 ppm to 5.14 ppm were measured by Traynor *et al.* (1983) in a test house heated by unvented gas space heaters.

There are no guidelines for acceptable concentrations of nitric oxide indoors.

### Nitrogen Dioxide

Nitrogen dioxide concentrations between 0.003 ppm and 0.540 ppm have been measured in homes with gas-fired stoves, ovens, or unvented heaters (Spengler and Cohen, 1985). Steady-state levels up to 0.250 ppm have been measured in a home with a radiant kerosene heater operating in a room with a door opened 1 inch; levels of 0.057 ppm were measured when a convective heater was operated in a room with the door open (Ritchie and Arnold, 1984). Nitrogen dioxide concentrations ranging from 0.225 ppm to 1.35 ppm were measured in a test house heated by unvented gas space heaters (Traynor *et al.*, 1983).

Based on its review of the nitrogen dioxide literature, the WHO recommends nitrogen dioxide guidelines of 0.21 ppm (400  $\mu\text{g}/\text{m}^3$ ) and 0.08 ppm (150  $\mu\text{g}/\text{m}^3$ ) for 1 hour and 24 hour ambient exposures, respectively. The Canadian exposure guidelines for residential indoor air quality are <0.25 ppm for 1 hour and <0.05 ppm for long-term exposures. The U.S. EPA standard for ambient air is 0.053 ppm (0.1  $\text{mg}/\text{m}^3$ ) as an annual arithmetic average.

### Carbon Dioxide

Outdoor concentrations of carbon dioxide are generally in the range of 300 to 330 ppm (multiply by  $10^{-4}$  to convert to %). In homes without sources, concentrations might be in the range of 0.07% - 0.20% (NRC, 1981). Concentrations in homes with kerosene heaters can reach concentrations

above 0.3% within several hours, and concentrations greater than 0.5% have been measured (Ritchie and Arnold, 1984). Concentrations of 0.177% to 0.815% were measured by Traynor *et al.* (1983) in a test house heated by unvented gas heaters.

The Canadian exposure guidelines for residential indoor air quality are <3500 ppm (<0.35%). ASHRAE's guideline for acceptable indoor air quality is 1000 ppm. ASHRAE, however, chose this level because it is used as an indicator of inadequate outdoor air, and not because of the potential health effects from carbon dioxide exposure.

### Sulfur Dioxide

Outdoor concentrations vary from <0.002 ppm in pristine areas to about 0.01 ppm for annual averages in urban areas (higher concentrations do occur). Homes without sources are not likely to have measurable sulfur dioxide levels unless the outside air is contaminated. Indoor sources are primarily faulty furnaces that burn oil or coal and kerosene heaters. Depending on the concentration of sulfur in kerosene, indoor levels have been reported from minimal to over 0.14 ppm (Ritchie and Arnold, 1984).

The WHO recommends a guideline value for sulfur dioxide of 0.174 ppm for a 10 minute maximum (equivalent to a 1 hour maximum of about 0.122 ppm). The Canadian exposure guideline is <0.38 ppm for a 5 minute maximum and <0.019 ppm for long term exposures.

### Benzo(a)pyrene

Benzo(a)pyrene (BaP) is probably the most widely known and measured of the several hundred PAH compounds which have been detected as byproducts of combustion. BaP is a potent carcinogen. The ambient air has background BaP levels of nearly zero (WHO, 1987); levels of less than 5  $\text{ng}/\text{m}^3$  were measured in the U.S. during the 1970s (Faoro and Manning, 1981).

Indoor levels of BaP have been measured during the combustion of wood, coal, kerosene, and tobacco. Because BaP and PAH compounds are carcinogens, there is no safe level of these compounds indoors.

### Mitigation Advice For Combustion Contaminants

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It is important to instruct residents about the problem of depressurization of the house when other fuel-burning appliances are present and there is insufficient oxygen. This problem is particularly important in tightly constructed homes.

It is important for all vented appliances to be properly installed, maintained, and operated in order to prevent emissions from entering the living space. If there are problems with the condition or installation of the appliance, flues, chimneys, chimney connectors, and so forth, these must be repaired, usually by a qualified contractor.

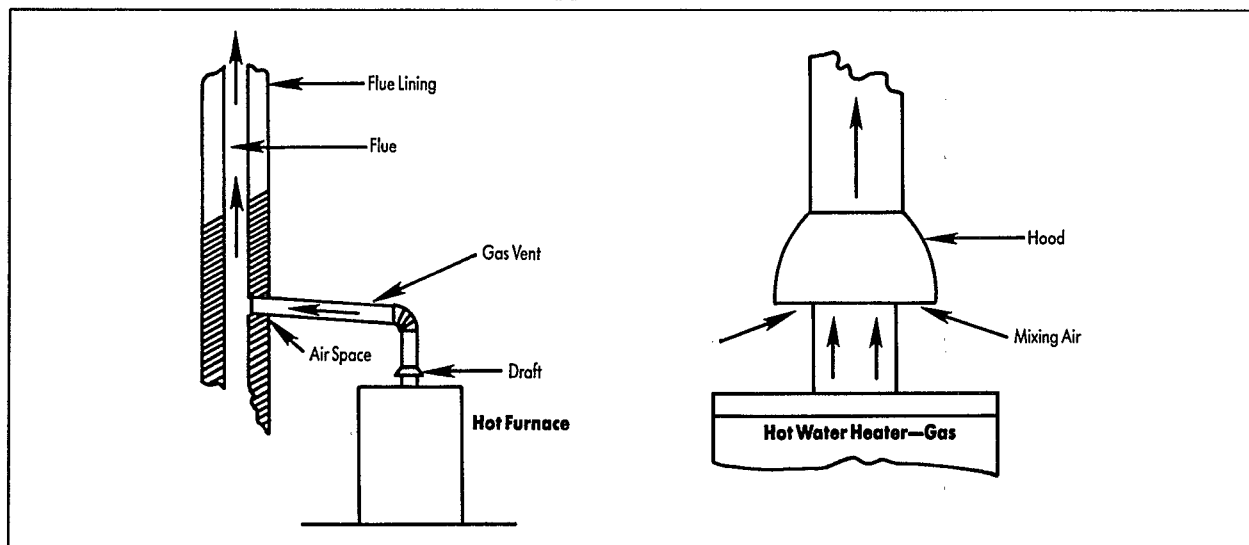
The most effective method of controlling gaseous and particulate combustion products is removal of the source or substitution with sources that emit fewer contaminants (for example, replacing

unvented kerosene heaters with electric heaters). However, in many instances substitution and/or removal will not be possible. In those cases, increased ventilation (local exhaust or whole house) will help reduce emissions.

Whenever local building codes allow unvented space heaters, the heaters should be checked for proper installation and specific limitations. Some jurisdictions allow the sale of kerosene heaters, but prohibit their use in single family and/or multiple family dwellings. Whenever this situation exists, efforts should be made to provide the consumers with information about of allowed and prohibited uses.

Regardless of the primary purpose of an investigation, if unvented heaters are present and their use is allowed by the local code, the investigator should take time to educate the occupants on safe usage of the appliance. It is important to first determine why unvented space heaters are being used in lieu of vented appliances. Whenever possible, central heating systems or vented appliances should be encouraged.

### Exhibit 8-3. Location and operation of typical backdraft diverter.



SOURCE: U.S. HEW (1976).



**Exhibit 8-4. CABO Building Code combustion air requirements for residential fuel-burning equipment.**

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**ONE AND TWO FAMILY DWELLINGS**

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**A. Combustion air requirements for unconfined spaces (M-1202):**

- No special combustion air source is required for unconfined spaces. Unconfined spaces are those with a volume not less than 50 ft<sup>3</sup> per 1000 Btu/hr or per the input rating of all appliances installed in the space. Rooms which open into the space where appliances are installed are considered part of the unconfined space if the openings do not have doors.

*Exception:* Sealed combustion system (direct vent) appliances or enclosed furnaces are exempt from these requirements.

**B. Combustion air requirements for confined spaces (M-1203):**

- Combustion air requirements are 2 in<sup>2</sup> of combustion air opening for each 1000 Btu/hr of input rating with a total area of not less than 200 in<sup>2</sup>.

*Exception:* 1 in<sup>2</sup> for each 1000 Btu/hr input rating may be permitted if the compartment floor area is >2 times the floor area of the appliance and the total area is not less than 100 in<sup>2</sup>.

If the outside air is used, it must be supplied through the required cross-sectional area extending to the appliance room; the same duct should not serve both the combustion air openings; the upper duct must be level or extend upward from the appliance room.

- One-half of the required opening must extend within the upper 12 in of the room and one-half within the lower 12 in of the room.

*Exception:* In any room that has gas- or liquid-burning appliances which has more than 2 times the floor area of all such appliances, the required combustion air supply may be reduced by 50%, but not less than 100 in<sup>2</sup>.

- The combustion air source can come from outside air or interior spaces. If an interior space is used it must have a volume in ft<sup>3</sup> that is equal to 1/20 of the input Btu/hr rating of all fuel-burning and water-heating appliances in the space (M-1204).
- Each appliance must have its own supply duct, and combustion air openings cannot have volume dampers. Requirements for cold climates are given in Section M-1211 of the CABO Code.

**C. Attic combustion air**

- Combustion air can be obtained from an attic if the required volume of combustion air can be provided. The combustion air opening must have a galvanized sleeve of not less than No. 26 gauge steel (or other approved material) extending from the appliance enclosure to at least 6 in above the top of the ceiling joists.
- Circulating air supplies for blower-type furnaces shall *not* be obtained from the attic area.

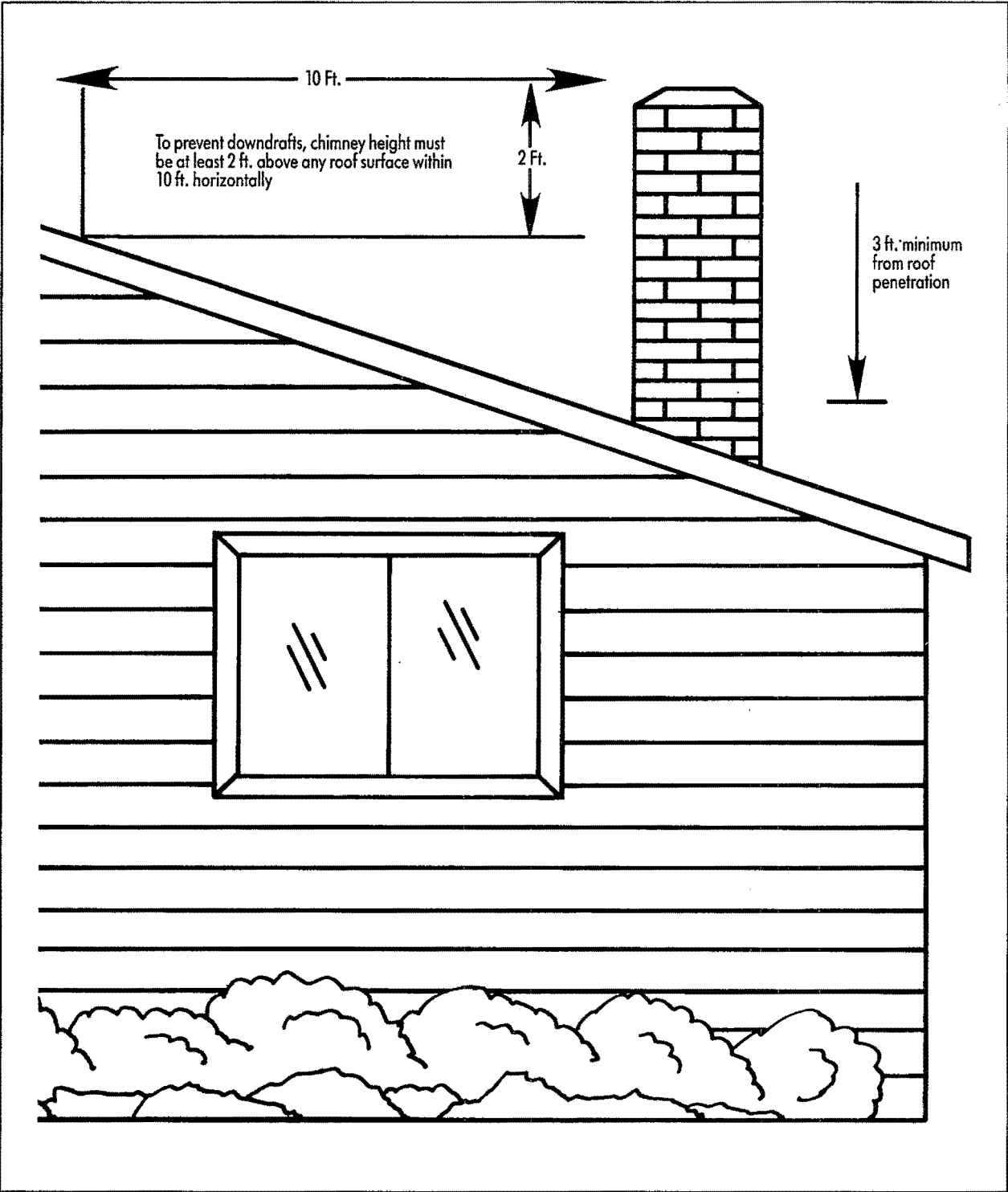
**D. Under-floor combustion air**

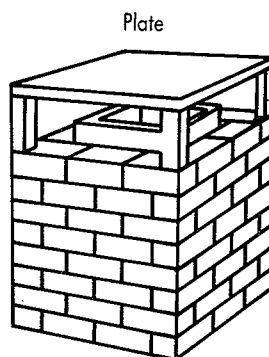
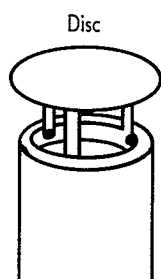
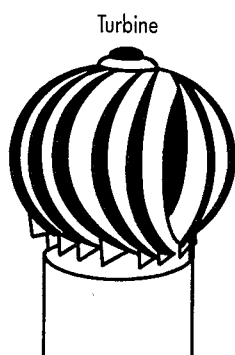
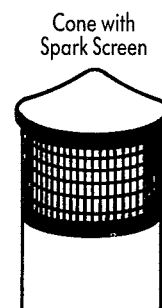
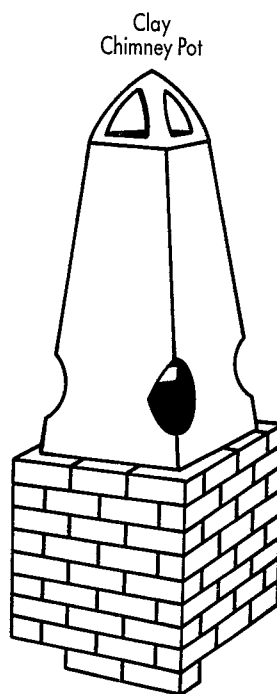
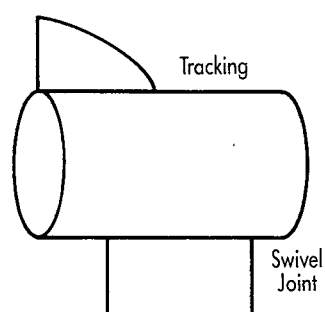
- The lower combustion air supply required in M-1203 of the code can be obtained from under-floor areas having unobstructed openings to the outside equal to at least 2 times the required combustion air openings.

SOURCE: CABO (1989)

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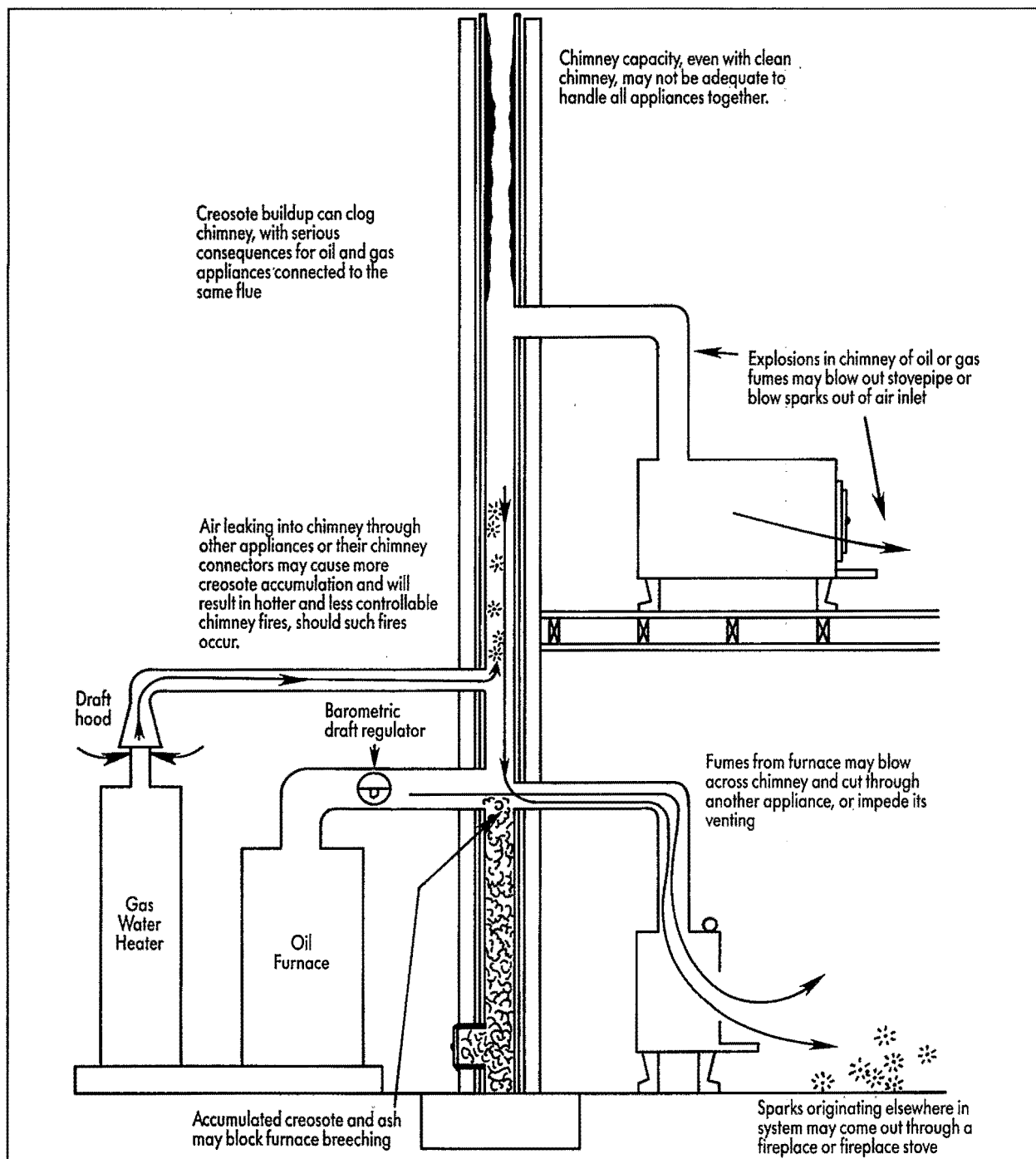
**Exhibit 8-5. Separation guidelines to prevent downdrafts into chimneys.**



**Exhibit 8-6. Examples of chimney caps.**

**Exhibit 8-7. Potential consequences when more than one appliance is connected to the same flue.**

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SOURCE: Shelton, J.W. 1979. *Wood Heater Safety*. Garden Way Publishing: Carlotte, VT. Used with permission.

**Exhibit 8-8. Combustion inspection form.**

Address: \_\_\_\_\_ Date: \_\_\_\_\_

**HOME HEATING INSPECTION CHECKLIST**

Central Heat: Present?	Y	N	Operable?	Y	N
			If no, why not? _____		
			(Turn on if not in operation at time of inspection, if possible.)		

Fuel Source: \_\_\_\_\_

**VISUAL INSPECTION**

Cover on Furnace	Y	N
Obvious Damage to Any Part	Y	N
Duct Work Connected	Y	N
Chimney in Good Condition	Y	N
Smell Fuel Source/Odor	Y	N
Registers Clean	Y	N
Location in BA or BR	Y	N
Cold Air Return Clean/Open	Y	N
Combustion Air Intake Blocked/Dirty	Y	N

**FLUE/VENT**

Secure to Chimney	Y	N
Correctly Sized	Y	N
Secure to Furnace	Y	N
Flue/Vent Slopes Upward	Y	N

**237****OTHER SOURCES OF HEAT**

(Specify)

- a) Unvented Gas Space Heater
- b) Kerosene Heater
- c) Gas Cooking Stove
- d) Fireplace

- e) Vented Gas Space Heater
- f) Wood Stove
- g) Coal Stove
- h) Electric Space Heaters

**WATER HEATER**

Present	Y	N
Gas	Y	N
If in Garage, 18 in Off Ground N/A	Y	N
Cover on Water Heater	Y	N
Obvious Damage/Rust	Y	N
Located in BA or BR	Y	N

**VENT**

In Good Condition	Y	N
Slopes Upward	Y	N
Connected Directly/Securely to Chimney	Y	N
Chimney in Good Condition	Y	N
Correctly Sized	Y	N

**WOOD/COAL STOVES**

36 in Minimum Floor Protection	Y	N
Accessible to Children	Y	N
Combustibles 36 in Away	Y	N
<25 lbs Logs Stored Inside	Y	N

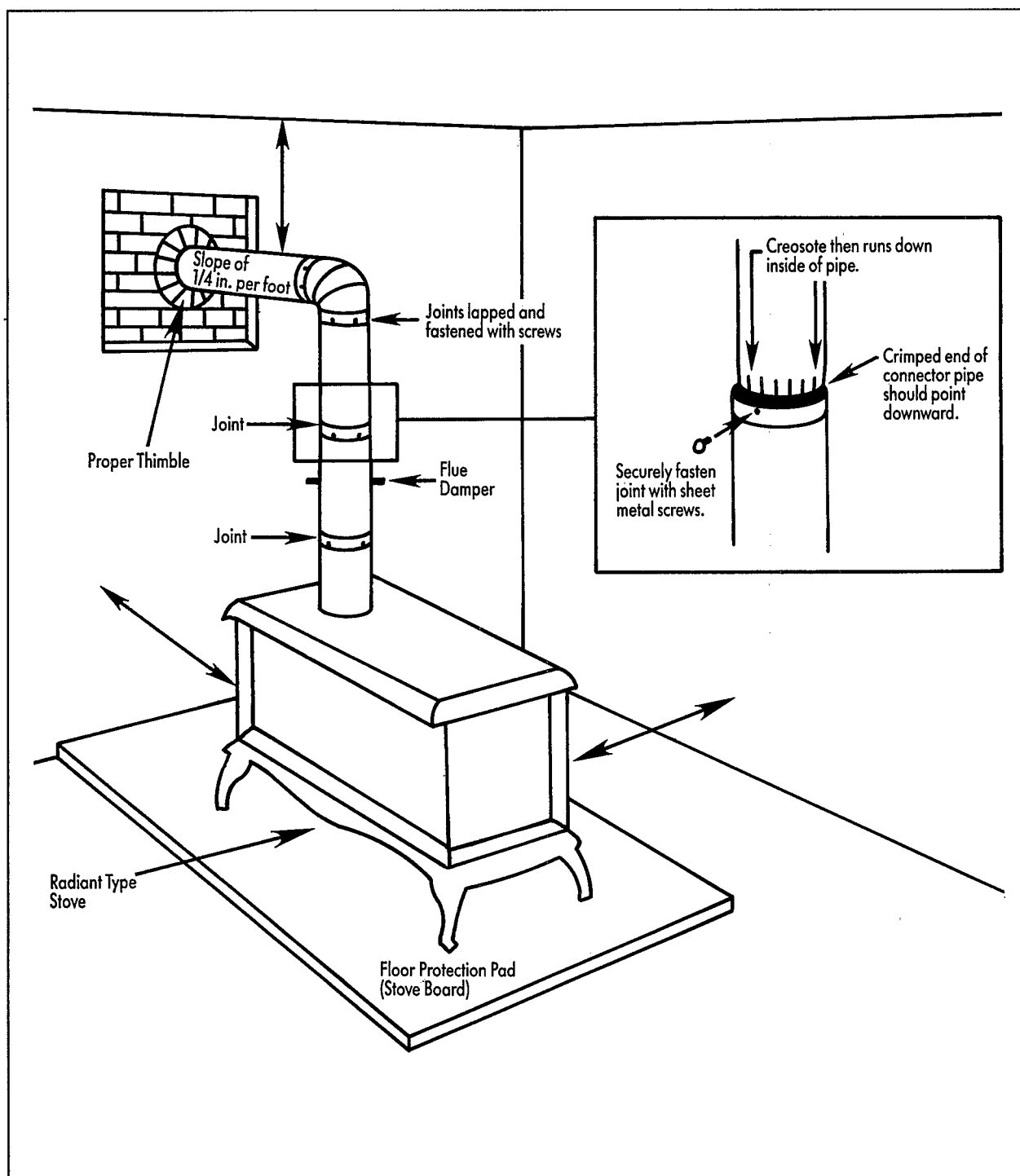
Use Double/Triple Wall Flue	Y	N
Flue Correctly Sized	Y	N
Sheet Metal Screws in Flue	Y	N

**ASBESTOS MATERIALS** (List location and note condition)

Present	Y	N
Friable	Y	N

Comments and Code Violations: \_\_\_\_\_

SOURCE: Adapted from Marion County Health Department (1988).

**Exhibit 8-9. Features of proper stove installation.****238**

SOURCE: Jenkins and Vacca (1979)

**Exhibit 8-10. Suggested chimney sizes for residential wood-burning equipment.<sup>1</sup>**

APPLIANCE TYPE <sup>2</sup>	SUGGESTED INSIDE DIAMETER FOR ROUND CHIMNEYS OR FLUE LINERS (INCHES)	SUGGESTED RECTANGULAR FLUE DIMENSIONS (NOMINAL EXTERIOR) (INCHES)
Small stoves <sup>4</sup>	4 - 6	4 x 8
	5 - 7	8 x 8
Medium and large stoves <sup>4</sup>	6 - 8	8 x 8
	7 - 8	8 x 8
Fireplace stoves, <sup>3,4</sup> small fireplaces furnaces, boilers	8 - 10	8 x 12
	10	8 x 12
Medium fireplaces <sup>5</sup>	10	8 1/2 x 8 1/2 <sup>a</sup>
		8 1/2 x 13 <sup>b</sup>
Large fireplaces <sup>5</sup>	12	8 1/2 x 13 <sup>c</sup>
		8 1/2 x 18 <sup>d</sup>
		13 x 13 <sup>e</sup>
		13 x 18 <sup>f</sup>

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<sup>1</sup> Additional sizes can be found in Sheldon (1979), Self (1980), or other handbooks.

<sup>2</sup> Each type of appliance spans a range of collar sizes; thus location of type in table is approximate.

<sup>3</sup> A common rule of thumb for fireplace and fireplace-stove chimneys is that the cross-sectional area of the flue should be about 1/10 of the area of the fireplace opening if the chimney is 15 feet or more in length from the hearth to the chimney top. If the flue is unlined or less than 15 feet tall, the needed flue size is 1/8 of the fireplace opening. Bigger is not always better. Oversize flues tend to create less draft and accumulate more creosote.

<sup>4</sup> Sheldon (1979)

<sup>5</sup> Self (1988)

<sup>a</sup> fireplace opening — 28" x 24" x (16" - 18")

<sup>b</sup> fireplace opening — (30" - 32") x 28" x 18"

<sup>c</sup> fireplace opening — 36" x 28" x 18"

<sup>d</sup> fireplace opening — 42" x 28" x 18"

<sup>e</sup> fireplace opening — 48" x 32" x (18" - 20")

<sup>f</sup> fireplace opening — 54" x 36" x 20"

SOURCE: Sheldon (1979); Self (1988)

**Exhibit 8-11. Safety guidelines for unvented gas-fired heaters.**

- Turn off the fuel valve whenever there is a strong fuel odor, and call for service.
- Strike the match before the gas valve is opened. This prevents the possible buildup of fuel vapor which could easily ignite. If there is an accumulation of fuel vapor, sufficient time should be allowed to pass before relighting to dissipate the fuel.
- Observe the flame to be sure it is adjusted properly. A yellow flame indicates incomplete combustion and will result in higher carbon monoxide and particulate levels.
- Always keep a window partially open whenever a fuel-burning unvented space heater is in use. Adequate ventilation is needed to reduce contaminant levels and to replace oxygen that is used for combustion. One inch of open window space for every 10,000 Btu of heater rating is a general rule of thumb (equal to about 4 in<sup>2</sup> for every 1,000 Btu of heater rating).
- Never leave the heater unattended while it is in operation. Never use the heater overnight while people are sleeping.

**Exhibit 8-12. Safety guidelines for unvented kerosene heaters.****TO MINIMIZE INDOOR AIR POLLUTION:**

- Use only water clear, or K-1 kerosene, as a fuel. K-2 kerosene and fuel oil have a greater sulfur content and will increase emissions. Never use gasoline because of explosion/fire hazards. Do not use kerosene that is yellow or that has been stored over a period of time (summer season).
- Examine wicks and burners for excessive carbon buildup after burning 1 or 2 tanks of fuel. Carbon buildup is indicative of inefficient combustion.
- Do not operate the heater in confined areas such as bathrooms. *Never* operate the heater in bedrooms while people are sleeping.
- Size the heater correctly for the space to be heated. A general rule of thumb for calculating the required Btu is to multiply the floor area by 28. The resulting number is an approximation; anyone who is contemplating the purchase of a kerosene heater should consult with the sales representative to more closely match the space to be heated with the correct size of heater. Avoid oversized heaters.
- *Always* keep the wick at the proper setting. A wick that is too high or too low can significantly increase emissions. Do not "turn down" the flame in an effort to cool a room that is too hot. This will only decrease the efficiency of combustion and increase the emissions of carbon monoxide and particulates. Do not "turn up" the flame in an effort to generate more heat because this will increase the oxides of nitrogen.



**Exhibit 8-12. Safety guidelines for unvented kerosene heaters (continued).**

- *Always* provide adequate ventilation. Do not use heaters in a closed room. Some manufacturers recommend using the heater in a room that is open to other rooms. Air exchange with other rooms in the house does not provide sufficient ventilation air. Fresh outside air must be provided. Windows should be opened at least 4 in<sup>2</sup> for every 1000 Btu of heater capacity.
- Consider other heating options if anyone in the house is ill, has allergies or asthma, pregnant, or if there are small children in the house.

**TO MINIMIZE SAFETY HAZARDS:**

- Do not leave kerosene heaters unattended.
- Be sure there is sufficient clearance between the heater and combustibles.
- Do not move the heater while it is burning or if the flame flares or appears to be uncontrolled. Turn off the heater, and if this fails or cannot be done, leave the area immediately and call the fire department.
- Store kerosene in a container labeled "kerosene." Do not store other fuel in this container. Store fuel in a safe place, where children cannot reach it.
- Do not store fuel inside the house. Fill heaters with fuel outdoors, never indoors. Never add fuel to a heater that is burning or hot.
- Keep children away from kerosene heaters to protect them from touching hot surfaces.
- Check the temperature of rooms where heaters are being used to be sure that rooms are not too hot. Temperatures over 100°F have been measured.

**241****REFERENCES**

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### 8.3 INVESTIGATION TECHNIQUES FOR PESTICIDES

A routine indoor air quality investigation should identify which pesticides are present and the potential hazards posed by storage and use practices. Education about the prudent control of pests can be an important goal of an indoor air quality program and individual inspections. Clients should be informed about potential hazards of products they store or use, encouraged to dispose of products which are used infrequently, and encouraged to use less hazardous products whenever possible.

During an inspection, the investigator should ask if pesticides are used. If so, the following information should be obtained:

- inventory of pesticides which are present;
- frequency of use and the date of last use;
- methods of storing, mixing, and disposal;
- methods of application (for example, spray);
- ventilation and personal protection used for mixing and application; and,
- for termiticides and large area applications, date of application, method, and chemical (if known).

The inventory should include questions to identify the use of products such as flea and tick collars, insect repellents, disinfectant sprays, no-pest strips, roach and rodent baits, insect sprays, and so forth. A request to see the location where these products are stored can reveal important information about storage practices. Products which are stored in areas where children have access should be relocated. Any evidence of spills or leakage requires removal and cleanup. Pesticide products which are in unmarked containers or those which are not in original containers should be disposed of properly. Any products which have been banned should be re-

moved and disposed of properly; a list of these pesticides can be obtained from the EPA regional office.

The investigator should also determine the type of applicator that is or has been used (aerosol cans, foggers, bombs, handsprayers, pressurized hose sprayers, brushes/cloths, lawn or garden spreaders, hand dusters, or shake containers) and the procedures used to apply the products. If any of the equipment appears to be contaminated, the investigator should inform the client of the need to clean equipment after application and the procedures to be followed.

Mixing and application practices are important factors that affect personal exposures during application and contamination of the indoor environment. Asking for a demonstration of how the client uses equipment and products (even aerosol or pump sprays) can sometimes reveal more information than asking for a simple explanation of procedures which are followed. Attention should also be given to the ventilation which is provided and reentry after application.

A history of the recent application of pesticides and flu-like symptoms should alert the investigator to a possible pesticide contamination problem.

## Termiticide Investigations

Termiticides are applied to the soil in one of two ways. Pre-treatment (before a house is built) is done by trenching around the foundation. Remedial treatment is done by drilling, rodding, and sometimes by trenching chemicals into the soil.

The levels of the termiticide that might result in the indoor air depends on the volatility of the termiticide, the method of application and route of entry, and environmental factors that affect the movement of air and degradation of the termiticide. A buildup of termiticide can result when the heating system becomes contaminated, when

building is depressurized, or when there are entry points into the living space.

If odors (even faint ones) linger more than a few days, structural problems or improper application should be suspected.

All structural elements located between the treated soil and the inside of the building should be examined if possible. Typical problems include cracks or openings in the floor, ductwork in the crawl space which leaks, and holes around plumbing and utility lines in slab foundations.

Misapplication problems can include accidental contamination of ducts, spraying termiticides onto a wooden structure, open or poorly sealed injection holes, not cleaning spills that occur during injection; transfer from one hole to another; and applying termiticides to areas which provide the termiticide access to the indoor air. Potential problem areas and mitigation methods are summarized in Exhibit 8-13.

Wells and drinking water can also become contaminated during termiticide applications. Common problems include wells that are not properly sealed, old cistern or dug wells that are not properly filled, and tree roots which act as channels for pesticide flow. If a well is located within the foundation, the house should not be treated with a termiticide. Contaminated wells require expert assistance.

### Crawl space contamination problems

If a crawl space is present and odors intensify when the heating or cooling system blower operates, the crawl space should be evaluated. Problems can come from several sources:

- 1) openings in the floor between the crawl space and the living space;
- 2) a furnace which draws combustion air from the crawl space;

- 3) cold air return ductwork which has faulty seams or openings;
- 4) contamination of joists, piers, and other subflooring members;
- 5) contamination of insulation or water pipe wrapping;
- 6) contamination of the surface soil of the crawl space; and
- 7) ducting which uses joists and sheet metal and/or fiberboard to make the air channels.

Termiticides should *not* be applied to crawl spaces when the crawl space is used as a hot or cold air plenum.

#### **Intra-slab or sub-slab contamination problems**

A lingering odor in a structure with intra-slab or sub-slab ductwork suggests that contaminants from the treated soil are entering the living space through openings, cracks, or deteriorated sections of ductwork.

Termiticides should *not* be applied to sub-slab or intra-slab floors made with cardboard, defective metal, tile, cracked concrete, or fiberglass ducts. Application of pesticides in these areas is likely to result in duct contamination.

Accidental injection of termiticide into the ductwork should be suspected if odors occur immediately after the termiticide has been applied and as a result of operating the blower on the heating and ventilating system.

To investigate these problems, ventilate the home to clear odors. Then starting with the registers nearest to the blower, smell each vent to determine the source of the odor. Work from the blower outward. If an odor is detected from a particular vent, the duct near that vent is the most likely source. If the

source of the odor cannot be determined, each register should be removed and a light and mirror should be used to look for rusty or moisture-stained sections of the duct.

#### **Other surface contamination problems**

Any puddles, seepage, wet or moist surfaces in floors, walls, or insulation that have a chemical odor suggest contamination with a termiticide, if a recent application has occurred. Sampling may be required to verify the contaminant.

#### **Measuring Pesticide Contaminants**

Pesticide measurements will probably not be taken during routine investigations of indoor air quality problems. As mentioned previously, a recent history of use, lingering chemical odors, and symptoms may be sufficient to diagnose a problem. There may be instances when measurements of pesticides will be useful and surface residues, airborne samples, or water can be collected and tested. Measurement of airborne residues provides as estimate of respiratory exposure to the pesticide; water samples and surface residues (soil, wood, furniture, household objects) can help identify potential hazards and the sources of contamination. Procedures for air and residue samples are outlined below. Water samples should be collected as instructed by the laboratory doing the analysis.

#### **Air sampling**

Pesticide concentrations can be measured to determine if pesticides are present or to evaluate the efficiency of mitigation efforts. Collecting pesticide samples is relatively easy, but the analysis is complex and requires highly trained analysts and sophisticated equipment. **Extreme care must be used to prevent contamination problems during all phases of sampling and analysis.**

Cooperative agreements between local and state agencies can generally be developed for analytical capability. Private consulting laboratories can also

conduct sampling and analysis, but costs are high, generally \$100 to \$200 per sample. The laboratory must have a rigorous quality assurance program, and the analyst should be experienced not only with the general analytical technique, but should also have experience with pesticide analysis.

EPA has developed a method for collecting and analyzing several pesticides in ambient and indoor air using low volume polyurethane foam (PUF) sampling with gas chromatography/electron capture detection (GC/ECD) (U.S. EPA, 1989a,b). Exhibit 8-14 identifies pesticides which have been measured using this method.

The indoor sample is collected by using a personal sampling pump to draw air through a polyurethane foam cylinder that is slightly compressed into a borosilicate glass tube; these can be purchased assembled or fashioned by the user. The sample is collected by using low flow rates in the range 1 to 5 lpm for sampling periods of 4 to 24 hours. Stationary or personal samples can be collected. After collection, the samples are extracted, concentrated, and analyzed using GC/ECD. Gas chromatography can also be followed by mass spectroscopy/multiple ion detection (GC/MS/MID) for confirmation and to quantify nonchlorinated compounds.

Quality control procedures and proper technique are very important in this procedure to prevent the possibility of contamination. The laboratory should include field, process, and solvent blanks at a level of 5%. Blank levels should not exceed 10 nanograms (ng)/sample for single components or 100 ng/sample for mixtures with multiple pesticides. Replicate determinations of collection efficiency should be made using spiked samples. Relative standard deviations for the replicate determinations of  $\pm 15\%$  or less are acceptable, and recoveries of 75% are acceptable (U.S. EPA, 1989b).

Air samples should be placed at the breathing height (3 feet to 6 feet above the floor) for the occupants. The sampler should be located at least 12 inches from any obstacle to insure adequate air

flow. Sampling is conducted at a rate of 1 to 5 l/min., and the sampling pumps are calibrated before and after sampling in the laboratory. The collected samples should be refrigerated until analysis.

Ideally, for complaint and emergency investigations, duplicate samples should be collected from each living area for a period of 4 hours to 24 hours. A field blank should be included if a single residence is sampled; if more than one residence is sampled, field blanks at a rate of 5% should be included (U.S. EPA, 1989b).

### Special Samples

Wipe samples (sometimes called swipe or smear samples) can be collected from surfaces such as kitchen tops, floor surfaces close to walls and injection areas, furniture, walls, and other areas where contamination is suspected. Wipe samples should not be used in lieu of air samples, but they can provide useful information about sources and extent of contamination. EPA does not have guidelines for wipe samples, but wipe sampling procedures developed by OSHA can be used [(29 CFR 1910.132(a))]. The OSHA procedure is not limited to pesticides.

Clean gloves which are impervious to the contaminant should be worn during all phases of collection. Surface samples are collected by wetting Whatman 42 (7 cm) filter paper with acetone, water, or other solvent as recommended by the analytical laboratory) and wiping across the suspected area.

The OSHA procedure is as follows: Moisten the filter paper with the solvent, and wipe an area of about 100 cm<sup>2</sup>. Without allowing the filter to contact any other surface, fold it with the exposed side in, and then fold it over to form a 90-degree angle in the center of the filter. Place the filter, angle first, into a clean glass vial (provided by the laboratory to minimize contamination problems), replace the top, seal it, and send it to the laboratory for analysis. A blank filter also moistened with solvent should be submitted in a separate vial along with the samples.

The Wood Protection Council (1987) recommends a similar, somewhat abbreviated procedure; a filter size of at least 10 cm x 10 cm is recommended.

Swipe samples should not be used on carpets or furnace filters; instead a 10 cm x 10 cm section of these materials should be collected (Wood Protection Council, 1987).

### Interpretation of Pesticide Data

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Interpreting measured air data can be difficult because of the lack of guidelines on acceptable concentrations of pesticides. The National Academy of Sciences reviewed the seven most frequently used termiticides in the U.S. and recommended the following guidelines: aldrin—1  $\mu\text{g}/\text{m}^3$ ; chlordane—5  $\mu\text{g}/\text{m}^3$ ; chlorpyrifos—10  $\mu\text{g}/\text{m}^3$ ; heptachlor—2.00  $\mu\text{g}/\text{m}^3$  (NRC, 1982). The NAS also reviewed the data for lindane and pentachlorophenol, but guidelines were not suggested for these contaminants.

In the absence of guidelines for the general population and the uncertainty about the long-term health effects of exposure to pesticides, a conservative approach is indicated. The presence of pesticides on swipe samples should prompt an investigation of possible sources and corrective action. The investigator should attempt to contact and consult with physicians in those instances where respiratory, allergic, or other effects appear to be experienced by exposed individuals. Every effort should be made to minimize pesticide exposures, even in situations where the complaint is limited to odors.

### Mitigation Advice for Pesticides

#### General Advice

It is almost impossible to eliminate pests entirely. Regular use of pesticides often initiates a vicious cycle of pesticide applications that are more frequent and potent in order to maintain the same degree of control. The best control strategy is to prevent pests from invading in the first place and

avoid the unnecessary use of pesticides. The use of nonchemical pest control methods (particularly proper hygiene and removal of food, water, shelter, and breeding sites) and maintaining healthy plants should be encouraged in place of chemical control methods.

If pests become established, nonchemical controls may not be sufficient to correct problems, and pesticides may be necessary. The use of a combination of methods to control pests is called integrated pest management (IPM), and education programs which emphasize the prevention of pest infestations and integrated pest management may be available from (or could be developed in conjunction with) county cooperative extension agencies. Useful sources of consumer information on pesticides are contained in Exhibit 8-15.

When pesticides must be used, clients should be instructed verbally or by fact sheets about the safe use, storage, and disposal of pesticides. In general, if pesticide products have not been used during the preceding 6 months, the proper disposal of these products should be encouraged. (A community-sponsored free drop-off program for the disposal of household hazardous waste is an effective way to dispose of pesticides and other hazardous materials that may be found in the home.) If professional applicators are hired, consumers should ask what products will be used, what potential health effects could result, and what reentry times are needed. Exhibit 8-16 contains a list of safety tips for the safe use of pesticides in the home. This list can be modified easily for other applications.

#### Pesticide Spills, Improper Applications, and Odors

If pesticide spills occur in or around the home or office, quick action is important. The investigator should be prepared to respond if he/she is on scene and emergency help is not available. Exhibit 8-17 provides guidelines for administering first aid in emergencies.

When spills or accidents occur, the basic response includes stopping the source, containing the pesticide, securing the area, obtaining first aid if needed, removing excess pesticide, cleaning the area, disposing of waste, and evaluating the area after cleanup. Proper respiratory protection (organic vapor and particulate cartridges) and clothing (impervious gloves, apron, and shoes; disposable coveralls) must be worn during all phases of cleanup and residue removal. These should be part of the investigator's field equipment. General guidelines for cleaning spills and residues which can be given to clients as part of an education program are summarized in Exhibit 8-18.

One problem related to pesticide application is premature reentry. Safe reentry times vary depending on the product, and these must be followed as specified by the manufacturer to prevent accidental poisonings.

If professional applicators are responsible for improper applications, they should be contacted to provide remedial assistance. If pesticides have been applied and odors linger, the area should be ventilated and checked for the presence of liquid pesticide. If present, liquids should first be absorbed, then removed. Manufacturers of products should also be contacted to obtain information on proper mitigation. Sampling should be conducted to verify the effectiveness of ventilation and cleanup.

Methods for mitigating termiticide contamination are given in Exhibit 8-13.

### Pest Management Indoors

There are some types of products that consumers could replace with other control measures in order to reduce their exposure to pesticides. Solid baits can provide a safer alternative to sprays, and pumps that deliver larger droplets can provide more control than aerosolized products. The use of pesticide strips (containing propoxur, chlorpyrifos, diazinon) and paint-on formulations have been suggested as safe alternatives to sprays because sprays (aerosol or

compressed) are likely to result in higher concentrations of contaminants compared to paint-on formulations or strips. A two-fold increase was observed in one study (Ware and Cahill, 1984).

Pest strips, however, still release pesticides into the living space and over a longer period of time because they are formulated as controlled releases. A safe alternative to pest strips are sticky paper strips which are coated with a sugar attractant instead of pesticides.

The use of insect repellents (containing DEET or other active ingredients) which are applied as a lotion or spray should not be used on infants and young children because of potentially serious health effects.

There are many simple, but often effective, nonchemical pest control methods which can be used in and around residences. Hand removal, vacuuming, and the use of a flyswatter can control many flying and crawling insects. Maintaining healthy plants and thorough washing of stems and leaves at the first sign of some pests can minimize pest problems on plants. Ants can usually be controlled by removing visible ants and *eliminating all* food sources. Diatomaceous earth or a mixture of boric acid and sugar can be effective controlling roaches, ants, and blister beetles. Rats and mice can be controlled by ratproofing structures; Vitamin D3 pelleted bait can also be effective. Infestations of fleas can often be controlled by thorough vacuuming of floors, carpets, and upholstery, followed by shampooing. All removable bed and furniture coverings should be laundered. Heavy infestations may require two of these cleanings, or the use of pesticides.

In general, removing food and water and eliminating shelter and breeding sites are fundamental principles to be encouraged.

**Removing food and water sources:** All pests need food and water to survive, and an important step in controlling pests is to remove needed nutrients.

Standing water can be eliminated from the home by fixing leaky plumbing, removing water collectors such as tires from yards, correcting drainage problems, and by removing standing water from trays under houseplants. Food sources should also be removed. Foods (including pet foods) should be stored in sealed containers and should not be allowed to stand open for long periods of time. Garbage should be placed in tightly covered, heavy-gauge garbage cans and stored outside.

***Eliminating shelter and breeding sites:*** Shelter and breeding sites can be eliminated by sealing cracks and crevices to keep pests from entering the building, removing wood and paper debris from the yard or under houses in crawl spaces, removing standing water, maintaining relative humidity below 50% in all areas, and removing pet feces.

#### **Pest Management Outdoors**

Pesticide use can be reduced significantly by keeping grass, yard, and garden plants healthy. Healthy plants can be grown by planting new plants at the right time of the year to minimize the stress of transplantation; watering adequately, but not overwatering; and applying mulch to retain moisture, reduce weeds, and maintain even soil temperatures. If pests become well established in gardens, it may be necessary to apply pesticides judiciously according to instructions on the label. Only the minimum required for the job should be used. For example, instead of applying an herbicide to an entire lawn, weeds can be individually spot-sprayed. This can dramatically reduce the amount of pesticide that is applied.

A new industry is emerging to support and foster sustainable gardening and agriculture through integrated pest management which focuses on preventive cultural practices and nonchemical

controls. The careful selection of disease-resistant seed or plant varieties, using plant (crop) rotation and diversification, and ensuring good drainage and soil aeration are important cultural practices which can help prevent pest infestations. Other cultural strategies include using "trap" plantings to lure pests away from vulnerable plantings, planting companion plants which have insect-repellent properties, and spacing plants properly.

Nonchemical alternatives must be tailored to the individual pest and location of the problem. Biological controls include using beneficial birds, insects, and pathogens such as bacteria, viruses, and other microorganisms to limit the pest population (Exhibit 8-19). Other biological control methods include pheromones (sexual attractants which lure the pest to the trap), release of sterile males, and hormones to inhibit the growth of juvenile pests.

Physical controls can also effectively reduce pest populations. A simple, but effective measure for residential lawns and gardens is to handpick pests from gardens and flowers, and weeds from lawns and gardens. Some other examples of physical controls include traps to remove insects and rodents, vacuums to remove insects from crops, screening living spaces to limit mosquito and fly access, and the use of oils to prevent mosquito larvae from growing to adulthood.

Healthy lawns, gardens, or commercial crops can be achieved through the use of nonchemical controls. While nonchemical pest control generally requires more work, attention to timing of the application of methods, and a longer period of time for results, these methods do not pose a hazard to humans or pets. In addition, pesticide-resistant populations are not created, and special clothing and respirators are not required for application of pesticides.



**Exhibit 8-13. Sources of termiticide contamination and potential mitigation methods.****GENERAL**

- 1) Call the manufacturer for specific information about the appropriateness and likely success of a particular method, required personal protective equipment, cleaning agents, and other procedures.
- 2) Conduct air monitoring after mitigation to determine whether or not the method was successful.

**CRAWL SPACE**

- 1) contaminated crawl space
  - install vents if none exist
  - install fans to create a slight vacuum in the space; fans should be installed away from the furnace and ducts inside the space; air should be exhausted away from air conditioners, windows, and doors
  - remove contaminated soil; install a plastic vapor retarder over the soil surface and use untreated soil to seal the edges
  - correct site grade problems or install drainage tiles to divert excess soil moisture
  - pour a concrete slab at least two inches thick over the soil within the crawl space
- 2) termiticide enters through faulty ductwork
  - insure that any outside combustion air supply is not located in the crawl space
  - repair any cracks or openings in the duct work and seal joints with duct tape
  - seal or remove ductwork and install an attic ducting system

**INTRA-SLAB OR SUB-SLAB DUCTWORK**

- 1) termiticide enters through openings, crack, or deteriorated sections of the ductwork
  - install air filters at furnace intake ducts and at the floor vents; a qualified contractor should be used; activated charcoal filters or polyurethane foam (60 pores/in) can be tried; filters should be changed every two weeks initially and less frequently after odors are reduced
  - sleeve the ducts by inserting a new liner; a qualified contractor should be used

- plug all duct openings and seal with concrete at least 12 in on both sides of vent registers; install an above-floor duct system
- 2) termiticide has been injected into ductwork
    - for limited problem, remove affected section and replace with new ducting
    - for significant contamination, seal all duct openings with concrete; install an above-slab heating system

**FOUNDATION WALL SEEPAGE AND ODORS**

- 1) termiticide enters through cracks or openings in subflooring members above the foundation walls
  - seal all drilled application holes in foundation walls and pillars with concrete patching
  - cap hollow foundation blocks by filling the top row of blocks with expandable polyurethane foam or concrete; the tops can also be coated with roofing cement, followed by a strip of roofing paper on the cement; the roofing paper is held in place with a wood strip over the paper which is toenailed in place
- 2) termiticide seeps through hollow block or masonry wall and causes damp or wet surfaces
  - wash and rinse until the wall is clean; apply a commercial basement sealer when the wall is dry
  - install drainage tiles and a sump pump
  - correct surface grade
- 3) termiticide enters through cracks or openings in the hollow or masonry wall
  - cracks should be cleaned as above, sealed with a silicone-based caulk and painted over with polyurethane or silicone-based paint

**CONTAMINATION OF NON-TARGET SURFACES**

- 1) joists, piers, and other subflooring members are contaminated
  - wash the affected subflooring and rinse; repeat several several times
  - remove the affected areas and replace with new materials
- 2) insulation is contaminated
  - remove and install new insulation

SOURCE: Velsicol Chemical Corporation (undated); Velsicol Chemical Corporation (1984); Dow Chemical Corporation (1985)

### Exhibit 8-14. Pesticides that can be measured using low volume PUF sampling with GC/ECD.

#### ORGANOCHLORINE

Aldrin	Methoxychlor
p,p,-DDT	Mexacarbate
p,p,-DDE	Mirex
Dieldrin	trans-Nonachlor
Dicofol	Oxychlordan
2,4,5-Trichlorophenol	Pentachlorobenzene
Pentachlorophenol	Folpet
BHC (- and -hexachlorocyclohexanes)	Heptachlor
Captan	Heptachlor epoxide
Chlordane, technical	Hexachlorobenzene
Chlorothalonil	Lindane (-BHC)
2,4,-D esters	

#### ORGANOPHOSPHOROUS

#### UREAS

Chlorpyrifos	Chlortoluron
Diazinon	Diuron
Dichlorvos (DDVP)	Fluometuron
Ethylparathion	Linuron
Malathion	Tebuthiuron
Methyl parathion	
Ronnel	

#### CARBAMATES

#### TRIAZINE

Bendicarb	Atrazine
Carbaryl	Propazine
Carbofuran	Simazine
Mexacarbate	
Propoxur	

#### PYRETHRIN

Allethrin	Pyrethrin I
d-trans-Allethrin	Pyrethrin II
Dicorophos	Resmethrin
Fenvalerate	

SOURCE: U.S. EPA (1989b)

**Exhibit 8-15. Useful sources of information on pesticides.**

The following publications are available on request from EPA, Office of Pesticide Programs (TS-766C), 401 M Street, S.W., Washington, DC. 20450. Additional publications and sources of information are also available from EPA.

- *Pesticide Fact Book*. Brief summary of EPA pesticide regulatory program.
- *Labeling Fact Sheet*. Brief description of EPA requirements for the contents of a pesticide label.
- *Pesticide Safety Tips*. Suggested safety tips for consumers.
- *Suspended, cancelled, and restricted pesticides*. List of pesticides which are no longer available to the public.
- *Recognition and Management of Pesticide Poisoning*. Reference manual for health care professionals which categorizes pesticides according to toxicity, describes symptoms or signs of poisoning, gives information for confirming diagnosis, identifies antidotes.
- *List of Pesticide Fact Sheets*. Lists the different fact sheets that EPA has developed for specific pesticides.
- *Citizen's Guide to Pesticides*. Provides general and specific information on the safe use of pesticides and an overview of EPA's regulatory programs for pesticides.

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**Other Resources**

Bio-Integral Resource Center (BIRC)  
P.O. Box 7414  
Berkeley, CA 94707

BIRC publishes a journal, *Common Sense Pest Control Quarterly*, which focuses on the least toxic alternatives to pesticides and pamphlets on specific pesticide problems.

Natural Resources Defense Council  
Toxic Substances Information Line  
(1-800-648-6732)

NRDC has additional information on hazards of toxic substances.

Rachel Carson Council, Inc.  
8940 Jones Mill Road  
Chevy Chase, MD 20815

This organization has information about pesticides and lawns.

**Exhibit 8-16. Guidelines for using pesticides safely.****GENERAL PRECAUTIONS**

- Identify the pest to be controlled and select a pesticide which is effective on that pest; help can be obtained from county extension agents or supply houses.
- Select the least toxic product that has the required active ingredient—help can be obtained from your state agencies or EPA regional offices.
- Do not use restricted pesticides. These are especially dangerous and should only be used by a certified applicator.
- Make sure the product bears an EPA registration number.
- Look for the signal words on the front of the label and observe warnings:

**DANGER, POISON** (Skull & Crossbones) — “Fatal (poisonous) if inhaled.”  
“Do not breathe vapors.”

**WARNING** — “May be fatal if inhaled.” “Do not breathe vapors.”

**CAUTION** — “Harmful if inhaled.” “Avoid breathing vapors.”

**CAUTION** — (no additional signal words required)

- Read the entire label for correct application technique, timing of the application, precautions, and treatment measures. (Failure to use pesticides in accordance with label directions is subject to civil and/or criminal penalties.)
- Use with adequate ventilation.
- Use protective clothing and respirators as recommended. Paper masks, canvas, leather, and fabric do not provide protection. Information on protective equipment can be obtained from safety supply houses, local, or state agencies.
- Prepare only the amount needed for each application—do not use or store extra material.
- If the pesticide requires mixing or dilution, do this outdoors. Be sure that the product will not become airborne because of wind.
- Keep children and pets away from areas where pesticides are mixed, used, or stored.
- Never smoke while using pesticides. Some formulations are flammable and residues on the hands can be carried to the mouth.

**Exhibit 8-16. Guidelines for using pesticides safely (continued).****253**

- Do not transfer pesticides to containers, such as empty soft drink bottles, which were not intended for them.
- Do not store pesticides in living areas. Store outside living spaces, in the original containers, and in secure areas not subject to flooding.
- Shower and shampoo thoroughly after using a pesticide product. Wash all clothes that were worn separately from the family laundry. Also, rinse boots and shoes.
- Clean up spills promptly. *Do not* wash spills with water. Instead sprinkle with kitty litter, sawdust, or vermiculite; sweep into a plastic garbage bag; and dispose with the rest of the trash. Follow product instructions for further cleanup. In the absence of instructions, call the local or state poison control center.
- Triple rinse tools or equipment that have contacted the pesticide. This should be done in a toilet or sink taking care not to splash water.

**DISPOSAL**

- Follow label directions.
- Determine if local regulations allow pesticides to be disposed of with municipal waste. Strictly comply with local regulations.

In general, if local regulations allow the disposal of pesticides with municipal wastes, unused containers can be handled as follows: Be sure that container caps are tight, then wrap the containers or packages in several layers of newspapers and tie securely. Place the package into a covered trash can for collection along with household wastes.

- Empty pesticides containers are hazardous. Handle as above. Do not puncture pressurized containers.
- If there is no regular trash collection, crush and then bury *empty* containers at least 18 inches deep in a place away from water sources, where food is grown, or where children may play.
- Do *not* burn pesticide containers inside or outside of the home. Hazardous fumes, gases, or explosions could result.
- Do *not* pour unused portions of pesticides down the sink! Pesticides can interfere with the operation of septic systems and can contaminate waterways.

(continued next page)

**Exhibit 8-16. Guidelines for using pesticides safely (continued).****INDOOR APPLICATIONS**

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- Remove all food, dishes, utensils, food wrappings, pots and pans before treating kitchen cabinets. Do not let pesticides come in contact with these items. Wait until shelves are dry before refilling them.
- Make sure that adequate ventilation is provided when applying pesticides indoors. This means fresh outdoor air! Vacate the house for at least the length of time given by the label.
- If pesticides are sprayed outdoors, close the doors and windows of the home and keep them closed for several hours after spraying. Fresh air intakes should be closed.
- Apply surface sprays only to limited areas. Do not treat entire walls, floors, or ceilings. Be sure to remove pets and cover aquaria and fishbowls.

**254****OUTDOOR APPLICATIONS**

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- Never spray or dust on windy days.
- Do not use spray nozzles that deliver a fine mist; a coarse droplet spray is less hazardous.
- When spraying or dusting outdoors cover fish ponds and avoid wells.
- Do not spray nontarget plants; use only the smallest amount of pesticides needed to do the job. Overspraying can contaminate water supplies and leave harmful residues on home-grown produce.
- Do not spray plants which are in bloom.

**PERSONAL APPLICATIONS**

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- Do not use sprays or lotions on infants or toddlers. Use of these products on small children can result in health problems, and the long term health effects are not known. Use these products cautiously on older children. Do not use these products routinely. Do not use pesticides on pets which are kept indoors.

**LOCAL EMERGENCY TELEPHONE NUMBERS**

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Poison Control Center:

Physician:

*SOURCE:* Adapted from U.S. EPA (1987)

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**Exhibit 8-17. First aid guidelines for pesticide poisonings.****GENERAL GUIDELINES**

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- Avoid direct contact with heavily contaminated clothing, gloves, or bodily excretions.
- Give first aid, if it can be rendered without contaminating the responder.
- Call for immediate emergency aid or transport the victim to a medical facility.
- Provide accurate information to medical personnel. Do not rely on memory. Bring pesticide containers (with labels attached) with the victim. Do not transport pesticide containers in the passenger space. Transport containers in the trunk of the vehicle. If medical help is coming, have the pesticide container available.
- Determine appropriate actions from the "Statement of Treatment" on the container if it is available. If the container is not available, contact a poison control center, emergency room, or the National Pesticide Telecommunications Network (1-800-858-7378).

**255****DERMAL OR EYE CONTACT**

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- For skin or eye contact, flood with water and remove contaminated clothing. Wash affected skin and hair with soap and water. Wear rubber gloves to prevent secondary contamination. Dry and wrap the victim until medical assistance arrives.
- Do not administer ointments, drugs, eye drops, or other preparations.

**INHALATION**

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- Do not attempt rescues in contaminated areas unless protective clothing, respirators, and a "buddy" are available. Call for emergency assistance instead.
- If the area is not contaminated, move the victim to fresh air immediately.
- Loosen clothing and give CPR if the victim is blue or is not breathing.

**INGESTION**

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- If the victim is unconscious, be sure that no further exposure will occur via skin contact or inhalation. Get emergency aid *immediately*. Do not attempt to induce vomiting if the victim is unconscious or has convulsions.
- A conscious victim should rinse his/her mouth with plenty of water and drink up to one quart of milk. Emergency help should be called and information should be obtained to determine if vomiting should be induced. Vomiting should not be induced if the poison is corrosive, an oil solution, or an emulsifiable concentrate.
- Aspiration of vomitus into the lungs is a potentially life-threatening situation, and the victim should be monitored carefully to prevent this possibility.

SOURCE: Morgan (1989); U.S. EPA (1987)

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## Exhibit 8-18. Guidelines for cleaning pesticide spills and residues<sup>a</sup>.

### 1) STOP THE SOURCE

- Stop leaking application rods by shutting off the pump and releasing hose pressure. Place the leaking rod into a waste container.
- Right containers only if it can be done without contamination or if protective equipment is available.

### 2) CONTAIN THE PESTICIDE AND SECURE THE AREA

- Prevent spilled liquids from spreading by adsorbing with spill control pillows, paper towels, and cat litter. (Cat litter that contains bleach can cause stains in some materials).
- Prevent people and pets from entering the area until the cleanup has been completed and determined to be successful.

### 3) REMOVE EXCESS PESTICIDE

- Soak up excess liquid with commercial spill control material, cat litter, paper towels, sawdust, or soil. Approach the spill from the outer edges and work toward the center. Sweep the contaminated material into heavy duty plastic bags.
- Sweep solid pesticides into plastic bags.

### 4) CLEAN UP THE AREA

- Large areas or the cleanup of liquid pesticides which have dried onto porous surfaces such as unfinished concrete or wood flooring require expert assistance.
- Small areas should be washed using a soft bristle brush and heavy-duty detergent followed by rinsing with clean water. Used detergent and rinse water should be removed to a separate container before washing and rinsing again.

### 5) VENTILATE THE AREA

- Ventilate the area after the cleanup has been completed by opening doors and windows for several hours or more depending on the extent of the spill.

### 6) REMOVE PESTICIDE RESIDUES

- Minimize pesticide residues on unfinished wood or concrete by applying two coats of sealant after the area has been washed and rinsed. If large areas are involved, the material should be removed. Sealants which seem to be effective include polyurethane and epoxy. Latex paints should not be used.
- Washing will remove small spills of pesticides from most vinyl flooring. If the pesticide penetrates beneath the tile, the tile and the underlying floor should be removed and replaced. In some instances it may be possible to simply wash and rinse the underlayment and replace only the floor tile.
- If a pesticide is spilled or sprayed on carpeting or padding, they should be removed and replaced. Steam cleaning should not be used.
- Plaster walls and other porous wall surfaces should be washed and rinsed to remove residues. If large areas are affected, removal is necessary.
- Clothing should be washed separately using hot water and the maximum wash time. Presoaking and repeat washings may be needed. In the case of small spills, it may be possible to professionally clean drapery and upholstered furniture (the cleaning company should be informed of the pesticide residue). If the affected area is large or if the pesticide has penetrated into batting materials, disposal is needed. Other household goods such as dishes, silverware, and appliances can be washed and rinsed to remove residues.

### 7) DISPOSE OF WASTE MATERIALS

- Dispose of waste according to local, state, and federal regulations:

### 8) POST CLEANUP EVALUATION

- Evaluate the effectiveness of cleanup procedures by monitoring the air.

<sup>a</sup>No action should be attempted without proper protective equipment and clothing.



**Exhibit 8-19. Examples of biological control of pesticides.**

BENEFICIAL ORGANISM	TARGET PEST
ladybugs	aphids, mites, and other soft bodied pests
predatory mites	spider mites, greenhouse mites
lacewing larvae	aphids, mealybugs, leafhopper nymphs, mites, caterpillar eggs, thrips, scales
<i>Trichogramma pretiosum</i> / <i>Trichogramma minutum</i> (wasps which will not bother humans)	eggs of corn borer, cabbage looper, cutworm, codling moth, budmoth, leafroller, and many caterpillars
<i>Encarsia formosa</i>	whiteflies
<i>Cryptolaemus</i>	mealybugs
<i>Pediobius foveolatus</i> (wasps)	Mexican bean beetles
<i>Bacillus thuringiensis</i> (bacteria)	cabbage looper, imported cabbage worm, tomato hornworm, diamond-back moth, gypsy moth, fruit maggots, cotton bollworm, tent caterpillars
<i>Bacillus thuringiensis israelensis</i> (bacteria)	mosquito, blackfly midges
<i>Nosema locustae</i> (disease spore)	grasshoppers
Milky Spore Disease	Japanese beetle grubs

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## 8.4. INVESTIGATION TECHNIQUES FOR FORMALDEHYDE AND OTHER VOLATILE ORGANIC COMPOUNDS

### Investigation Techniques for Formaldehyde (HCHO)

Any new or recently remodeled home or office area can be a potential source of HCHO. Although there has been a shift away from particleboard/plywood construction in manufactured homes (mobile homes), these homes may still have HCHO concentrations which are of concern. The age of the structure or time since remodeling is important information because HCHO emissions are known to decrease over time. The emission rate appears to decrease rapidly (probably due to the release of free HCHO) just after manufacturing of the HCHO-containing product. The rate then decreases more slowly over a period of months or years.

Several monitoring and modeling studies have been conducted in an attempt to determine the decay rate of HCHO. In general estimates range from a half-life of several months to over 5 years. Indoor concentrations of HCHO from urea formaldehyde foam insulation (UFFI) and other urea-HCHO products depend on changes in ventilation rate, the operation of air cleaners, indoor and outdoor temperatures, and humidity. The rate of release of HCHO from UFFI and other urea-HCHO products increases with the temperature, wood moisture content, humidity of the surrounding air, and with decreased HCHO concentrations in the surrounding air (Fisk et al., 1987). HCHO also demonstrates diurnal and seasonal variations. HCHO concentrations vary by as much as 50% throughout the day and are higher during the summer than during the winter (Gammage and Gupta, 1989).

CPSC staff reviewed data for HCHO emissions from particleboard and concluded that a rapid decrease in HCHO concentration occurs during the first year followed by a "semi-steady" emission rate for at least the next four years (CPSC, 1986). CPSC staff concluded that there were insufficient data to

evaluate the decay rates of HCHO after five years. HCHO in mobile homes has been reported to have a half-life of about 4-5 years (Cohn et al., 1984).

One of the first activities in the investigation of potential HCHO problems is identifying possible HCHO-releasing materials, the age of these materials, and time periods when symptoms appear to get worse or better. Because HCHO levels can vary diurnally, it is important to characterize adequately when and where symptoms occur along with occupant activities so that sampling will identify worst-case exposures. It should be remembered that susceptibility to HCHO varies widely—it is possible for some family members to experience effects daily, while others are not affected at all. Symptoms can vary from person to person, and usually no one has all symptoms.

### **Recognizing Formaldehyde-containing Materials**

The most likely sources of HCHO (pressed wood, particleboard, hardwood plywood, and UFFI) can be recognized visually in many instances. Other sources which can contribute to elevated indoor concentrations and health effects are more difficult to recognize visually, and a process of elimination may be required to evaluate their impacts.

In new homes the most likely sources of HCHO are those which contain pressed wood or particleboard. CPSC staff estimated that about 24% of new single-family detached house construction uses some type of urea-HCHO pressed wood material (CPSC, 1986). In new single-family detached homes, particleboard may be used as underlayment over a softwood plywood (not a urea formaldehyde resin product). The particleboard underlayment might be used throughout the entire house or only in the kitchen and bathrooms. The underlayment may be covered by carpeting, carpet padding, ceramic tile, resilient flooring, and solid hardwood coverings which generally reduce emissions into the living space, but higher levels of HCHO can still occur.

The presence of particleboard underlayment can be confirmed by lifting the floor covering to expose the material underneath (this should be done in an inconspicuous area). If the home has floor registers, these can be removed and the wood material can be inspected.

Waferboard and oriented-strand board can also be present as subflooring material. These products use phenol-HCHO as the bonding material and do not produce significant HCHO emissions. Waferboard and oriented-strand board are characterized by large wood flakes in contrast to particleboard which is produced from small flakes.

Cabinets and furniture made of wood products can be additional sources of HCHO. Today's kitchen, bathroom, and other "wood" cabinets are typically made of wood products—not solid wood. Even top grade products advertised as solid wood usually have medium density fiberboard (MDF) shelves covered by hardwood plywood. In top grade cabinets, wood products are used as shelving because solid wood is more likely to warp when in contact with moisture. These products may have an alkyd urea-HCHO finish. Less expensive cabinets usually have a core of MDF which is covered by hardwood plywood, vinyl, or a paper overlay. Exterior doors of this product grade are usually solid wood or hardwood plywood. The least expensive grades of cabinets usually have all parts made of MDF covered by vinyl or paper overlay.

Lower grades of furniture are typically constructed from particleboard or MDF with a paper overlay; some components may be plastic. Medium to higher grade furniture might be constructed of particleboard or MDF with an overlay of hardwood veneers. The particleboard or MDF components can usually be identified by examining unfinished exposed areas such as the underside of tables, chairs, or other pieces. All grades of furniture and some hardwood floors may be finished with alkyd urea-HCHO finishes which can increase indoor HCHO levels.

Another important source of HCHO indoors is urea formaldehyde foam insulation (UFFI); homes insulated with UFFI can be recognized by sealed openings in the exterior siding which were used to inject the UFFI. This clue can, on occasion, be misleading because cellulose insulation is also blown into similar openings. Another problem is that openings may not be visible if the exterior siding was replaced.

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If openings are present, a screwdriver or similar tool can be used to lift the opening cap or mortar and inspect the material underneath. UFFI may be present if the material is soft, spongy to granular in texture, and white to brown in color. If exterior openings are not visible, the presence of UFFI can be evaluated by removing and inspecting electrical outlets which are located on exterior walls. Studies of the release of HCHO from UFFI products show that even if UFFI is installed under optimum conditions, the products can still emit significant HCHO and interior levels of HCHO can be elevated for long periods of time.

In the past, manufactured housing had HCHO levels that were significantly higher than conventional housing. This was due to the greater use of HCHO-emitting materials in construction and the high surface to volume ratio of these homes. In an effort to reduce HCHO levels, construction techniques have shifted to include the use of gypsum-board panels rather than plywood paneling. However, manufactured housing is still constructed with particleboard decking, and the cabinets and furniture in these homes are still likely to be made of particleboard, hardwood plywood, or MDF.

### Measuring Formaldehyde

There are many different methods available for measuring HCHO concentrations including personal and stationary methods and active and passive methods. Evaluations of some of these methods are given in Wallace and Ott (1981), Kennedy *et al.* (1985a, b), and Godish (1985).

Both automated and nonautomated measurement systems can be purchased ranging in price from several hundred dollars for nonautomated systems to over \$5000 for a fully automated system. The continuous monitors allow longer term real-time measurements to be made, but their usefulness for routine residential monitoring is limited by the time required for instrument stabilization and standardization.

Regardless of which method is used, it is important to use standardized conditions during testing. Closed house conditions should be observed for short-term samples (1/2 to 1 hour); this means that doors and windows should be kept closed for about 12 hours prior to testing. Temperatures before and during sampling should be at about 23-25°C (73°-77°F), if possible.

Because of the seasonal differences in the release of HCHO, it has been recommended that sampling should not be conducted during the winter months, from December to March (Godish, 1985). As a practical matter, if an individual appears to have symptoms related to HCHO then sampling should be conducted regardless of the season, recognizing that it may have to be repeated at a later time.

Since HCHO concentrations vary diurnally, measurements should be taken during the times of the day when, and in locations where, symptoms appear to be worse. It may be necessary to sample more than once or to collect samples over a longer period of time in order to sufficiently characterize the environment, but for most sampling a single set of two samples will be sufficient. Samples should be collected at the breathing height and away from drafts and impediments to airflow. Outside walls should be avoided, and samplers should be located 6 inches to 12 inches away from inside walls. Locations near sources of heat should be avoided. A rigorous quality assurance program should be maintained throughout sample collection and analysis.

After the samples have been collected, instructions given in the method for storage, transport, and time to analysis should be followed strictly. Some methods require refrigeration of the collecting medium and collected samples.

Regardless of the sampling method which is used, the outdoor and indoor temperatures, barometric pressure, and indoor relative humidity should be measured and recorded. Godish and Rouch (1985) have recommended standardizing measured HCHO concentrations to a temperature of 25°C and relative humidity of 60% RH using the Berge equation:

$$C_x = C[1 + A(H - H_o)e^{-R(1/T - 1/T_o)}]^{-1}$$

where,

$C_x$  = standardized concentration (ppm),

$C$  = measured concentration (ppm),

$R$  = temperature constant (9799),

$T$  = measured indoor temperature (°K),

$T_o$  = standardized indoor temperature (°K),

$A$  = humidity constant,

$H$  = measured indoor relative humidity (%), and

$H_o$  = standardized relative humidity (%).

#### Active Methods

##### *EPA's Method IP-6A (DNPH HPLC Method):*

This method utilizes solid adsorbent sampling followed by high performance liquid chromatographic analysis (HPLC) (U.S. EPA, 1989). HCHO gas (and other aldehydes or carbonyl compounds) is adsorbed onto acidified DNPH (2,4-dinitrophenylhydrazine)-coated silica gel cartridges to form a stable derivative. Commercial cartridges are

available, but random samples from each lot should be analyzed to determine background levels of HCHO.

Samples can be collected at a rate of 500-1200 ml/min. Samples should be refrigerated after collection, and they can be stored for not more than 90 days. The precision of field replicates should be  $\pm 20\%$  or better, and replicate HPLC injections should have a precision of  $\pm 10\%$  or better.

This sampling procedure requires a moderate degree of skill and training; the analysis requires a highly skilled person who is proficient in HPLC techniques.

##### *EPA's Method IP-6B (Automated Colorimetric Method):*

This method utilizes a commercially available continuous colorimetric gas analyzer (Model TGM-555-FD) manufactured by CEA Instruments, Inc. or its equivalent (U.S. EPA, 1989). The method of analysis is based on the HCHO selective pararosaniline method in which HCHO is absorbed into sodium tetrachloromercurate (II) solution containing a fixed amount of sulfur dioxide. Acid bleached pararosaniline is added to form a purple dye. The concentration of HCHO is proportional to the intensity of the dye. This method has been modified (Model TGM-155-D analyzer) to eliminate the toxic mercury reagents.

The instrument can be calibrated using liquid formaldehyde standards or certified permeation tubes. If permeation tubes are used, alpha-polyoxymethylene is recommended rather than paraformaldehyde because the paraformaldehyde tubes are unstable and lack reproducibility.

This instrument has a range of 0-5 ppm in the standard range and 0-250 ppm in the low level range. The accuracy is  $\pm 3\%$  referenced to the chromotropic acid procedure; the reproducibility is 1%; and the minimum detection limit is 0.003 ppm at 0 to 0.25 ppm full scale. It has an optimum temperature range of 60°F to 80°F and a relative humidity range of 5% to 95%.

Advantages of this instrument are that it is portable, provides real time measurements, and has a practical detection limit of about 0.02 ppm. Disadvantages include cost (about \$6000), and the need for personnel with the expertise to operate the instrument and conduct the required calibrations.

**Modified NIOSH Method P&CAM 125 (Chromotropic Acid Method):** The chromotropic acid procedure (NIOSH, 1977) utilizes midget impingers to collect HCHO into an absorbing solution. Modification of the method to use 1% sodium bisulfite rather than distilled water as the absorbing solution increases the collection efficiency to 98% and eliminates the need for a second impinger for sample collection (Meadows and Rusch, 1983).

HCHO reacts with chromotropic acid-sulfuric acid solution to form a purple-colored complex which is read in a spectrophotometer at 580 nm. Samples are typically collected at a flow rate of 1 lpm for 30 minutes to 1 hour. This method has a sensitivity of 0.16 ppm for 15 minute samples and 0.04 ppm for 1 hour or longer samples.

A relatively simple, portable active sampling system can be built using readily available equipment (sampling pump, critical orifice, sampling impinger, trap impinger, tubing) for about \$150. Commercially available sampling systems cost \$500 to \$800.

This method has been widely used in both residential and nonresidential sampling. Advantages are that it is a relatively simple technique which utilizes equipment that is readily available. A moderate degree of training is needed for the sampling and analytical techniques. Disadvantages are that confidence decreases significantly below 0.10 ppm and that concentrated sulfuric acid is used in the analysis. It should not be used in situations where phenol may be present.

**Modified Pararosaniline Method:** One of the most sensitive methods available is the Lawrence Berkeley

Laboratory (LBL) pararosaniline method (Miksch *et al.*, 1981). This method utilizes midget impingers for sample collection and spectrophotometry for analysis. HCHO reacts with pararosaniline in the presence of sodium sulfite to produce a colored product which is read at 570 nm. The method has a sensitivity of 0.01 ppm and is not subject to interferences from nitrate, nitrite, phenol, ethanol, or higher molecular weight alcohols. Other advantages of the method are that toxic mercury compounds are not required, and it is more sensitive and more reproducible than the chromotropic acid procedure. A disadvantage is that refrigeration is required during collection and storage.

### Passive Methods

Passive personal collectors are available in which HCHO diffuses through a tube onto a treated filter, onto an impregnated media, or into a liquid sorbent. Sample collection is relatively easy in all of these methods, but the analytical methods require moderate to high skill levels. Exhibit 8-20 summarizes some of the available methods. If monitors are returned to the manufacturer for analysis, the cost is typically \$15 to \$30 for the monitor plus analysis. Lower detectable limits range from 0.005 ppm to 0.01 ppm for a 1 week exposure; shorter sampling times result in decreased sensitivity (typically, 0.1 ppm to 0.3 ppm for 8 hours and 0.7 ppm to 8 ppm for 15 minute samples).

Care must be taken to ensure proper detection limits for the proposed application and proper placement of the samplers. Another problem with these monitors is lack of reliability and cost for routine monitoring programs.

**EPA's Method IP-6C (Passive DNPH HPLC Method):** This method utilizes a passive sampler which consists of DNPH-impregnated glass fiber filters which are placed behind diffusion screens and sandwiched between two protective caps (U.S. EPA, 1989). The size of the completed sampler is 1.5 inches in diameter and 0.5 inches in depth. HCHO and other aldehydes diffuse to the sampler and react

with the DNPH treated filters to form a stable DNPH derivative.

Precision for field replicates should be better than  $\pm 20\%$ , and HPLC replicates should have a precision of  $\pm 10\%$  or better. Advantages of this method include the small size of the sampler, no noise, low unit cost, and the ability of unskilled personnel to place and retrieve the samplers. The major disadvantage of this method is the sophistication of the analysis which requires highly trained personnel.

**MBTH Bubbler Method:** The MBTH passive bubbler method has been designated as a standard test method for HCHO by the American Society of Testing and Materials (ASTM, 1990). This method utilizes the Passive Bubbler™ which consists of a glass vial with a septum cap that retains a Knudsen disk. The vial, which contains an aqueous solution of 3-methyl-2-benzothiazolinone hydrazone hydrochloride (MBTH), is inverted for sampling. HCHO diffuses through the Knudsen disk at a constant rate. After collection, a solution of ferric chloride-sulfamic acid is added to form a derivative which is measured in a spectrophotometer at 628 nm. This method allows HCHO to be measured in the range of 0.025 ppm to 14 ppm for sampling times between 15 minutes and 8 hours. A four-hour sampling time is recommended to measure HCHO concentrations in the range of 0.05 to 1 ppm.

A major advantage of this method is that laboratory support is not needed. Kits can be purchased which contain a mini-spectrophotometer and all needed reagents.

## Interpretation of Formaldehyde Data

Both workplace and residential standards and guidelines have been recommended and promulgated for HCHO. These standards and guidelines are based primarily on the irritant effects of HCHO.

In 1984 the WHO Working Group on Indoor Air Quality Research (WHO, 1986) identified  $<0.06$  ppm as a consensus concentration of limited or no

concern and  $>0.12$  ppm as a consensus concentration of concern for both long-term and short-term exposures.

The Canadian exposure guidelines identify 0.05 ppm as the long-term target level and 0.10 ppm as action level for long-term exposure (Environmental Health Directorate, 1987).

The U.S. Department of Housing and Urban Development established a product standard for HCHO emissions from particleboard and hardwood plywood paneling used in manufactured housing (U.S. HUD, 1984). This standard limits the emissions of HCHO as measured by a specific air chamber test to no more than 0.3 ppm from particleboard floor decking and no more than 0.2 ppm from interior plywood. Although HUD did not establish an ambient standard, the intent of the emissions standards is to limit ambient HCHO concentrations to less than 0.4 ppm. HUD recognized that sensitive subgroups of the population would react to lower levels, and the regulations require posting of health notices in the home and in consumer manuals to alert potential buyers to this risk.

Exhibit 8-21 shows a dose-effect relationship between HCHO concentration and reports of irritation effects in a study of nearly 2000 residents living in 397 mobile homes and 494 conventional homes (Ritchie and Lehen, 1987). The results of this larger-scale study support the conclusions of the WHO Working Group that concentrations greater than 0.1 ppm may cause adverse reactions in some people and may require corrective action.

Standards or guidelines should not be the sole basis for determining whether a given low-level concentration might result in irritant health effects for two reasons. First, there is considerable variability in response to exposure to HCHO. Although it appears that 0.1 ppm is a concentration of concern, some individuals may be affected at lower HCHO concentrations. Second, existing standards are not based on the carcinogenic potential of HCHO.

Each case must be considered individually based on the symptoms that are presented. Even though occupants report no symptoms, they should be encouraged to reduce their exposures, if possible, because of HCHO's potential role as a carcinogen.

## Mitigation Advice for Formaldehyde

### Manufacturers' Strategies

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Manufacturers can reduce HCHO emissions by improving quality control during the manufacture of pressed wood products or the installation of UFFI. In addition, the use of alternative resins (phenol-HCHO, methyl diisocyanates, lignosulfonates), resin modifications, processing changes to condition the product (increasing temperature or curing time) (Fisk *et al.*, 1987). The substitution of alternative resins, however, for urea-HCHO resins may pose other health problems. For example, interior grade products which are made of diisocyanate resins pose a potential health risk because diisocyanate is a potent sensitizing agent. Another problem with products using diisocyanate resins is the potential formation of hydrogen cyanide under fire conditions.

### Consumers' Strategies

Consumers can minimize their exposures to HCHO by not purchasing potential HCHO-emitting products such as UFFI and those made of urea-HCHO resins and urea-HCHO wood finishes. Although the use of UFFI has diminished in the U.S., it is still available. It is also used to insulate concrete blocks and panels which are used to construct nonresidential structures. There is some concern that as UFFI ages and deteriorates, HCHO and particulates with irritant properties could be released into the indoor air (Fisk, *et al.*, 1987). Fiberglass batts and cellulose are possible substitutes for UFFI. Cellulose, however, settles in sidewall applications which reduces its effectiveness.

Products made of particleboard, hardwood plywood, and MDF should be avoided unless they have a barrier which covers any exposed surfaces. Acceptable substitutes are products made of solid wood, metal, plastic, or other material that does not emit HCHO. Another strategy is to limit HCHO-emitting products to small areas.

Because HCHO is released from its sources over a period of time, time itself, is a way of reducing HCHO concentrations. Additional storage of HCHO-emitting materials such as particleboard prior to use could decrease initial HCHO indoor concentrations, but this is not generally practical once consumers have purchased products. HCHO decay rates (and half-life) will vary depending on the product and its environment. If occupants are experiencing symptoms, allowing additional time for decay is not an effective strategy.

### Coatings and Barriers

Both manufacturers and consumers can apply coatings and barriers to pressed wood products (or to MDF or hardwood plywood) to reduce emissions. These act in one of three ways: 1) by preventing the release of HCHO, 2) by preventing the transport of moisture into the board, or 3) by the reaction of scavenger chemicals with HCHO.

Coatings are most effective on products such as particleboard shelving, subflooring and decking, and unfinished surfaces such as joints, edges, and undersides of cabinets or countertops. Coatings which have been reported to be moderately effective include polyurethane and lacquer (Fisk *et al.*, 1987). Standard latex paints are not reported to be effective, but some other paints may be effective. For maximum effectiveness, several coats should be applied and all exposed edges should be coated.

Other barriers which are reported to have varying effectiveness include melamine-impregnated paper, acid curing lacquers, decorative laminates, veneers,



polyacrylamide, vinyl wallpaper, vinyl carpet, vinyl flooring, and a paint with HCHO-reactive chemicals (Fisk *et al.*, 1987). When consumers apply any of these barriers, care should be taken to cover all exposed edges. It should be noted that many of these materials can release other volatile organic compounds.

### Environmental Strategies

Using environmental factors to control HCHO (and other volatile organic compounds) has been reported by several investigators (Andersen *et al.*, 1975; Godish and Rouch, 1986). Exhibit 8-22 shows measured decreases in HCHO concentrations as a function of temperature and relative humidity. A disadvantage of reducing temperature and relative humidity to control HCHO might be energy penalties of about 20-30% depending on the season. Also, even if dehumidification were used to slow the rate of HCHO emission, the total amount of HCHO released over time might remain the same (Fisk *et al.*, 1987).

Residential dehumidifiers, increased ventilation with less humid outdoor air, and local ventilation near humidity sources (bathroom, kitchen) are dehumidification methods which might reduce HCHO concentrations. Fisk *et al.* report that dehumidification alone or in combination with other methods may be effective in reducing small increases in HCHO concentrations caused by infiltration from house tightening.

### Other Strategies

Laboratory data suggest that adsorbents and absorbents have some potential to remove HCHO from nonindustrial indoor air, but there is limited field data to evaluate these techniques.

In some instances, HCHO-emitting products will require removal. Caution must be used when multiple sources are present because there is a possibility that removal of only one major source might result in only marginal decreases in HCHO

concentrations. All major sources may require removal in order to provide the greatest decrease in HCHO concentration. In the case of UFFI removal, the National Research Council of Canada (Bowen, *et al.*, 1981) recommends treating wall cavities with a 3% solution of sodium bisulfite after removal. This treatment prevents HCHO release from urea-HCHO resin which might remain in gypsum board, wall studs, and other surfaces.

Ammonia fumigation has been identified as a post-installation treatment for HCHO in residences (Fisk *et al.*, 1987). Application methods have included setting out pans of ammonium hydroxide, spraying ammonium hydroxide, and releasing gaseous ammonia. These methods have not been verified for different situations. The treated house cannot be used during treatment and for several weeks after treatment, and an irritating ammonia odor can remain for as long as several months after treatment (Muratzky, 1987).

### Investigation Techniques for Volatile Organic Compounds (VOCs) Other Than Formaldehyde

VOCs should be considered as a source of health complaints whenever there are sensitization reactions or symptoms typical of sick building syndrome (typically, irritation of nose, throat, eyes; fatigue; nausea; difficulty concentrating; skin irritation; headache; and dizziness).

The investigation of these symptoms should focus on the characterization of health effects and identification of potential sources which could contribute to those effects. Any recent changes in household or workplace environments should be evaluated carefully to identify the potential presence of VOCs. Any new home or office building is a potential source of hundreds of VOCs which are emitted by wood products, plastics, solvents, glues and adhesives, fillers, dyed fibers, and floor and wall coverings. If occupants in a new building complain of odors or symptoms, the building should be evalu-

ated for sources of VOCs and adequate ventilation. Suspect materials in any home or office include new carpeting, paint, furnishings, wallpaper, and vinyl flooring. Recently dry-cleaned clothing or upholstery and activities such as smoking tobacco products and the recent use of pesticides, solvents and solvent-based cleaners, caulks, glues or adhesives, or paints and related supplies are also suspect. In addition, any changes in brands of products such as personal care products or cleaning products may be suspect. In the office environment, the use of copiers, spirit duplicators, and other equipment which might release VOCs can also be suspect.

In many instances, the sources can be identified and various strategies can be employed in an attempt to reduce emissions and eliminate symptoms. For example, shortly after the carpeting in a home was replaced, the eyes of one of the children in the home became irritated and somewhat swollen. When the child left the home, the irritation and swelling improved, but the symptoms became worse when the child returned to the home. This scenario suggests that the carpeting (dyes or adhesives) may be responsible for the child's condition. This is a relatively simple and straightforward example; in other instances there may be so many potential sources that a health effects or building systems questionnaire alone may not be able to identify sources.

### Measuring Volatile Organic Compounds (Other Than Formaldehyde)

Extensive sampling and analysis of VOCs may not be possible or practical for most investigations for several reasons. There are many potential organic compounds in the indoor environment, and these compounds are generally present in very low concentrations. There is a general lack of data that relates low level exposures to health effects, and there is considerably variability in the response to exposure to VOCs and other contaminants. Finally, the measurement of VOCs and other organic compounds is complicated and expensive.

However, sampling may be needed in situations where sources cannot be identified easily or in situations where a physician recommends identifying specific contaminants.

If sampling is conducted, portable VOC detectors might be useful in determining if VOCs are present or identifying potential sources, but these devices may not be sensitive enough to detect very low concentrations which might affect some individuals.

Methods for sampling VOCs must be capable of measuring concentrations in the ppb-ppt range. These methods include both passive and active methods, methods which are direct reading, and those which require laboratory analysis. An additional review of analytical methods for VOCs in indoor air is given by Sheldon *et al.* (1985).

EPA has developed guidelines for two methods which are based on either the collection of whole air samples in SUMMA<sup>R</sup> passivated stainless steel canisters or collection on solid adsorbent tubes (U.S. EPA, 1989).

**Method 1P-1A (Collection Using Stainless Steel Canisters):** This method utilizes passivated stainless steel canisters (chemically treated to form an inert chrome-nickel oxide on the inner surface) under subatmospheric pressure or pressurized sampling modes to collect the sample. The collected gases must be transported to a laboratory for analysis.

At the laboratory the contents of the canister are concentrated, separated by a gas chromatograph (GC), and analyzed by one or more detectors. Possible detectors for the high resolution gas chromatograph include specific detectors such as the mass spectrometer (MS) in the selected ion monitoring (SIM) mode or the SCAN mode or ion trap detector. Nonspecific detectors such as the flame ionization detector (FID), electron capture detector (ECD), nitrogen-phosphorous detector (NPD) and the photoionization detector (PID) can also be used.

Exhibit 8-23 summarizes some of the advantages and disadvantages of different systems. The selection of the most appropriate detector depends on many variables including the type of compounds to be identified, budget, required detection limits, potential interferences, project objectives, equipment, and personnel capability.

The precision, accuracy, sensitivity, and potential interferences will vary depending on the compound of interest. EPA will provide at *no charge* some cylinder gas standards which are traceable to NIST.

Advantages of this method include the ability to identify and quantify a variety of VOCs and SVOCs at very low levels (ppb-ppt range). The primary disadvantages include the cost of analysis by an outside laboratory (about \$200/sample) or developing in-house analytical capability, the high level of skill required by analytical personnel, and the caution needed to prevent accidental contamination or loss of samples.

Method 1P-1A also contains operating procedures for a portable gas chromatograph equipped with a photoionization detector. This method is intended to provide qualitative information on the presence and intensity of unknown volatile compounds which assists in the placement of fixed-site samplers. Exhibit 8-24 contains a summary of commercially available portable VOC detection instruments.

**Solid Sorbents:** Solid sorbents are the most commonly used materials for collecting vapor phase organics. Once the samplers are prepared they can be deployed and collected easily which makes them useful in large-scale surveys. Samplers must be returned to the laboratory for analysis by GC/MS or GC combined with nonspecific detectors (FID, ECD, NPD). The collection of vapor phase organics by solid sorbents involves three basic steps: collection on the sorbent, desorption of organics from the sorbent, and analysis of the desorbed organics.

Solid adsorbents have several limitations which include:

- formation of artifacts on some adsorbents, especially Tenax<sup>®</sup> in the presence of NO<sub>x</sub>;
- extensive cleanup and thermal conditioning is required to ensure contaminant-free cartridges; cartridges must be carefully handled, shipped, and stored to prevent contamination prior to and after sampling;
- breakthrough volumes of certain compounds are very small on some resins sorbents which prevents quantitative results; and
- irreversible adsorption may occur onto charcoal which decreases the recovery of the analyte (U.S. EPA, 1989).

In spite of these limitations, adsorption onto solid sorbents has several advantages including the small size of the samplers, portability of the sampling devices, ease of use, and the ability to collect integrated samples over periods of 8 hours to 12 hours.

Exhibit 8-25 summarizes some of the characteristics of different collection methods. Either thermal or solvent desorption techniques can be used to desorb the organics from the sorbent. The preferred method of analysis for polymeric resins which adsorb through thermal desorption is GC/MS because it provides broad spectrum analysis as well as identification of target compounds. Solvent desorption can limit the analysis of low molecular weight organics because of interferences from the solvent and the overall sensitivity of the analysis compared to thermal desorption because only a fraction of the sample (1/100 or 1/500) is used for the analysis.

**Method 1P-1B (Adsorption using Tenax<sup>®</sup>):**

Method 1P-1B utilizes solid adsorbent tubes containing 1-2g of Tenax<sup>®</sup> to capture a variety of VOCs. The cartridges are stored under refrigeration until analysis when the organics are thermally desorbed, collected into a cryogenic trap, and analyzed by a GC/MS data system.

The analytical finish is the same as for Method IP-1A. The precision and accuracy of the method will vary depending on the contaminant of interest and factors such as breakthrough volumes, background contamination of the cartridges, and factors related to the analytical instrument and skill of the analyst.

### **Interpretation of Volatile Organic Compounds Data**

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There are limited standards and guidelines for evaluating exposures to VOCs (Exhibit 7-1, Section 7 contains a summary of some existing standards and guidelines; Exhibit 3-3, Section 3 contains a summary of EPA risk assessments; and Section 8.3 contains guidelines for some pesticides). The use of OSHA, NIOSH, and ACGIH standards and guidelines do not provide adequate protection to the general public, and their use in nonindustrial environments is not appropriate.

Because of the inherent variability in response to VOCs and other organics, guidelines should not be the sole basis of determining whether a given low-level concentration might result in irritant health effects. Each case should be considered individually based on the symptoms that are presented.

### **Mitigation Advice for Volatile Organic Compounds**

It is difficult to provide mitigation advice for VOCs other than HCHO because there is very little information on control methods and concentrations of concern. In general, the methods suggested for the mitigation of HCHO also apply to other VOCs.

#### **Consumer Strategies**

Clients who are concerned about VOCs should be encouraged to use products which do not contain VOCs or contain lower levels of VOCs whenever possible. A major problem with this advice is that consumers may not be able to identify which products contain VOCs; and further, emissions of

VOCs may vary from product to product. In those instances where VOC-containing products must be used, adequate ventilation during storage and use should be emphasized.

Consumer practices can also be important in minimizing indoor air quality impacts from the use of VOC-containing products. Storage of these products outside the living area (perhaps in the garage) can reduce indoor air concentrations. In addition, minimizing the use of VOC-containing products or using these products with adequate ventilation is critical. In general, clients can be advised that cross-ventilation should be enough to prevent any noticeable odor when VOC-containing products are used in the home.

Caulks, sealants, glazing compounds, and joint fillers release VOCs (typically aliphatic hydrocarbons, xylene, toluene, petroleum hydrocarbons, or methyl ethyl ketone) at varying rates depending on the formulation. Fast-drying products (those containing styrenes, for example) emit a significant fraction of their total weight, but they do so in a relatively short period of time (several to 10 days). Slow-drying products can be significant contributors to indoor air contaminants over a longer period of time (up to one year). Consumers can reduce their exposure to contaminants from these products by proper selection and use of the product.

For example, the release of emissions from the installation of carpet or other flooring materials can be minimized by selecting a fast drying adhesive and using maximum ventilation during the installation.

There appear to be some instances, however, when consumer practices will not appreciably reduce VOC concentrations. For example, emissions from recently dry cleaned clothing can result in elevated levels of perchloroethylene in homes. But airing clothes out in a garage for 4 hours did not prove effective in reducing indoor perchloroethylene concentrations (Tichenor, *et al.* 1988). In this case,

other methods such as venting the closet to the outside might be effective in reducing these concentrations.

### Conditioning

The potential effectiveness of VOC control by conditioning is illustrated by VOCs chamber studies of caulk. VOC emissions decreased by more than 90% from caulk treated for 4 hours at room temperature and 1.8 ach. At 0.4 ach the time for 90% of VOCs to be emitted increased to about 20 hours, or five times as long as for 1.8 ach (Tucker, 1988). This method can be used for individual products or larger areas (for example, after installation of new carpeting or after painting).

HCHO and other VOCs might also be reduced by using increasing temperature and ventilation for

some period of time (several days to 1 to 2 weeks). Under these conditions, emissions of volatile organic compounds will accelerate and be exhausted from the building. Girman *et al.* (1987) provided one of the first reports of the potential effectiveness of this procedure in office buildings.

### Removal

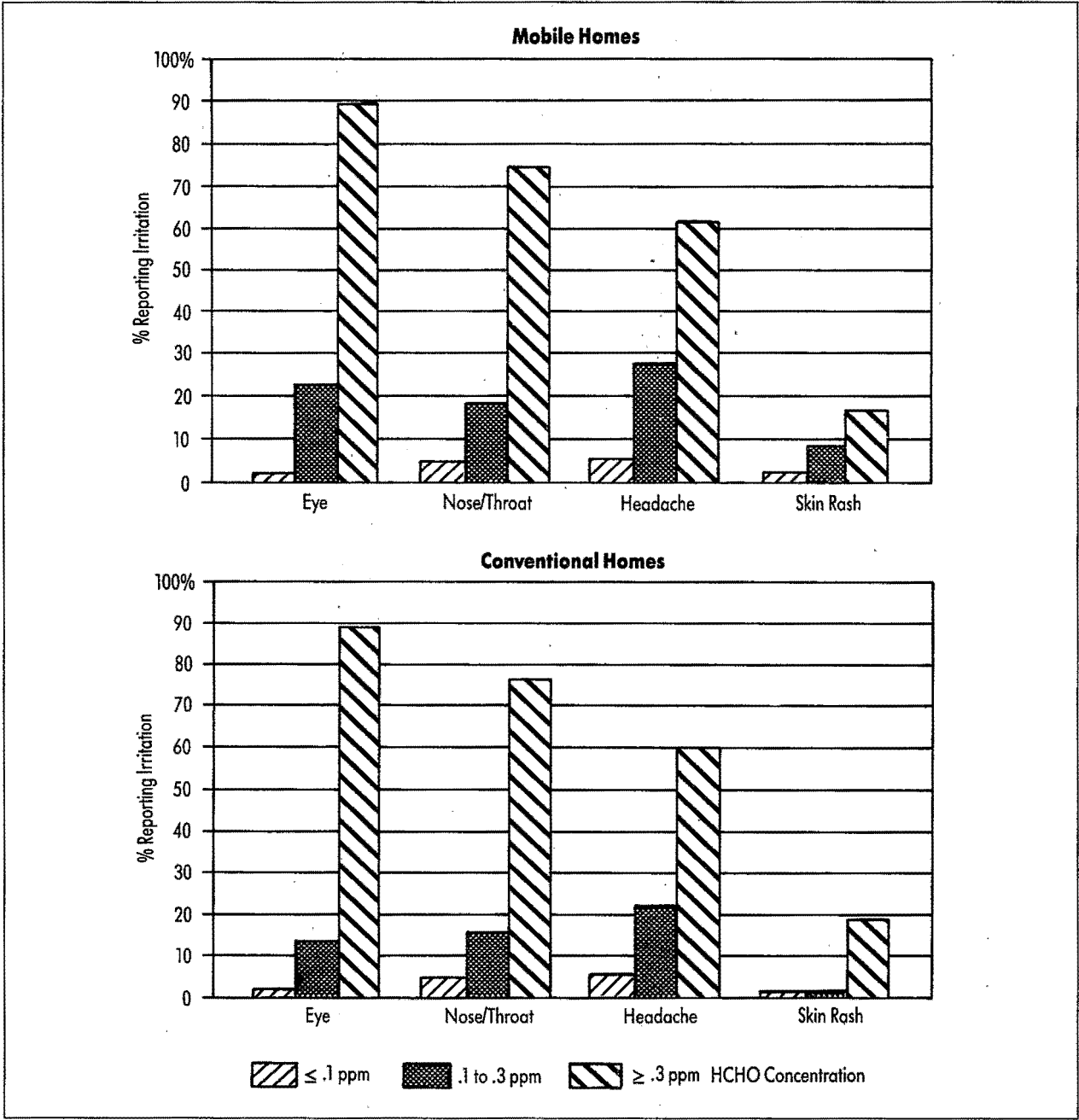
When concentrations cannot be reduced or symptoms persist, avoidance of the product or removal of the source may be required. The mitigation of VOCs and other organics in the environment of hypersensitive individuals is difficult and requires an integrated approach including substitution of products and materials, removal, mechanical ventilation, and control devices.

**Exhibit 8-20. Selected passive formaldehyde measurement methods.**

<u>ANALYTICAL TECHNIQUES</u>				
Method	Sampling	Analysis	Sensitivity, ppm	Comments
Air Quality Research <sup>a</sup>	HCHO reacts with sodium bisulfite-treated filter paper in a vial	spectrophotometry (chromotropic acid procedure)	1.68 ppm-hr (0.011 ppm for 1 week exposure)	recommended minimum exposure of 1 week; reproducibility of $\pm 25\%$ ; not sensitive for short-term residential sampling
DuPont <sup>a</sup>	HCHO reacts with sodium bisulfite solution in a badge	spectrophotometry (chromotropic acid procedure)	1.6 ppm-hr (0.010 ppm for 1 week exposure)	shelf life of sampler is 2 weeks after exposure which suggests a maximum exposure of 2 weeks; accuracy of $\pm 13.1\%$ over the range of 1.6 to 54 ppm-hrs; precision of 5.9%
3M <sup>a</sup>	HCHO reacts with sodium bisulfite-treated filter paper in a badge	spectrophotometry (chromotropic acid procedure)	0.8 ppm-hr (0.005 ppm for 1 week exposure)	not sensitive enough for short-term residential sampling; requires sophisticated equipment and analytical skills; accuracy $\pm 25\%$
U.S. EPA <sup>b</sup>	HCHO reacts with DNPH impregnated filter paper in the presence of acid	HPLC	0.05 ppm for 4 hr exposure	overall accuracy of $\pm 10\%$ to $\pm 19.8\%$ in laboratory and field testing, respectively; precision of $\pm 5\%$
Air Technology Labs <sup>c</sup>	HCHO reacts with MBTH solution in the Passive Bubbler <sup>TM</sup>	spectrophotometry (MBTH)	0.025 ppm for 8 hr exposure; 0.05 ppm for 4 hr exposure	samples should be stored in the dark; overall system accurately in field testing of $\pm 19.8\%$

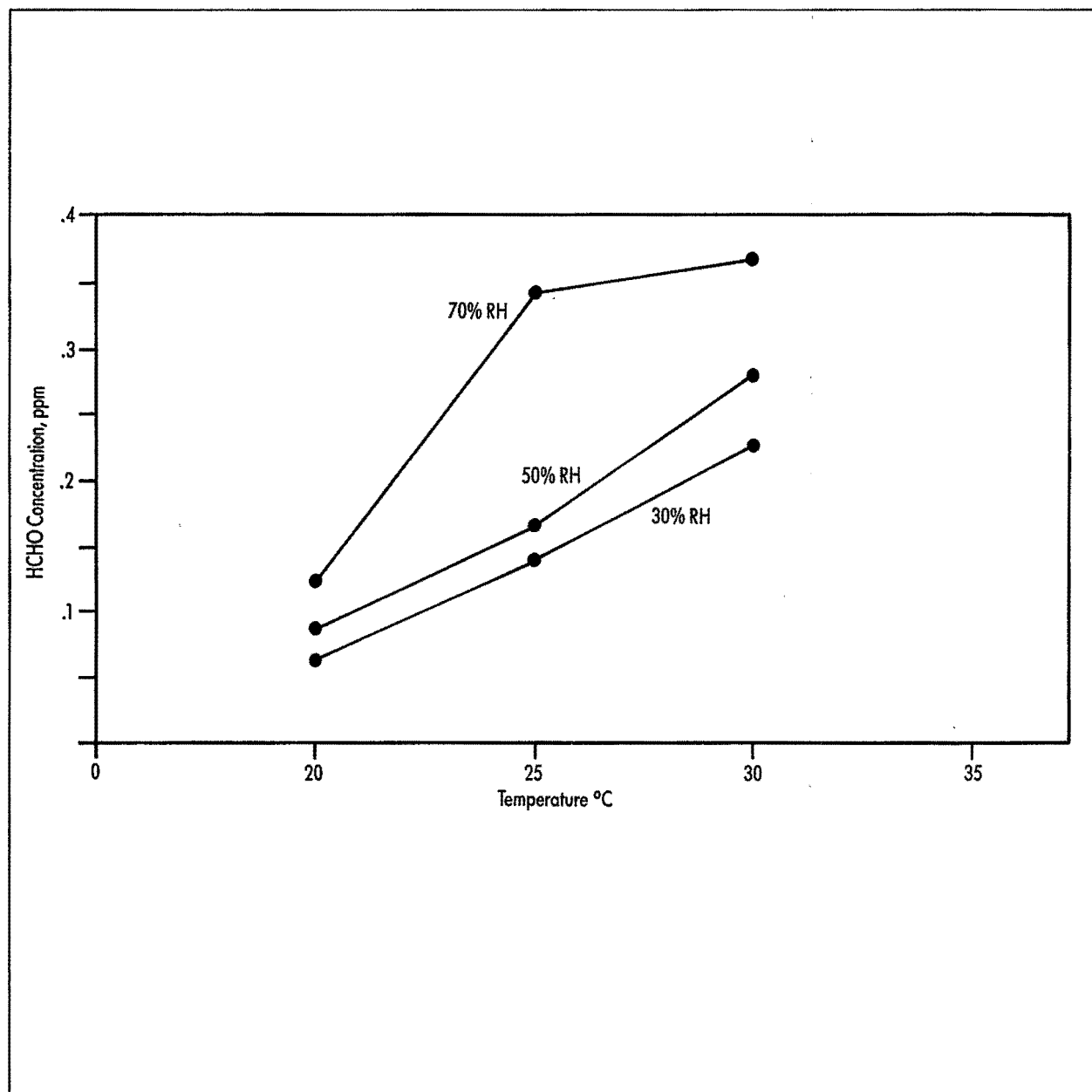
SOURCE: <sup>a</sup>Nagda, Rector, and Koontz (1987); <sup>b</sup>U.S. EPA (1989); <sup>c</sup>ASTM (1990)

**Exhibit 8-21. A dose-effect relationship between formaldehyde (HCHO) exposure and selected health effects in mobile and conventional homes.**



SOURCE: Ritchie and Lehnen (1987).

**Exhibit 8-22. Effect of temperature and relative humidity on formaldehyde (HCHO) levels in a mobile home under controlled conditions.**



SOURCE: Adapted from Godish and Rouch (1986).



### Exhibit 8-23. Advantages and disadvantages of nonspecific and specific detector systems for VOC and SVOC analysis.

#### NON-SPECIFIC MULTIDETECTOR ANALYTICAL SYSTEM

##### ADVANTAGES

- somewhat lower equipment cost than GC-MS
- less sample volume required for analysis
- more sensitive

##### DISADVANTAGES

- cost of calibrating multiple detectors
- compound identification is not positive
- lengthy data interpretation (2 hr for analysis and data reduction)
- interference(s) from similar (co-eluting compounds)
- cannot identify unknown compounds outside of calibration and without standards
- does not differentiate targeted compounds from interfering compounds

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#### SPECIFIC DETECTOR ANALYTICAL SYSTEM

##### GC-MS-SIM

##### ADVANTAGES

- positive compound identification (ions)
- greater sensitivity than GC-MS-SCAN
- less operator interpretation than for multi-detector GC
- resolve co-eluting peaks to achieve enhancement in sensitivity
- more specific than the multidetector GC

##### DISADVANTAGES

- can't identify nonspecified compounds
- somewhat greater equipment cost than multidetector GC
- greater sample volume required than for multidetector GC
- universality of detector sacrificed

##### GC-MS-SCAN

##### ADVANTAGES

- positive compound identification
- can identify all compounds
- less operator interpretation than for multidetector GC
- can resolve co-eluting peaks

##### DISADVANTAGES

- lower sensitivity than GC-MS-SIM
- greater sample volume required than for multidetector GC
- somewhat greater equipment costs

SOURCE: U.S. EPA (1989)

**Exhibit 8-24. Commercially available portable VOC detection instruments.**

MONITOR	DETECTION PRINCIPLE	RANGE, PPM	SENSITIVITY	RESPONSE TIME, s	ACCESSORIES	CALIBRATION TECHNIQUES	WEAKNESSES	SERVICE RATE	LACK OF RESPONSE	COST, \$	SAMP RATE LPM
550,551 555,580 (AID, Inc.)	PID PID	0-200, 0-2000, 0-10,000	0.1 ppm at 0-200 ppm	<5		• Bag Sampling	• Umbilical cord too short • Digital readout hard to read • Flame out frequently	8 hrs		4300	1.5
OVA 108, 128 Century Systems, Inc. (Foxboro)	FID	0-10, 0-100, 0-1000, 0-10,000 0-100,000	0.2 ppm (Model 128) 0.5 ppm (Model 108)	2  2	• Thermal Desorbers available • Optional GC available	• Hand Space • Direct Injection • Bag Sampling	• Battery failure • Sample line kinks • Compounds containing O <sub>2</sub> /N give low response • Neg. resp. to CO/CO <sub>2</sub>	8 hrs		6300	
PI-101 (HNu Systems, Inc.)	PID	1 1-20 1-200 1-2000	0.1 ppm Low molecular weights aromatics	<5	• Three lamps available • 9.5 (aromatics) • 10.2 (2-4 compounds) • 11.7 (halocarbons)	• External Gas Cyl. • Bag Sampling	• Three lamps — may miss something	10 hrs	• Cl hydrocarbons • CH <sub>4</sub>	4955	0.5
TLV Sniffer (Bacharach)	Catalytic combustion	0-500 0-5000 0-50,000	2.0 ppm	5		• Bag Sampling • Head Space				900	
Ecolyser 400 (Energetics Science)	Catalytic combustion	0-100% LFL	1% LFL	15		• Bag Sampling	• Changes in gas temp/humidity affects response				
Miran 1A (Foxboro)	IR	ppm to %	1 ppm	1,4,10 and 40						9500	
Miran 1B (Foxboro)	IR	ppm to %								12,500	
Scentor (Sentex)	GC/EC, Argon Ionization PID		0.01 ppb Cl organics	2	Preconcentrator Thermal Desorption GC Columns Auto Cal. from Integral Gas Cylinder	• Internal gas cyl. • Preconcentrator • GC Column				12,950	
Photovac Standard Automatic Computer Auto Comp. Communication	PID (UV Light)	0	0.1 ppb Benzene with signal-to-noise ratio 4:1, Good for aromatics	2	• Dual Column • Manual/Auto Injection • Column Cond • Pre-flush • Auto Dial Modem • Programmable		• Column operates at ambient temperature • STD in lab, then to field at different temperature • Can't inject liquid sampling • Light fractions interfere		• H <sub>2</sub> O • O <sub>2</sub>	6995 8995 10,500 10,955 12,955	
Photovac Tip	PID	0-2000 ppm	0.05 ppm Benzene	3							

SOURCE: U.S. EPA (1989)

**Exhibit 8-25. Characteristics of sorption collection methods.**

SORBENT	APPLICATION	DESORPTION	ANALYSIS
organic polymeric resins (Tenax GC, XAD)	sample by 60-300°C, except highly polar compounds	thermal	CG/MS
inorganics (silica gel, alumina, florisil, molec- ular sieves)	strongly sorb water; not generally useful	—	—
activated carbon	sample bp 0-300°C, polar and nonpolar compounds	solvent	GC/FID GC/ECD GC/NPD
carbon molecular sieve	sample bp 0-70°C, very polar and volatile compounds	thermal	GC/MS

SOURCE: U.S. EPA (1989) Method 1P-1B. Collection using solid absorbent tubes.

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## 8.5. INVESTIGATION TECHNIQUES FOR BIOLOGICAL CONTAMINANTS

Many investigations of biological contaminants, particularly those involving fungi, can be handled by obtaining a detailed symptom history and performing a careful inspection of the building. Discussions with the physician or other health care provider (if one has been consulted) may be helpful. It is important to identify the presence of activities which may precipitate or aggravate symptoms and any changes in lifestyle and/or building characteristics which could contribute to symptoms.

A useful reference to assist in the investigation of bioaerosols is a document developed by the Bioaerosols Committee of the ACGIH (1989). The focus of this document is on the office environment, but the principles also apply to residential environments. Areas which are covered in the guidance document include medical preassessment, on-site investigations, air sampling, and remedial actions for viruses, bacteria, endotoxin, fungi, protozoa, and antigens. Biocides are also discussed.

## Walk-Through

A telephone interview can be used to obtain preliminary information, but a walk-through is generally needed to identify potential sources of contamination. A survey form that can be used for potential sources of allergens is given in Exhibit 8-26.

Both indoor and outdoor environments must be evaluated to identify materials or situations which can foster the growth and amplification of biological agents. It should be remembered during these investigations that some problems depend on season or climatic changes, and these may not be detected during the inspection.

An important area of emphasis during investigations related to fungi and some bacterial contaminants is identifying moisture problems; Section 5 of the *Reference Manual* provides a foundation for understanding the moisture balance in the home. Other useful references that can help the investigator to detect and solve moisture problems are published by the National Center for Appropriate Technology (NCAT, 1983) and ASHRAE (1988, 1989).

## Outdoor Environment

Any barriers to air movement around the house, such as heavy vegetation or firewood, can result in the accumulation of moisture and promote mold growth. The outdoor environment should be evaluated for landscaping close to the house which might result in shade and moisture levels which favor the growth of microorganisms. The grounds should be evaluated for proper drainage; any standing water should be noted. If a sump pump is used, the outlet for the drainage pipe should be evaluated for adequate distance from the house, and the slope of the ground should be checked to be sure that drainage occurs away from the house.

The presence of accumulated bird droppings around the grounds or in air intakes should be noted. The

grounds should be evaluated for trash and food sources, harborage, and fecal material from pets.

### Exterior of the House

The soffits, fascias, gables, bottom edges of siding, areas below windows, exterior siding at bathrooms, flashing, and remaining exterior should be examined for signs of physical and moisture damage. The presence of blistering paint or black/dark streaks or lines which border a discoloration may indicate problems. Uneven, warping, or sloping surfaces should be noted. Wood can be tapped to detect wet or decaying wood (characterized by a dull, dead, muted sound in contrast to dry wood which has a sharp, clear sound when tapped).

The foundation should be examined for signs of "efflorescence" (a white powdery substance or line of minerals that is left after moisture has moved through it) which may indicate the presence of microbial contamination. Crumbling concrete may also indicate problems.

Some moisture problems are weather or seasonally dependent. For example, some roof drainage problems can only be observed if it is raining. Also, roof designs with valleys are more likely to have ice dams during the winter which can damage roofing materials and promote moisture problems through constant freeze/thaw cycles.

The exterior of mobile homes should be checked for unusual water stains which may appear along the outside corner where the wall meets the ceiling.

The foundation area of all homes should also be evaluated for signs of rodent entry. Downspouts and the slope of the ground around the foundation should be checked to determine if water drains properly away from the foundation.

### The House and Its Interior

A major emphasis of the interior inspection should be to identify evidence of situations or conditions

which foster or could lead to moisture problems. There are many visual and sensory clues that suggest moisture problems, but some problems may be hidden and require additional investigation. Although microbes will not typically be sampled, temperature and relative humidity should be measured. A relative humidity between 30% and 50% promotes comfort and reduces the likelihood of problems with microorganisms. A relative humidity below 30% can cause problems with dryness and irritation of the mucous membranes; humidities greater than 50% are more likely to cause problems with mold and mildew. If someone in the household has respiratory problems which require a more humid environment, a potential solution is to humidify only one area of the house, rather than the entire house.

**Visible mold and mildew:** The interior should be examined for evidence of visible mold and mildew. Special attention should be given to wall-ceiling joints and wall-floor joints, areas behind furniture, plants, poorly ventilated closets, and window coverings. Greenhouses (all areas, including plants), bathrooms (showers, bathtubs, behind and at the base of the toilet, windows, underneath sinks), and kitchens (underneath sinks) should be carefully checked for signs of mold, mildew, and rotting wood.

Indoor swimming pools and hot tubs should be checked for visible mold and mildew problems, and the method and adequacy of moisture control should be noted. The interior should also be evaluated for the presence of organic substrates. If carpeting or other flooring materials are damp or have been water damaged, the floor underlayment and any pads must be examined for evidence of microbial growth. If water leaks have occurred, it may be necessary to examine insulation inside of walls for damage.

**Presence of organic substrates:** Other sources of microbes and biological agents such as carpeting, wicker and straw items, pets, and plants should be noted. The presence and condition of pets should be

evaluated. (For example, do dogs have fleas? Are bird cages cleaned regularly?) General dust levels should be noted along with the presence of pests such as cockroaches.

**Dampness, standing water, and condensation on surfaces:** A history of water damage (flooding, broken pipes, overflowing toilets, sinks, or bathtubs) should be obtained. The interior should be examined carefully for evidence of water damage or moisture. Smaller houses (under 800 ft<sup>2</sup>) tend to be more prone to moisture problems because of the ratio of sources to total living area. Musty odors or a sensation of dampness in the air are indicative of mold, mildew, or rot. Also, lingering odors from normal household activities may indicate inadequate ventilation, which in turn, could be related to moisture problems.

Condensation problems can occur during the winter or summer. The presence of condensation on windows or other smooth surfaces such as concrete or masonry walls is a sign of excessive moisture (or the need to insulate or warm the surface). Based on average window glazing and 74°F interior temperature, the maximum relative humidity within a space for no condensation on single glazed (ASHRAE, 1988) and for double glazed windows (ASHRAE, 1989) is:

Maximum Relative Humidity

Temperature	Single Glazing	Double Glazing
40°F	39%	59%
30°F	29%	50%
20°F	21%	43%
10°F	15%	36%
0°F	10%	30%
-10°F	07%	26%
-20°F	05%	21%
-30°F	03%	17%

Moisture problems with double-hung windows might not be as readily visible because condensation can occur inside the wall cavity as a result of warm

moist air condensing on the cold weights inside the wall cavity.

Sweating pipes and water leaks are potential causes of microbial growth. If plumbing runs underneath a crawl space, it should be checked for leaks (after running the water for 10 to 15 minutes); exterior faucets should also be checked. Standing water in the crawl space or basement should be noted.

Areas where insulation is easily accessible (attic, crawl space, basement) should always be checked for dampness and adequacy of air spaces.

It may be necessary to examine the building materials on the cold side of the building envelope to determine if a vapor retarder is present or has been improperly installed. Tightly built and well-insulated homes require a properly installed vapor retarder to prevent moisture transfer through building materials. If a vapor retarder is absent or if it has been improperly installed, every point subject to air leakage could be a potential cause of condensation within the walls. Common problems include: 1) the installation of vapor retarder on the cold side of the wall surface resulting in condensation in the walls, 2) installation of low-perm retarders on both sides of a wall designed to prevent moisture intrusion can also prevent moisture from escaping; 3) breaks in the vapor barrier; and 4) the lack of a ground-cover vapor retarder in the crawl space.

The building materials on the cold side of the home should be inspected to determine whether sheathing or siding may be acting as an unwanted vapor retarder, and the building should be evaluated to determine if there are areas where the vapor retarder was not installed (rim joists, between floors, and so forth).

**Heating, ventilating, and air-conditioning systems:** The heating, ventilating, and air-conditioning systems should be checked for condition and obvious problems. Special attention should be given to the condition, operation, and maintenance

of humidifiers and dehumidifiers (in-line and portable), water or swamp coolers, heat recovery ventilators; these should be examined for the presence of moisture, stagnant water, and slime growth. Filters and air cleaning devices should be evaluated for the presence of dust buildup and moisture.

It is important to determine if there have been any changes in the energy efficiency of the home or other factors which could affect the efficiency of the heating and cooling system. If the house has been weatherized and tightened, but the heating and cooling systems have not been upgraded, problems can result. The temperature settings that are typically maintained during the different seasons should be noted.

Humidifiers which are commonly used include ultrasonic, steam, evaporative, warm-mist, and cool-mist units. All humidifiers can be a source of microbial contamination, and they must be cleaned frequently. Portable and console humidifiers should be examined for the presence of film or scum on the water surface, on the sides or bottom of the tank, or on exposed motor parts. The presence of any of these conditions may indicate the presence of bacteria or fungi. A crusty deposit or scale within the tank, or on parts of the tank, or a white deposit in the surrounding area is minerals which have settled out of the water or become aerosolized, creating a surface where bacteria or fungi can grow.

Ducting in crawl spaces should be examined for obvious openings. Fiberboard plenums should be evaluated, particularly in the absence of vapor barriers in the crawl space. Interior registers should be removed and ducts should be checked for signs of microbial growth and a buildup of dust.

**Crawl space, basement, and attic:** The crawl space, basement and attic should be examined for moisture damage and/or standing water. Floor and ceiling joists and exposed sheathing should be checked for signs of rot, mildew, or mold. Rotting wood can be detected easily by tapping the wood as

described previously or by using a sharp implement (ice pick, small chisel, screwdriver) to test the toughness of the wood. To perform this test, the implement is jabbed into the wood and pried up. Decayed or rotting wood breaks out with little resistance and in relatively short lengths; wood in good condition is hard to pry up, and it breaks into long slivers.

Decayed wood can be affected by white rot (wood appears whiter than normal with dark lines bordering the discoloration), brown rot (brown or black discoloration), soft rot (wood is soft and cracked), and blue stain (a blue, brownish black, or steel-gray colored stain). White rot and brown rot are the most serious forms of damage, and removal of wood is indicated if these forms are present.

Sumps and drains should be checked for proper capping and drainage (run water for 5 minutes and observe for water backup). The crawl space floor should be checked for the presence of a vapor retarder. Any standing water, loose insulation, wood, and paper products must be removed. Vents should be evaluated for condition, total number and size, and obstructions.

The basement should be checked for additional signs of moisture—damp air, damp walls, seepage of water, efflorescence, and visible mold or mildew. Any insulation in the basement or attic should be checked for dampness.

## Measuring Biological Contaminants

### House Dust Mites

House dust mites can be identified directly through air sampling or indirectly by analyzing dust samples. Air sampling is complicated by the fact that the allergen is associated with larger particles (>10 microns) which may be removed rapidly from the air and are subject to reentrainment through routine activity. Dust mites can be reliably counted microscopically, but counting mites is not a direct measurement of allergen and it is subject to large



sampling errors. Allergen assays are more rapid, direct measurements that are easily standardized and have accuracies of 620% (Platt Mills *et al.*, 1990).

A simple test is available in the U.S. for testing dust mite allergen levels indirectly by a semiquantitative analysis of guanine levels (ACAREX test kit) in house dust. Guanine is contained in the excreta of dust mites and other arachnids, but the dust mite appears to be the primary source of guanine in indoor dust. In this method, guanine is first dissolved out of the dust sample. The solution is then tested with a strip containing an azo reagent. A positive test is indicated by a red color which varies in intensity depending on the guanine concentration. Test kits can be purchased for about \$15 for ten tests and \$7.50 for four tests. Bischoff (1987) reports on evaluations of house dust mites using this test in European homes.

### Airborne Microorganisms

In many instances the symptom history, combined with the walk-through inspection will be sufficient to determine if microbial contamination exists and is a likely cause of problems. At this stage of the investigation if no apparent microbial sources are found, it is unlikely that air sampling will provide additional, useful information (ACGIH, 1989). However, sampling may be required in some instances. If so, it is important to have adequate information and knowledge. The investigator must work closely with the laboratory to ensure the use of proper sampling techniques, correct enumeration of organisms, correct interpretation of data, and the development and use of a quality assurance program.

The ACGIH Committee on Bioaerosols stresses that careful thought and planning must precede any sampling program. The investigator should be aware that there is no single sampling method which will recover all potential bioaerosol components, and air sampling rarely provides proof of inappropriate exposures to bioaerosols. It is especially important to utilize a laboratory that has

mycologists and bacteriologists who are experienced in the assessment of *environmental* microbial problems.

Some guidelines for sampling and analyzing fungi are provided below. These methods are appropriate for organisms that result in hypersensitivity diseases, but not for infectious disease-causing organisms such as bacteria and viruses. The reader should consult the ACGIH's guidelines and Chatigny (1983), Chatigny *et al.* (1983, 1989) for further information on sampling bioaerosols.

**Surface Sampling:** A relatively simple technique that can be used in residential investigations is to collect surface samples using sterile cotton swabs that are premoistened with water to maintain viability of the collected organisms. An area that is about 25 cm<sup>2</sup> (about 4 in<sup>2</sup>) is swabbed and the collected material is inoculated directly onto the surface of culture plates. Also, bulk samples can be collected into sterile sample containers and then processed onto culture media; dilution may be required. Both of these methods can prove useful in identifying "hot spots." Used in conjunction with a symptom questionnaire, further sampling may not be required to make an informed judgment. Another relatively simple technique, cellophane-tape imprinting, can be used for the rapid identification of mold colonies growing on organic materials (Kozak *et al.*, 1980).

The ACGIH Committee on Bioaerosols does not recommend taking surface swabs and "bulk" samples unless these are taken in conjunction with a well-controlled indoor/outdoor sampling program. However, the Committee acknowledges that collecting these samples during the walk-through may prove useful if indoor air sampling is subsequently needed. (Burge and Solomon, 1987; ACGIH, 1989; Kozak *et al.*, 1985).

**Air Sampling:** The sampling of bioaerosols is similar to sampling for particulates. Biologically-derived particles that can become airborne indoors range in size from less than 1 micron for viruses to

over 200 microns for fungal spores. This large range in particle size and the variety of particles that can be present in the airstream combine to make sampling and characterization of bioaerosols a challenging task. The collection of quantitative data requires special expertise and is expensive; several different sampling devices and analytical schemes may be required. For this reason, most investigators report qualitative results and these may be sufficient in many investigations.

Sampling location should include both outdoors and indoors. The outdoor sample (from a site that is removed from obvious sources) serves as a reference point to determine whether or not amplification is occurring indoors. During nonresidential investigations outdoor samples should also be collected from the air intake of buildings.

Indoors, samples should be collected in areas near occupants who complain of symptoms and those who do not. Samples should be collected from or near potential sources such as humidifiers and air inlet and exhaust diffusers at different times during the day.

For example, in an office building samples can be collected before the HVAC is turned on and before workers arrive. During work hours, samples can be collected at the beginning of the day, when maximum occupancy occurs, and before and after operational changes are made in the HVAC system. Samples can also be collected at the end of the day, after occupants leave and with the HVAC off.

Kozak *et al.* (1985) recommend at least one outdoor sampling site to evaluate taxonomic groups and concentrations, multiple indoor studies with emphasis on areas with water damage, and at least one volumetric survey in the area suspected of having a problem.

Sampling equipment for bioaerosol sampling includes gravity samplers, inertial impactors, and filtration samplers. Gravity samplers such as culture plates and adhesive-coated glass are the

most widely used samplers, but these are not recommended by the Committee on Bioaerosols. The efficiency of sampling depends both on particle size and the movement of air over the sampling device. Gravity samplers tend to overestimate the concentration of large-sized particles, and underestimate smaller-sized particles which may be more important biologically. Another weakness of these devices is that they do not provide volumetric data.

Exhibit 8-27 summarizes the samplers that have been recommended by the Committee on Bioaerosols. Of these samplers, the slit to agar samplers and the glass impingers are the most efficient and accurate. But this level of accuracy is not always needed and other samplers such as filter cassettes may be used. Filter cassettes underestimate viable aerosol concentrations, but they can be used in situations when high concentrations are suspected. Filter cassette samplers are not recommended for bacteria because of potentially low viability which results from drying; however, impingers with appropriate media can be used.

In situations where the investigator does not know what agents to expect, a combination of samplers is recommended. A broad range of agents can be identified using a combination of slit sampler and visual identification, culture plate cascade samplers with several culture media, and either a filter sampler or liquid impinger followed by bioassay, biochemical, or immunological analysis (Burge and Solomon, 1987). Collected samples should be transported to the laboratory within 24 hours, and source samples should be processed immediately.

There may be instances when illness exists, but measured spore counts are low using the recommended techniques. In these situations large volume air samples can be collected either into a liquid or onto a filter. If the air flow rate of the sampler is greater than that provided by the ventilation system, samples can still be collected for identification of spores, but the data should be not be used for quantitative purposes.

The ACGIH Committee on Bioaerosols recommends the following sampling modalities for organisms associated with specific fungal diseases:

- 1) Histoplasmosis—sample at the source only; cannot culture from air samples;
- 2) Aspergillosis—culture plate sieve or slit impactor with efficient collection to 1  $\mu\text{m}$ ;
- 3) Hypersensitivity pneumonitis—culture and particulate sieve or slit impactors with efficient collection to 1  $\mu\text{m}$  or high-volume filtration when the antigen is known;
- 4) Allergic asthma, rhinitis—culture and particulate impactors with known particle collection efficiency or high-volume filtration when the antigen is known.

**Quality assurance** programs that begin with sample collection and end with data analysis are vital to the success of bioaerosol sampling. A quality assurance program includes, but is not limited to, proper sampler selection, sampler disinfection, routine calibration of flowrates, proper choice of media and checks for sterility, quality control procedures for analysis, and written protocols. In addition, it is important to use blank samples (duplicates or triplicates) for each culture medium used at the sampling and control sites.

Samplers should be sterilized before each use, but this may not always be possible. Samplers that use culture plates should be swabbed with alcohol or bleach before each use. Plastic culture plates are recommended, particularly if samples are to be mailed to a laboratory. Fluids for impingers should be sterile, and before the impinger is used it should be rinsed with sterile fluid. Filter cassettes can be presterilized before use, and the Committee suggests that disposable cassettes from major manufacturers are clean enough for most saprophytic sampling.

Samplers should be calibrated according to the manufacturer's instructions before and after field use. Calibrations should be performed with the equipment set up as it will be used in the field; sampling pumps should not be calibrated unless they are in the sampling train.

**Enumeration of organisms** which are collected can be determined by a variety of methods including culture assay, bioassay, immunological assay, biochemical assay, and direct microscopy. These methods which are summarized below are discussed further by Burge and Solomon (1987; Platts-Mills *et al.*, 1989). Consultation with the analyst is advisable before sampling. The type of analysis should be specified to the laboratory before sampling begins.

*Cultural assays* involve growing the collected organisms and identifying them macroscopically, microscopically, or biochemically. These methods can be used with culture plate collectors, for processing eluates from filters, and for processing source samples such as swabs collected from contaminated surfaces. Cultural assays are appropriate when only viable organisms are of interest; for example, for infectious agents (*Legionella*, *Staphylococcus*) and invasive fungal pathogens (*Aspergillus f.*). Culture plate assays, however, underestimate actual levels and the investigator should be aware of limitations of the method.

*Bioassays* rely on a living substrate to indicate the prevalence of allergenic agents. Allergists use bioassays in skin testing. Human skin can react to microgram quantities of specific antigens which are typically introduced as extracts of dust, pollens, or spores, but suitably prepared filter eluates and impinger fluids can also be used.

*Immunological assays* are newer methods that are proving increasingly useful. These tests can be useful in studying building-related epidemics such as hypersensitivity pneumonitis, humidifier fever, or

residential problems such mite and cockroach antigens, animal-derived sensitizers, and fungal-related antigens.

*Direct microscopy* is useful for the identification and counting of morphologically distinctive particles or total fungal spores. Total colony counts (CFU/m<sup>3</sup>) are calculated by dividing the adjusted number of colonies on the plate by the total volume of air sampled in cubic meters. In order to facilitate the identification of sources and amplification sites for microorganisms, the Committee on Bioaerosols recommends identifying the predominant taxonomic groups for fungi at a minimum. In addition, viable microorganisms that are present in concentrations greater than 75 CFU/m<sup>3</sup> should be identified.

### Interpretation of Biological Contaminant Data

#### Fungi

If the walk-through reveals the presence of overt mold or mildew contamination (for example, mold covering a portion of a wall or floor underlayment), sampling is generally not required. Evidence of overt contamination is sufficient for recommending control measures, and these may be enough to bring relief.

If sampling is conducted, the interpretation of data is complicated by the complexity of natural aerosols and the large population variances that are encountered. There are no published standards for acceptable exposures to saprophytic aerosols in indoor environments. There is no agreement on exact levels of fungal bioaerosols which are responsible for the onset of disease, nor is there adequate information on dose-effect relationships.

Some allergists consider fungal levels of 1000 CFU/m<sup>3</sup> to be unacceptable to sensitive individuals (Tyndall *et al.*, 1987), but levels lower than this have been shown to be problematic (Morey, 1988). Ohgke *et al.* (1987) have identified levels of 100 CFU/m<sup>3</sup> to be indicative of fungal colonization.

Some researchers suggest that levels greater than 500 CFU/m<sup>3</sup> are high enough to warrant a detailed environmental survey (Gammage and Kerbel, 1987).

**Indoor vs outdoor levels:** Indoor levels of saprophytic organisms can also be compared to outdoor levels to evaluate if a problem exists. During the growing season outdoor fungus spore concentrations have been reported to range from 1000/m<sup>3</sup> to 100,000/m<sup>3</sup> of air (Burge, 1987). If outdoor air is the only source, indoor levels of pollen and fungus spores are likely to be in the range of 10% to 40% of outdoor levels. Levels in mechanically ventilated buildings are generally less than 10% of outdoor levels depending on the quality of filtration (Burge, 1988).

Another method that can be used to compare indoor levels to those outdoors is rank order assessment. In this method individual taxa are identified and listed in descending order of importance for both indoor and outdoor locations. A nonparametric statistical test such as the Spearman rank order correlation can then be used to determine statistical significance of differences between the indoor and outdoor ranking.

#### Mites

It is not clear what level of dust mites or dust mite allergens should be regarded as a risk level, nor is it clear if floor dust levels and exposure are related in the same way for different allergens (cat, dust mites, and so forth). Proposed values of 2 µg/g Group I *Dermatophagoides* allergen (equivalent to 100 mites/g dust or 0.6 mg guanine/g dust) have been suggested as a risk factor for sensitization, the development of bronchial reactivity, and symptomatic asthma; 10 µg/g Group I allergen (or 500 mites/g dust) should be regarded as a risk factor for acute attacks of asthma (Platts-Mills *et al.*, 1988).

#### Bacteria

*Legionella* can be isolated from a variety of sources indoors (humidifiers, shower heads, hot water tanks,

and so forth). The significance of these findings, however, is not clear. If a known case of disease has occurred, sources must be cleaned and disinfected. In the absence of disease, each case must be evaluated individually.

### **Mitigation Advice for Biological Contaminants**

Efforts to control microbial growth and the dispersion of allergens in residential and office settings should initially focus on removing the offending agent or contaminated material. After initial control has been achieved, the basic requirements for growth (food and water) should be removed and good housekeeping activities should be maintained.

In some cases, the removal of the offending agent or source will be direct and simple; for example, removing a cat or portable humidifier in a residence. In other cases, removal may be difficult or impossible (contaminated floor joists or air ducts in an office or residence). In some of these instances, cleaning, disinfection, and drying may be effective.

After remedial actions have been taken, it is important to reevaluate the original complaint both in terms of symptoms and sampling. Sensitized individuals should be interviewed to determine if remedial action has been effective. If sampling is conducted, the area may need to be resampled using the same protocol. The occupants should be encouraged to report any signs of microbial regrowth.

In some office situations personnel may have to be reassigned to another area even after remedial action because the offending agents have not been eliminated. Relocation may also be needed in some residential problems. The investigator should consult with the attending physician to verify the condition of sensitized individuals and determine if further action is needed.

### **House Dust Mites/Animal Danders/Plants**

A variety of measures have been recommended for reducing dust mite populations and symptoms in mite-sensitive asthmatic children. These include replacing feather and down pillows with pillows that have synthetic fillings; thoroughly vacuuming mattresses, pillows, carpets, and other furniture; covering the mattress and box springs with plastic; and damp wiping the mattress and box springs (Sarsfield *et al.*, 1974; Murray and Ferguson, 1983; Mathison *et al.*, 1982). However, other studies have not found these measures to be effective.

Of these methods, removal of carpeting and fibrous furniture coverings may be effective. High efficiency filtration systems are probably not effective because the dust quickly settles after becoming airborne.

Frequent vacuuming using conventional machines is probably not effective because dust particles are not efficiently collected in the size range which has the greatest allergenic potential. Vacuums employing steam should be avoided because they may increase mite proliferation by increasing warmth and moisture levels. Vacuum attachments which prevent the release of collected particulates may be more effective than conventional vacuums alone. HEPA-type vacuums are also more effective.

Enclosing the mattress and box spring in plastic covers can be effective; these can be purchased from department stores or purchased from allergy specialty supply companies. Even when these are used, it is important for all bedding to be removed and washed each week in a hot wash and rinse cycle (a water temperature of 130°F is needed to kill mites). The liners of waterbeds should also be washed with hot water on a weekly basis.

Dust mite populations can also be controlled by applying acaricides to mite-infested materials; the

use of these chemicals should be considered cautiously to avoid potentially dangerous products and application methods. Benzyl benzoate (4.6%) can be applied as a dry powder to materials such as carpets, followed by vacuuming to remove the miticide and killed mites. Although this miticide is considered to be safe (Morgan, 1989), it is important to remove all of the miticide before allowing children or pets to reenter the area. If residues remain, irritation effects could result from contact. Ingestion of toxic amounts can result in seizures.

Since avoidance measures have not been as effective as desired, Korsgaard (1983) has proposed climate control as a potentially effective strategy for reducing mite populations. Specifically, mite populations can be reduced if indoor humidity levels are maintained below 45%. Anderson and Korsgaard (1986) have suggested designing new and remodeled buildings so that interior environmental temperature and humidity conditions will control the number of house dust mites to less than 100 mites per gram of dust.

Removal of pets from household interiors may be required to avoid allergic responses. If an individual is sensitive to plant pollens, removal of interior plants is not needed, providing that flowering plants are not allowed to pollinate. Air-conditioning and air filtration are usually effective in removing outdoor pollen from the circulating air.

#### Airborne Microorganisms

The growth and dispersion of microorganisms can be controlled by maintaining the proper moisture balance in the home; some specific strategies which can be implemented are as follows.

#### Outdoor Environment

Any obstructions to airflow should be removed; for example, firewood should be relocated to an area away from the house. Problematic trees and shrubs

should be pruned or removed. If bird droppings are a problem, nesting areas and feeders should be removed or relocated. Trash, garbage, and other food and harborage should be removed.

Chronic dampness near the structure can be eliminated by ensuring that all surface drainage slopes away from the house. Porous borders such as washed gravel can be installed around foundations to facilitate drainage. Perimeter footing drains can be installed, but this is a relatively costly procedure. These drains should be installed in new construction if drainage is poor. If a high water table is a problem, the crawl space can be ventilated and a ground water retarder can be installed. Drainage problems in the basement and crawl space can be solved by sump pumps, drain pipes, or drain tiles.

#### Exterior of the House

The exterior of the house should be kept in good repair; this includes painting if needed; repairing or replacing roofs, flashings, chimneys, vents, soffits, fascias, siding, and so forth. Downspouts should be installed, cleaned, or repaired as needed to ensure proper drainage. Foundation cracks and any entry points for rodents should be repaired.

#### The House and Its Interior

Indications that moisture control is needed indoors include humidity greater than 50%; a sensation of dampness; lingering odors; or the presence of visible contamination, water damaged or rotting surfaces, and condensation.

Excessive humidity indoors can be eliminated by four general approaches: 1) eliminate unnecessary evaporation and sources; 2) discharge moisture to the outdoor air; 3) ventilate the interior; and 4) prevent condensation from occurring by providing the proper barriers.

**Ventilation and air circulation:** If high outdoor humidity is a seasonal or year around problem,

crawl spaces, attics, and interior spaces should be ventilated. Ventilation can also be increased through wall vents or window vents.

Bathrooms and kitchens should be vented to the exterior, and venting fans should be used. In the bathroom ventilation can be provided by windows or a fan rated at about 100 cfm. In the kitchen, a fan rated at about 100 cfm for conventional stoves is adequate, but 400 cfm and greater may be needed for draft stoves. A central exhaust fan or attic fan may be needed.

Aquaria should be covered; too many houseplants can also pose problems. Clothes dryers should not be vented indoors, to the crawl space, or to the attic. If there is less than 250 ft<sup>2</sup> per person or animal, increased circulation and ventilation alone may solve the problem, but dehumidifiers may also be needed.

**Visible mold and mildew:** Smooth surfaces that have been contaminated should be washed and disinfected. A dilute bleach solution (1:10 to 1:50 solution) is recommended by the Committee on Bioaerosols (ACGIH, 1989). Stronger solutions may be needed. *Adequate ventilation and proper protective equipment should be used during cleaning.* Other disinfecting agents include phenol compounds (Lysol), ethylene oxide for items that cannot be discarded or would be damaged by water, and paraformaldehyde. UV light can be used for bacteria, but it is not adequate for fungal spores (Burge, 1985).

Porous materials that are contaminated will probably require removal and disposal. These materials can include carpets and pads, upholstery, ceiling tiles, paper, leather, wicker or straw baskets, wall coverings, window frames, baseboards, and others. In some instances, particularly aggressive action may be needed such as the removal of subflooring or even floor joists.

After interior walls, floors, and furniture have been cleaned, disinfected, and dried, they can be sealed with impermeable finishes such as alkyd paints.

As a preventive measure in the bathroom, regular cleaning of all surfaces is a must. Vinegar, borax, and bleach solutions (1 cup to 1 gallon of water) and trisodium phosphate solutions (4 T to 1 gallon of hot water) are inexpensive, but effective cleaning solutions.

**Condensation on surfaces, dampness, and standing water:** Any condensation or standing water must be eliminated. Dripping pipes should be identified and repaired. Plants should not be overwatered or allowed to stand in water. Increased air circulation and ventilation may be needed.

In the bathroom, dampness can be controlled by careful caulking to seal all seams around tubs, baseboards, sinks, and shower doors. Tight fitting shower doors of glass and metal are preferred to plastic shower curtains. Insulation under the tub, cold water pipe insulation, and insulated toilet tank liners can reduce sweating.

Floor materials in the bathroom and kitchen should be impervious to water; carpeting should be discouraged (it is not allowed in building codes). Walls and ceiling paints should be waterproof; alkyd oil paints are preferred. An exception to waterproofing ceilings is if humidity will be removed through attic spaces. Bathroom windows with metal or plastic frames are easiest to clean and keep dry; wood frames require more maintenance.

Greenhouses should have floor drains and drainage built into beds and planters to prevent standing water. To minimize the collection of water on exposed surfaces, all cracks should be sealed and the space should be well ventilated (preferably by an automatic ventilator). If greenhouse humidity is high, air circulation from it into the living space may not be advisable. Vapor retarders and insulation should be evaluated and corrected as needed.

Damp insulation and wood in the attic may require replacement of insulation, installation of vapor retarders, or the installation of natural or mechanical exhaust vents.

Vapor retarders that are not installed properly (for example joints and penetrations are not sealed) can be upgraded by a skilled homeowner or a skilled tradesperson. If a double vapor retarder (on both sides of a wall surface) is causing problems, or if the vapor retarder is on the cold side, the remedy may be to place a vapor retarder on the warm side only.

There are several strategies for waterproofing walls. Vapor retarding paints can be applied. Another method is to remove the wallboard or plaster, staple up sheets of polyethylene (4 to 6 mils), and replace the wallboard with new material. Other methods can also be used.

Concrete block homes (1940s and 1950s construction) that have not been renovated may have condensation problems because of poor circulation of warmed air. These homes often require the installation of second wall against the existing wall. Insulation can be stapled between the studs, and a vapor retarder can be installed over the insulation. Wallboard is then nailed to the framing. Door and window frames must also be adjusted.

**Heating, ventilating, and air-conditioning systems:** Improperly sized heating, ventilating, and air-conditioning systems should be corrected. Any venting systems that introduce potential aerosols into the living space should be corrected. Intake ducts should be relocated, or sources of contamination should be removed.

In general, any condensation pans or drainage tubes in the heating, ventilating, and air-conditioning systems should be checked on a regular basis. Drainage tubes that are plugged should be cleaned; drain pans should be emptied and slanted toward drains. Regular cleaning and maintenance of all system components is a must.

Condensation in the venting system of mid-efficiency furnaces (or other furnaces) may be solved by checking and correcting the size of vents; these vents should not be insulated unless specifically approved by the manufacturer.

If disinfection of the heating, ventilating, or air-conditioning system components is required, the system should be off during cleaning. Disinfecting agents should not be sprayed through the system. Removal and replacement of entire units or ducts may be required if the contamination is heavy or if components are not accessible.

The continuous use of humidifiers particularly in new houses (which have a naturally higher moisture content from construction materials) and in houses without vapor retarders can be a problem. If humidifiers are used, water should be changed daily, and the tank should be emptied completely before filling. If the tank is not removable, it should be cleaned according to the manufacturer's instructions. If instructions are not available, units should be free of scale and slime at all times. These units should be disinfected (5% bleach or 3% hydrogen peroxide solution) every third day (ACGHI, 1989). Antifoulant agents that are added to humidifier fluid reservoirs to control microbial populations can become aerosolized, and they may not be effective (Burge *et al.*, 1980).

The Consumer Product Safety Commission (1988) recommends against the use of tap water in humidifiers to minimize mineralized aerosols (does not appear to be a problem with evaporative humidifiers). Instead, distilled or demineralized water should be used to reduce the buildup of scale and release of aerosols. If demineralization cartridges or filters are recommended for a particular unit, they should be used. Before humidifiers are stored, the tank should be drained and cleaned; the units should also be cleaned again prior to use.

Air conditioners are effective in reducing moisture levels indoors and indoor concentrations of bioaerosols, but they can also act as sources of contamination. Filters should be cleaned or replaced regularly (once/month to once/3 months). Air conditioner condensation should be drained to the outside, not to the crawl space.



Condensate from the air cooling coil of air conditioners should be collected and diverted to the outside of the building or other approved location; any other drainage methods such as discharge into a crawl space, under concrete slabs, or through a rigid connection into the building sanitary drainage system, must be corrected. If drainage is into the sewer system, an observable air gap must be installed if it is not present; this prevents sewer gas from entering the heating and cooling system.

If surface condensation is a possibility, all refrigerant ducts, pipes, and fittings installed within a structure should be sealed, insulated, and vapor retarders should be added as needed.

If the cooling coil or air-conditioning unit is located above a living space or if structural damage could result from condensate overflow additional measures may be needed. These include installing an additional watertight pan of corrosion resistant metal beneath the cooling coil or unit to catch overflow condensate due to a clogged condensate drain.

Water or "swamp" coolers are not recommended in humid climates because they are a constant source of humidity.

**Basement, crawl space, and attic:** Standing water in the crawl space should be removed by a properly working sump pump. Loose wood, paper, and insulation should be removed.

Vent openings should be clear of foundation plantings and other obstructions to airflow. An adequate number of vents should be installed (oriented to take advantage of the prevailing wind) and vents should be kept open during the summer to provide good airflow in the crawl space. If foundation vents are not sufficient to provide the required ventilation, an exhaust fan can be installed. Uninsulated heating ducts which are located in the crawl space should be wrapped at the joints with duct tape and insulated.

Ground moisture can be controlled in the crawl space by placing a layer of sheet plastic on leveled soil, followed by a 3 inch layer of sand. The foundation should be waterproofed on the outside wall (described below) and a drain tile should be installed around the footings to drain away any water.

An alternative method of controlling ground moisture in the crawl space is to seal the undersides of the floor joists with a vapor retarder. Ducts or pipes that pass through the retarder are sealed with duct tape to the retarder. A moisture-tight surface is needed, and this method may not be practical if many ducts or pipes are present.

In the basement, leaks should be sealed; cement-based sealants can be used. The walls and floors can be covered with a waterproofing compound. If this measure does not work, leakage can be stopped by adding a drain tile and waterproofing the foundation. This can be costly because excavation of the foundation is required. After the foundation has been excavated and the drain tile installed, the foundation walls are coated with a thick application of asphalt roofing cement (from the footing to grade level). A vapor barrier of black 4 mil polyethylene film is applied onto the asphalt roofing cement. Joints should be overlapped, and the entire barrier should be coated with a thin application of the roofing cement. The filled area should slope away from the house (about 1 in/ft). A knowledgeable contractor should be consulted for leakproofing operations.

It may be necessary to install a heater and/or dehumidifier in the basement to control moisture. Showers in the basement should be discouraged. Sumps or other openings to the ground should be sealed, and water traps must be properly maintained. If possible a source of light, preferable daylight, should be introduced.

In new construction a vapor retarder should be installed in crawl spaces and before pouring concrete slab floors and basements.

**Exhibit 8-26. Environmental survey form for evaluating the presence of potential sources of allergens.**

Date \_\_\_\_\_

Name \_\_\_\_\_ Phone \_\_\_\_\_ Age of House \_\_\_\_\_ Square Footage \_\_\_\_\_

Address \_\_\_\_\_ Construction Material \_\_\_\_\_ Number of Occupants \_\_\_\_\_

**1. OUTDOOR SURVEY (describe each category that applies)**

a. weather conditions at time of survey \_\_\_\_\_

b. cultivated fields \_\_\_\_\_

c. number of trees \_\_\_\_\_

d. other landscaping \_\_\_\_\_

e. shade level adjacent to structure \_\_\_\_\_

f. soil drainage \_\_\_\_\_

g. presence of organic debris \_\_\_\_\_

h. any unusual outdoor activity prior to survey \_\_\_\_\_

i. presence of accumulated bird droppings \_\_\_\_\_

**2. EXTERIOR OF HOUSE**

a. Evaluate the condition of the exterior shell (warping, blistering paint, rot or mildew on wood surfaces). \_\_\_\_\_

b. Evaluate the condition of the exterior foundation (water stains, efflorescence, crumbling concrete, rot or mildew on wood surfaces).  
\_\_\_\_\_c. Exterior footing drains present? If yes, is the point of discharge clear or buried?  
\_\_\_\_\_d. Evaluate condition of downspouts? Do they hamper drainage away from the house?  
\_\_\_\_\_e. Evaluate condition of roofing material (peeling or flaking, evidence of ice dams).  
\_\_\_\_\_f. Are attic vents present? If yes, describe type and number. \_\_\_\_\_  
\_\_\_\_\_g. Evaluate condition of chimneys (capping, chimney cracks, nests).  
\_\_\_\_\_**3. EVIDENCE OF INTERIOR WATER DAMAGE OR MOISTURE**

a. Relative humidity \_\_\_\_\_

b. Is there a sensation of dampness or a musty odor? If yes, give locations.  
\_\_\_\_\_

**Exhibit 8-26. Environmental survey form for evaluating the presence of potential sources of allergens (continued).**

c. Is there any visible mold, mildew, or rot? If yes, give locations.

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d. Is condensation present on windows or smooth surfaces? If yes, give locations.

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e. Is there evidence of water damage or dampness? (around tub and shower, behind and under toilet, behind sinks, at baseboards, around splash boards, ceilings, walls, around skylights) If yes, give locations.

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f. Is standing water present? If yes, give locations.

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g. Has there been any water disaster in the history of the home? (water softener/washer/bathtub/toilet overflow, chronic interior water leaks, roof leaks, basement leaks, backflushing of sumps) Describe in detail.

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4. HEATING SYSTEM: ON or Off during survey (circle one)

a. forced air \_\_\_\_\_ b. electric \_\_\_\_\_

c. gravity \_\_\_\_\_ d. fireplace \_\_\_\_\_

e. space heater (indicate type \_\_\_\_\_)

f. Heat recovery ventilators. If present, describe condition maintenance procedures, and frequency of maintenance. Especially note if condensation removal is needed. \_\_\_\_\_

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g. Have any renovations, weatherproofing, or other energy efficiency measures occurred since the original system was installed? If yes, describe: \_\_\_\_\_

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h. Has the heating system been changed? If yes, describe: \_\_\_\_\_

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(continued next page)

**Exhibit 8-26. Environmental survey form for evaluating the presence of potential sources of allergens (continued).****5. AIR CLEANING DEVICES (circle one)**

ON or OFF during survey (circle) PORTABLE or CENTRAL (circle)

- a. HEPA \_\_\_\_\_ b. electrostatic \_\_\_\_\_
- c. other \_\_\_\_\_
- d. Evaluate condition, maintenance procedures, and frequency of maintenance. \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

**6. AIR-CONDITIONING SYSTEM ON or OFF during survey (circle one)**

- a. portable \_\_\_\_\_ b. central \_\_\_\_\_ c. swamp cooler \_\_\_\_\_
- d. Evaluate condition, maintenance procedures, and frequency of maintenance. Especially note condensate removal procedures.
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

- e. Has the cooling system been changed? If so, describe: \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

**7. HUMIDIFICATION OR DEHUMIDIFICATION DEVICE**

ON or OFF during survey (check one)

- a. humidifier \_\_\_\_\_ b. dehumidifier \_\_\_\_\_
- c. in-line \_\_\_\_\_ d. portable \_\_\_\_\_
- e. How often is the device used? \_\_\_\_\_
- f. If present, evaluate condition and cleaning procedures.
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

- g. How frequently is the unit cleaned? \_\_\_\_\_

- h. Are slime or scale present? \_\_\_\_\_
- \_\_\_\_\_

**8. PRESENCE OF ORGANIC SUBSTRATES**

- a. Are there wicker or straw items? If yes, check for history of water damage.
- \_\_\_\_\_

**Exhibit 8-26. Environmental survey form for evaluating the presence of potential sources of allergens (continued).**

b. Are there indoor pets? If yes, which and how many?

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c. What type of bedding is used? Is it cleaned regularly?

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d. Are there house plants? If so, how many, and location. Is there an attached greenhouse? Is greenhouse air circulated into the living space?

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e. Is there carpeting? If so, what percent of the floor is covered? Describe condition (note water stains, dust loading). Note if carpeting is present in bathrooms.

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**9. BASEMENT, CRAWL SPACE, AND ATTIC**

a. Is there standing water in the basement or crawl space? If yes, check for length of time present. \_\_\_\_\_

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b. Check sumps and drains for proper drainage by running water in them with a hose for about 5 min. to see if they back up. Are the drains clear? \_\_\_\_\_

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c. Are there cracks or seepage in the basement? \_\_\_\_\_

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d. Are vapor retarders present in the crawl space, basement (floors or walls), or attic?

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e. Are ducts, pipes, and fittings properly insulated in the basement, crawl space, or attic? \_\_\_\_\_

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(continued next page)

**Exhibit 8-26. Environmental survey form for evaluating the presence of potential sources of allergens (continued).**

- f. Are there signs of water-damaged wood, damp or wet insulation, or visible mold in the basement, crawl space, or attic? \_\_\_\_\_

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- g. Do the attic, basement, and crawl space have adequate ventilation? Describe vents and exhaust fans.

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- h. Do the attic or crawl space act as air plenums? If yes, are there problems associated with this use?

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NOTES:

**Exhibit 8-27. Commonly used samplers for collecting indoor bioaerosols.**

SAMPLER	PRINCIPLE OF OPERATION	SAMPLING RATE, lpm	RECOMMENDED SAMPLE TIME	MINIMUM CFU DETECTED	APPLICATIONS/REMARKS
1. Slit to agar impactor	impaction onto agar on rotating plate or stationary plate	30-700 continuous	variable; 1-60 min or 7-day		Provides information on aerosol concentration over time; bulky AC operation
2. Sieve type impactors					
a. single-stage portable	impaction onto agar on "rodac" plate	90 or 185	0.5 or 0.3 min	22 or 16	About 40% as efficient as slit sampler; portable, useful as probe
b. single-stage impactor	impaction onto agar, 100 mm plates	28	1 min	35	Nearly as efficient as slit, bulky to handle, AC operation
c. two-stage impactor	impaction onto agar, two 100 mm plates	28	1-5 min	35	Same as 2b but divides samples into respirable and non-respirable fractions
3. Filter cassettes	filtration	1-2	15-60 min or 8 hr	8-33	Some dessication loss; portable, inexpensive, useful as a probe
4. High-volume filtration	electrostatic collection into liquid	up to 1000	variable		
5. All glass impingers	impingement into liquid	12.5	30 min	3	Fungi require wetting agent; useful over wide range of particle concentrations
6. Centrifugal sampler	impaction onto agar, plastic strips	40	0.5 min	50	Cannot be calibrated; small, portable, useful as a probe

SOURCE: Adapted from ACGIH (1989)

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