CHAPTER 3

ENVIRONMENTAL TOBACCO SMOKE CHEMISTRY AND EXPOSURE OF NONSMOKERS

CONTENTS

Introduction

The physicochemical nature of environmental tobacco smoke (ETS) is governed by the type and form of the tobacco product or products burned, by the prevailing environmental conditions, and by secondary reactions. Mainstream smoke (MS) is the complex mixture that exits from the mouthpiece of a burning cigarette, cigar, or pipe when a puff is inhaled by the smoker. Sidestream smoke (SS) is formed between puff-drawings and is freely emitted into the air surrounding a smoldering tobacco product. Sidestream smoke represents the major source for ETS. The exhaled portions of MS and the vapor phase components that diffuse through the wrapper into the surrounding air constitute minor contributors to ETS.

In the scientific literature, the terms "passive smoking," "involuntary smoking," and "inhalation of ETS" are frequently used interchangeably (US DHEW 1979; US DHHS 1982, 1984).

Laboratory Smoking

Data on the composition of MS and SS originate from laboratory studies. For such studies, cigarettes, cigars, or pipes are smoked by machines under standardized reproducible conditions. It is a major goal of these measurements to compare the yields of the specific components in the MS or SS or both of a variety of experimental or commercial tobacco products and to simulate, though not to reproduce, human smoking habits. The most widely used standard conditions for machine smoking cigarettes and little cigars ($\leq$ 1.5 g) are one 35 mL puff of 2-second duration drawn once a minute to a butt length of 23 mm, or the length of the filter tip plus the over-wrap plus 3 mm (Brunnemann et al. 1976). The annual reports of the U.S. Federal Trade Commission on the tar, nicotine, and carbon monoxide content of the smoke of U.S. commercial cigarettes are based on these laboratory smoking conditions. For cigars, the standard smoking conditions are a 20 mL puff of 1.5-second duration taken once every 40 seconds, and a butt length of 33 mm (International Committee for Cigar Smoke Study 1974). The most frequently used pipesmoking conditions call for the bowl to be filled with 1 g of tobacco and a 50 mL puff of l-second duration to be taken every 12 seconds (Miller 1964).

A number of devices for collecting sidestream smoke have been developed (Dube and Green 1982). The most widely used device is a collection apparatus made of glass and cooled by water circulating through an outer jacket. The air entering the chamber through a distributor has a flow rate of 25 mL per second (1.5 L/min) (Brunnemann and Hoffmann 1974). Under these conditions, the yields of mainstream smoke components from a cigarette approximate those obtained from the same cigarette when it is being smoked

in the open air. However, the velocity of the airstream through the chamber has considerable influence on the yields of individual compounds in SS (Klus and Kuhn 1982).

To collect the particulate phase of MS and SS, the smoke aerosols are passed through a glass fiber filter (a Cambridge filter with a diameter of 45 mm) that traps more than 99 percent of all particles with a diameter of at least 0.1 μm (Wartman et al. 1959). The portion of the smoke that passes through the glass fiber filter is arbitrarily designated as vapor phase, although it is realized that this separation does not fully reflect the actual physicochemical conditions prevailing in MS and SS. For the analysis of individual components or a group of components, specific trapping devices and methods have been developed (Dube and Green 1982).

Human Smoking

The standardized machine-smoking conditions used in the tobacco laboratory were set up to simulate the parameters of human smoking as practiced 30 years ago. The examination of current smoking practices suggests that machine-smoking conditions no longer reflect current practices. Human smoking patterns depend on a number of factors, one of which is the delivery of nicotine. Dosimetry of smoke constituents has shown that low nicotine delivery (<0.6 to 1.0 mg/cigarette) generally induces the smoker to draw larger puff volumes (up to 55 mL per puff), to puff more frequently (three to five times a minute), and to inhale more deeply (Herning et al. 1981). Furthermore, many smokers of cigarettes with perforated filter tips tend to obstruct the holes in these tips by pressing their lips around them; thus, they inhale more smoke than would be expected according to the machine-smoking data (Kozlowski et al. 1980). Smokers of cigarettes with a longitudinal air channel in the filter tip compress the tip in a similar manner so that the mainstream smoke delivery is increased over that measured with the laboratory methodology (Hoffmann et al. 1983).

These deviations from machine-smoking patterns cause a greater amount of tobacco to be consumed during MS generation. Consequently, the quantity of tobacco burned between puffs is diminished, and lower amounts of combustion products are released as SS. Because of the proximity to the burning tobacco product, the active smoker usually inhales more of the SS and ETS than a nonsmoker.

It is not known to what extent the different constituents of inhaled ETS aerosols can be retained in the respiratory tract of nonsmokers. Studies with MS have shown that more than 90 percent of the volatile, hydrophilic components are retained by the smoker (Dalhamn et al. 1968a) and that less than 50 percent of the volatile, hydrophobic MS components are retained by the smoker (Dalhamn et al. 1968b). On the basis of these data, it may be assumed that the

passive smoker retains a high percentage of the vapor phase components of ETS and significantly less of its hydrophobic volatiles.

Sidestream Smoke

Formation and Physicochemical Nature

When nonfilter cigarettes are being smoked under standardized conditions, approximately 45 percent of the tobacco column is consumed during the generation of MS (puff-drawing), whereas the remainder is burned between puffs and under conditions of a strongly reducing atmosphere. In addition, MS and SS is generated at distinctly higher temperatures than SS (Wynder and Hoffmann 1967). Thus, undiluted SS contains more tobacco-derived combustion products than does MS, and contains especially greater quantities of those combustion products that are formed by nitrosation or amination. Consequently, the composition of SS differs from that of MS.

The SS of a smoldering cigarette enters the surrounding atmosphere about 3 mm in front of the paper burn line, at about 350° C (Baker 1984). In Table 1, the MS and the SS from nonfilter cigarettes are compared. Under standardized conditions, the formation of the MS of a nonfilter cigarette (80 mm, 1,230 mg) is completed during 10 puffs, requires 20 seconds, and consumes 347 mg of tobacco. The formation of SS from the same cigarette during smoldering requires 550 seconds and consumes 411 mg of tobacco (Neurath and Horstmann 1963).

The pH of the MS of a blended U.S. cigarette ranges from 6.0 to 6.2 and the pH of SS, from 6.7 to 7.5. Above pH 6, the proportion of unprotonated nicotine in undiluted smoke rises; at pH 7.9, about 50 percent is unprotonated. Therefore, SS contains more free nicotine in the vapor phase than MS. The reported measurements of the pH of cigars were 6.5 to 8.5 for MS and 7.5 to 8.7 for SS; measurements for the pH of SS from pipes have not been published (Brunnemann and Hoffmann 1974).

Chemical Analysis

In order to establish reproducible chemical-analytical data, cigarette SS is generated in a special chamber. This assures that the cigarettes burn evenly during puff intervals when an airstream at a velocity of 25 mL per second is drawn through the chamber. At this flow rate in the chamber, MS generation is quantitatively similar to that measured without the SS chamber (Neurath and Ehmke 1964; Brunnemann and Hoffmann 1974; Dube and Green 1982). Throughout this chapter the data refer primarily to MS, SS, and ETS deriving from cigarettes and not from cigars or pipes; because

TABLE 1.—Comparison of mainstream smoke (MS) and sidestream smoke (SS) of a nonfilter cigarette: Some physicochemical data

Study	Parameters	MS	SS
Neurath and Horstmann (1963)	Duration of smoke production (sec)	20	550
	Tobacco burned (mg)	347	411
Wynder and Hoffmann (1967)	Peak temperature during formation (°C)	≃900	≃600
Brunnemann and Hoffmann (1974)	pH of total aerosol	6.0–6.2	6.7–7.5
Scassellati-Sforzolini and Savino (1968)	Number of particles per cigarette[1]	10.5×10^{12}	3.5×10^{12}
Carter and Hasegawa (1975); Hiller et al. (1982)	Particle sizes (nm)[1]	0.1–1.0	0.01–0.8
	Particle mean diameter (nm)[1]	0.4	0.32
Wynder and Hoffmann (1967); Keith and Derrick (1960); Baker (1984); Hoffmann, Brunnemann et al. (1984)	Smoke dilution (vol %)[2]		
	Carbon monoxide	3–5	2–3
	Carbon dioxide	8–11	4–6
	Oxygen	12–16	1.5–2
	Hydrogen	3–15	0.8–1.0

NOTE: Data obtained under standard laboratory smoking conditions of 1 puff per minute of 2-second duration and 35 mL volume.

[1] Fresh and undiluted mainstream smoke and sidestream smoke.

[2] Four mm distant from the burning cone (gas temperature, 350° C).

cigarette smoke is the major source of ETS in public places. Few data are available on the SS and ETS from cigars and pipes.

About 300 to 400 of the several thousand individual compounds identified in tobacco smoke have been quantitatively determined in both mainstream and sidestream smoke. A listing of selected agents in the MS of nonfilter cigarettes with their reported range of concentration and their relative ratio of distribution in SS compared with MS is presented in Table 2. Values greater than 1.0 reflect the greater release of a given compound into SS than into MS. The grouping of the compounds in Table 2 into vapor phase components and particulate phase constituents refers to the makeup of MS, but does not represent the physicochemical distribution of these compounds in SS. Some of the volatile compounds in MS and SS are compared. On the basis of the amount of tobacco burned in the MS and SS of a nonfilter cigarette (see Table 1), the ratio of SS to MS should be 1.2 to 1.5 if the combustion conditions during both phases of smoke generation were comparable. However, this is not the case,

as is indicated by the higher SS to MS ratios for carbon monoxide (2.5-4.7), carbon dioxide (8-11), acrolein (8-15), benzene (10), and other smoke constituents.

The high yield of carbon monoxide and carbon dioxide in SS indicates that more carbon monoxide is generated during smoldering than during puff-drawing. After passing very briefly through the hot cone, most of the carbon monoxide gas in both MS and SS is oxidized to carbon dioxide, most likely owing to the high temperature gradient and the sudden exposure to environmental oxygen upon emission.

The higher yields of volatile pyridines in SS compared with MS are probably caused by the preferred formation of these compounds from the alkaloids during smoldering (Schmeltz et al. 1979). In contrast, hydrogen cyanide (HCN) is primarily formed from protein at temperatures above 700° C (Johnson and Kang 1971), and the smoldering of tobacco at about 600° C does not yield the pyrosynthesis of HCN to the extent that it occurs at the higher temperatures present during MS generation. The very high levels of ammonia, nitrogen oxide, and the volatile N-nitrosamines in SS compared with the levels in MS is striking. Studies with ^{15}N-nitrate have underscored that the burning of tobacco results in the reduction of nitrate to ammonia, and that the latter is released to a greater extent during SS formation than during puff-drawing (Johnson et al. 1973). In a blended cigarette, this higher level of ammonia in SS causes its elevated pH to reach levels of 6.7 to 7.5, while the pH of MS is about 6 (Brunnemann and Hoffmann 1974).

The increased release of the highly carcinogenic volatile N-nitrosamines into SS (20 to 100 times greater than into MS) has been well established (Brunnemann et al. 1977). The carcinogenic potential of SS may also be affected by the levels of the oxides of nitrogen (NOx. Four to ten times more nitrogen oxide (NO) is released into the environment in sidestream smoke than is inhaled with the mainstream smoke. The smoker inhales more than 95 percent of the NO, in the form of NO, and only a small portion is oxidized to the powerful nitrosating agent nitrogen dioxide (NO_2). Only a fraction of NO is expected to be retained in the respiratory system of smokers by being bound to hemoglobin. The NOx gases released into the environment are partially oxidized to NO_2 (Vilcins and Lephardt 1975). Therefore, sidestream smoke-polluted environments are expected to contain the hydrophilic nitrosating agent NO_2.

Data for particulate matter and some of its constituents in MS and SS are also listed in Table 2. The release of tobacco-specific N-nitrosamines into SS is up to four times higher than that into MS. Whether the distribution of these agents in the vapor phase and the particulate phase of SS is of major consequence with respect to the carcinogenic potential of SS needs to be determined. It is equally

TABLE 2.—Distribution of constituents in mainstream smoke (MS) and the ratio of sidestream smoke (SS) to MS of nonfilter cigarettes

Vapor phase constituents[1]	MS range	SS/MS ratio	Particulate phase constituents[1]	MS range	SS/MS ratio
Carbon monoxide	10–23 mg	2.5–4.7	Particulate matter[2]	15–40 mg	1.3–1.9
Carbon dioxide	20–40 mg	8–11	Nicotine	1–2.5 mg	2.6–3.3
Carbonyl sulfide	18–42 μg	0.03–0.13	Anatabine	2–20 μg	<0.1–0.5
Benzene[1]	12–48 μg	10	Phenol	60–140 μg	1.6–3.0
Toluene	160 μg	6	Catechol	100–360 μg	0.6–0.9
Formaldehyde	70–100 μg	0.1–≅50	Hydroquinone	110–300 μg	0.7–0.9
Acrolein	60–100 μg	8–15	Aniline	360 ng	30
Acetone	100–250 μg	2–5	2-Toluidine	160 ng	19
Pyridine	16–40 μg	6.5–20	2-Naphthylamine[2]	1.7 ng	30
3-Methylpyridine	12–36 μg	3–13	4-Aminobiphenyl[2]	4.6 ng	31
3-Vinylpyridine	11–30 μg	20–40	Benz[a]anthracene[4]	20–70 ng	2–4
Hydrogen cyanide	400–500 μg	0.1–0.25	Benzo[a]pyrene[3]	20–40 ng	2.5–3.5
Hydrazine[3]	32 ng	3	Cholesterol	22 μg	0.9
Ammonia	50–130 μg	40–170	γ-Butyrolactone[4]	10–22 μg	3.6–5.0
Methylamine	11.5–28.7 μg	4.2–6.4	Quinoline	0.5–2 μg	8–11
Dimethylamine	7.8–10 μg	3.7–5.1	Harman	1.7–3.1 μg	0.7–1.7
Nitrogen oxide	100–600 μg	4–10	N'-Nitrosonornicotine[4]	200–3,000 ng	0.5–3

TABLE 2.—Continued

Vapor phase constituents[1]	MS range	SS/MS ratio	Particulate phase constituents[1]	MS range	SS/MS ratio
N-Nitrosodimethylamine[4]	10–40 ng	20–100	NNK[4]	100–1,000 ng	1–4
N-Nitrosopyrrolidine[4]	6–30 ng	6–30	N-Nitrosodienthanolamine[4]	20–70 ng	1.2
Formic acid	210–490 μg	1.4–1.6	Cadmium	100 ng	7.2
Acetic acid	330–810 μg	1.9–3.6	Nickel[3]	20–80 ng	13–30
			Zinc	60 ng	6.7
			Polonium-210[2]	0.04–0.1 pCi	1.0–4.0
			Benzoic acid	14–28 μg	0.67–0.95
			Lactic acid	63–174 μg	0.5–0.7
			Glycolic acid	37–126 μg	0.6–0.95
			Succinic acid	110–140 μg	0.43–0.62

[1] Values are given for fresh and undiluted MS and SS.

[2] Human carcinogen (IARC 1986).

[3] Suspected human carcinogen (IARC 1986).

[4] Animal carcinogen (IARC 1986).

SOURCE Elliott and Rowe (1975); Hoffmann et al. (1983); Klus and Kuhn (1982); Sakuma et al. (1983); Sakuma, Kusama, Yamaguchi, Matsuki et al. (1984); Sakuma, Kusama, Yamaguchi, Sugawara (1984); Schmeltz et al. (1975).

important to examine the significance of the abundant release of amines into SS (levels are up to 30 times higher than in MS), indicated by the data for aniline, 2-toluidine, and the alkaloids. This is of concern because certain amines are readily nitrosated to N-nitrosamines. However, analytical date on secondary reactions of amines in polluted environments are lacking.

For a meaningful interpretation of the data on the distribution of the compounds in cigarette smoke presented in Table 2, certain aspects of the methodology should be emphasized. First, the data are based on analyses of nonfilter cigarettes that were smoked under standardized laboratory conditions. Second, the standardized machine-smoking conditions were established according to human smoking patterns observed three decades ago and do not reflect the smoking behavior of contemporary smokers. This caveat applies particularly to smoking patterns observed with filter cigarettes designed for low smoke yields. Most consumers of these cigarettes inhale the smoke more intensely than smokers of nonfilter cigarettes (Herning et al. 1981; Hill et al. 1963). This change in smoking intensity affects the delivery of the sidestream smoke. The conventional filter tips of cigarettes influence primarily the yield of MS and have little impact on SS yield. However, in the case of cigarettes with specially designed filter tips such as perforations, the yield of SS is also affected (Table 3) (Adams et al. 1985).

Radioactivity of Tobacco Smoke

Naturally occurring decay products of radon are found in tobacco and, therefore, also in tobacco smoke. These include the isotopes of lead (Pb-210), bismuth (Bi-210), polonium (Po-210), and radon, which originates from the decay of uranium through radium (Radford and Hunt 1964; Martell 1975). Radon and its short-lived daughters (Po-218, Pb-214, Bi-214, Po-214), which precede long-lived daughters in the decay chain, are ubiquitous in indoor air and are largely derived from sources other than tobacco smoke. Most of the radon daughters are attached to particles in the air, but a small proportion, referred to as the unattached fraction, is not (Raabe 1969; Kruger and Nöthling 1979; Bergman and Axelson 1983).

It has been suggested that the presence of Pb-210 and subsequent decay products in tobacco is dependent upon an absorption of short lived radon daughters on the leaves of the tobacco plant, especially where phosphate fertilizers that are rich in radium have been used and have caused increased leakage of radon from the ground. These attached short-lived radon daughters then decay to long-lived Pb-210 and subsequent nuclides found in the tobacco (Fleischer and Parungo 1974; Martell 1975). However, the origin of these decay products may

TABLE 3.--Distribution of selected components in the sidestream smoke (SS) and the ratio of SS to mainstream smoke (MS) of four U.S. commercial cigarettes

Components	Cigarette A 85 mm NF		Cigarette B 85 mm F		Cigarette C 85 mm F		Cigarette D 85 mm PF	
	SS	SS/MS	SS	SS/MS	SS	SS/MS	SS	SS/MS
Tar (mg/g)	22.6	1.1	24.4	1.6	20.0	2.9	14.1	15.6
Nicotine (mg/g)	4.6	2.2	4.0	2.7	3.4	4.2	3.0	20.0
Carbon monoxide (mg/g)	28.3	2.1	36.6	2.7	33.2	3.5	26.8	14.9
Ammonia (mg/g)	524	7.0	893	46	213.1	6.3	236	5.8
Catechol (µg/g)	58.2	1.4	89.8	1.3	69.5	2.6	117	12.9
Benzo[a]pyrene (ng/g)	67	2.6	45.7	2.6	51.7	4.2	448	20.4
N-Nitrosodimethyamine (ng/g)	735	23.6	597	139	611	50.4	685	167
N-Nitrosopyrrolidine (ng/g)	177	2.7	139	13.6	233	7.1	234	17 7
N'-Nitrosonornicotine (ng/g)	857	0.85	307	0.63	165	0.68	338	5.1

NOTE: NF, nonfilter cigarette; F. filter cigarette; PF, cigarette with perforated filter tip; values given are for fresh and undiluted sidestream and mainstream smoke
SOURCE: Adams et al. (1985).

also depend on the general occurrence of radon in the atmosphere and not on the local emanation of radon (Hill 1982).

In recent years, it has been shown that relatively high levels of radon and short-lived radon daughters may occur in indoor air, and consistent observations in this regard have been made in several countries (Nero et al. 1985). In the air with a very low concentration of particles, the proportion of unattached radon daughters is increased beyond that found with a higher concentration of particles. The unattached daughters are removed more rapidly than those that are attached by plating out on walls and fixtures. The addition of an aerosol, such as tobacco smoke, increases the attached fraction, elevates the concentration of radon daughters, and reduces the rate of removal of radon daughters (Bergman and Axelson 1983). The dose of a radiation received by the airway epithelium depends not only on the concentration of radon daughters but also on the unattached fraction and on the size distribution of the inhaled particles. The interplay among these factors as they are modified by ETS has not yet been fully examined.

Environmental Tobacco Smoke

The air dilution of sidestream smoke, and of other contributors to ETS, causes several physicochemical changes in the aerosol. The concentration of particles in ETS depends on the degree of air dilution and may range from 300 to 500 mg/m^3 to a few $\mu g/m^3$. At the same time, the median diameter of particles may decrease as undiluted SS is diluted to form ETS (Keith and Derrick 1960; Wynder and Hoffmann 1967; Ingebrethsen and Sears 1986). Furthermore, nicotine volatilizes during air dilution of SS, so that in ETS it occurs almost exclusively in the vapor phase (Eudy et al. 1985). This is reflected in the fairly rapid occurrence of relatively high concentrations of nicotine in the saliva of people entering a smoke-polluted room (Hoffmann, Haley et al. 1984). Most likely there are also redistributions between the vapor phase and the particulate phase of other constituents in SS due to air dilution, which may account for the presence of other semivolatiles in the vapor phase of ETS. However, evidence of such effects needs to be established.

Comparison of Toxic and Carcinogenic Agents in Mainstream Smoke and in Environmental Tobacco Smoke

The combustion products of cigarettes are the source of both environmental tobacco smoke and mainstream smoke. Therefore, comparisons of the levels of specific toxins and carcinogens in ETS with the corresponding levels in the mainstream smoke are relevant to an estimation of the risk of ETS exposure. Although ETS is a far

less concentrated aerosol than undiluted MS, both inhalants contain the same volatile and nonvolatile toxic agents and carcinogens. This fact and the current knowledge about the quantitative relationships between dose and effect that are commonly observed from exposure to carcinogens have led to the conclusion that the inhalation of ETS gives rise to some risk of cancer (IARC 1986).

However, comparisons of MS and ETS should include the consideration of the differences between the two aerosols with regard to their chemical composition, including pH levels, and their physicochemical nature (particle size, air dilution factors, and distribution of agents between vapor phase and particulate phase). Another important consideration pertains to the differences between inhaling ambient air and inhaling a concentrated smoke aerosol during puff-drawing. Finally, chemical and physicochemical data established by the analysis of smoke generated by machine-smoking are certainly not fully comparable to the levels and characteristics of compounds generated when a smoker inhales cigarette smoke. This caveat applies particularly to the smoking of low-yield cigarettes, for which the yields of smoke constituents in machine-generated smoking and human smoking activities may be most divergent (Herning et al. 1981).

The levels of certain smoke constituents in the mainstream smoke of one cigarette compared with the amounts of such compounds inhaled as constituents of ETS in 1 hour at a respiratory rate of 10 L per minute are presented in Table 4. Unaged MS does not contain nitrogen dioxide (NO_2<5 µg/cigarette) because the nitrogen oxides generated during tobacco combustion in the reducing atmosphere of the burning cone are transported in the smoke stream (~10 vol % 0,) to the exit of the cigarette mouthpiece in less than 0.2 seconds, and it takes 500 seconds for half of the nitrogen oxide in MS to oxidize to nitrogen dioxide (Neurath 1972). The relatively low values for nicotine reported in ETS may be explained, in part, by the inefficiency of the trapping devices for collecting all of the available nicotine; the alkaloid is predominantly in the vapor phase, which escapes retention by the filters of such devices.

The assignment of benzene as a “human carcinogen,” benzo-[a]pyrene as a “suspected human carcinogen,” and N-nitrosodimethylamine and N-nitrosodiethylamine as “animal carcinogens” is based on definitions by the International Agency for Research on Cancer (1986). Accordingly, a human carcinogen is an agent for which “sufficient evidence of carcinogenicity indicates that there is a causal relationship between exposure and human cancer.” A suspected human carcinogen is an agent for which “limited evidence of carcinogenicity indicates that a causal interpretation is credible, but that alternate explanations, such as chance, bias, or confounding, could not adequately be excluded.” An animal carcinogen is an agent

TABLE 4.—Concentrations of toxic and carcinogenic agents in nonfilter cigarette mainstream smoke and in environmental tobacco smoke (ETS) in indoor environments

	Mainstream Smoke		Inhaled as ETS constituents during 1 hour			
			Range		Episodic high values[1]	
Agent	Weight	Concentration	Weight	Concentration	Weight	Concentration
Carbon monoxide	10–23 mg	24,9000–57,300 ppm	1.2–22 mg	1–18.5 ppm	37 mg	32 ppm
Nitrogen oxide	100–600 μg	230,000–1,400,000 ppb	7–90 μg	9–120 ppb	146 μg	195 ppb
Nitrogen dioxide	<5 μg	<7,600 ppb	24–87 μg	21–76 ppb	120 μg	105 ppb
Acrolein	60–100 μg	75,000–125,000 ppb	8–72 μg	6–50 ppb	110 μg	80 ppb
Acetone	100–250 μg	120,000–300,000 ppb	210–720 μg	150–500 ppb	3,500 μg	2,400 ppb
Benzene[2]	12–48 μg	11,000–43,000 ppb	12–190 μg	6–98 ppb	190 μg	98 ppb
N-Nitrosodimethylamine[3]	10–40 ng	9–38 ppb	6–140 ng	0.003–0.072 ppb	140 ng	0.072 ppb
N-Nitrosodiethylamine[3]	4–25 ng	3–17 ppb	<6–120 ng	<0.002–0.05 ppb	120 ng	0.05 ppb
Nicotine	1,000–2,500 μg	430,000–1,080,000 ppb	0.6–30 μg	0.15–7.5 ppb	300 μg	75 ppb
Benzo[a]pyrene[4]	20–40 ng	5–11 ppb	1.7–460 ng	0.0002–0.04 ppb	460 ng	0.04 ppb

NOTE: Values for inhaled mainstream smoke components were calculated from values in Table 2 and on a respiratory rate of 10 L per minute. Values for carbon monoxide and nicotine represent the range in mainstream smoke of U.S. nonfilter cigarettes as reported by the U.S. Federal Trade Commission (1985). Data under ETS are derived from Tables 8 through 15, with data from the unventilated interior compartments of automobiles excluded (Badre et al. 1978).

[1] The designation "episodic high values" was chosen to classify those data in the literature that require confirmation.

[2] Human carcinogen according to the IARC (Vainio et al. 1985) and suspected carcinogen according to the ACGIH (1985).

[3] Animal carcinogen according to the IARC (Vainio et al. 1985).

[4] Suspected human carcinogen, according to the IARC (Vainio et al. 1985) and according to the ACGIH (1985).

"for which there is sufficient evidence of carcinogenicity in animals but for which no data on humans are available."

Polonium-210 is not listed in Table 4 because there are no data on the concentration of this isotope in ETS, although it is a component of both MS and SS. Whereas in clean air the short-lived radon daughters tend to plate out on room surfaces, in the presence of an aerosol such as ETS, some of the short-lived radon daughters become attached to particles and consequently remain available for inhalation. Radon daughter background concentration may more than double in the presence of ETS (Bergman and Axelson 1983).

Number and Size Distribution of Particles In Environmental Tobacco Smoke

Environmental tobacco smoke consists of the combined products of both fresh and aged sidestream smoke and exhaled mainstream smoke. Coagulation, evaporation, and particle removal on surfaces occur simultaneously to modify the physical characteristics of the ETS particles; as a result, the "typical" particle size and chemical composition of ETS may vary with the age of the smoke and the characteristics of the environment. Other factors such as relative humidity, particle concentration, and temperature may also affect the characteristics of ETS.

The rapid dilution of SS smoke as it is emitted into a room leads to a number of physical and chemical changes. For example, the evaporation of volatile species as the ETS ages reduces the median diameter of the smoke particles. Several studies have measured the particle distribution of SS under controlled conditions (Table 5), and indicate that the mass median diameter (MMD) of ETS is between approximately 0.2 μm and 0.4 μm. The differences among the studies reflect the varying analytical methods. ETS particles are in the diffusion-controlled regime for particle removal and therefore will tend to follow stream lines, remain airborne for long periods of time, and rapidly disperse through open volumes.

As indicated, a number of factors can produce variation in the mean size of the particles in ETS; however, in considering transport, deposition, and removal in the human lung, it is useful to assume that the particle sizes of aged ETS will generally be between 0.1 and 0.4 μm. Although the results presented in Table 5 do not permit the assignment of a single value for the diameter of sidestream smoke particles, the difference in deposition efficiency in the human respiratory tract of 0.2 μm particles and 0.4 μm particles is negligible (Chan and Lippmann 1930). Particles in this size range are not efficiently removed by sedimentation or impaction. Although diffusion is the major removal mechanism for particles of this size, it is minimally efficient in the 0.2 to 0.4 μm range. The relatively low

TABLE 5.--Summary of sidestream smoke size distribution studies

Study	Cigarette	Method	Chamber concentration ($\mu g/m^3$)	Count median diameter	Mass median diameter	Geometric standard deviation	Number per cm^3
Keith and Derrick (1960)	Blended	"Conifuge"	Not reported	0.15	Not reported	Not reported	3.8×10^{11}
Porstendörfer and Schraub (1972)	Not reported	CNC/diffusion tubs	Not reported	0.24	Not reported	Not reported	3.3×10^{12}
Hiller et al. (1982)	Not reported	SPART analyzer	50-100	0.32	0.41	1.5	Not reported
Leaderer et al. (1984)	Commercial	EAA	700	Not reported	0.225	2.1	Not reported
Ingebrethsen and Sears (1986)		MC/CNC			0.2	1.5	

NOTE: CNC = Condensation nucleus counter; SPART = Single particle aerodynamic relaxation time analyzer; EAA = Electrical aerosol analyzer; MC = Mobility classifier.

particle deposition efficiency for SS particles in human volunteers observed by Hiller and colleagues (1982) is consistent with particles in this size range.

Several investigators have measured the size distribution of MS smoke (Table 6). As is the case with SS smoke, the different instruments and methodologies employed yielded differing results.

For purposes of comparison, only two sets of studies utilizing similar instruments are discussed. McCusker and colleagues (1983), using a single particle aerodynamic relaxation time (SPART) analyzer to study highly diluted MS smoke particles, found a mass median diameter of 0.42 μm with a geometric standard deviation (GSD) of 1.38. Hiller and colleagues (1982) used the SPART analyzer on SS smoke particles and found a mass median diameter of 0.41 μm and GSD of 1.5. Chang and colleagues (1985) used an electrical aerosol analyzer (EAA) to measure MS for various dilution ratios and reported a MMD of 0.27 μm (GSD 1.26) for the highest dilution. Leaderer and colleagues (1984) used an EAA to determine the size distribution for SS smoke particles in an environmental chamber and determined an MMD of 0.23 μm (GSD 2.08). These results also show that studies utilizing similar instruments provide similar results for the size distribution of both SS and MS particles. As discussed in an earlier section, however, the chemical composition of the MS and ETS particles can be quite different because of the very different conditions of their generation and the subsequent dilution and aging ETS undergoes before inhalation.

Estimating Human Exposure to Environmental Tobacco Smoke

Human exposure to ETS can be estimated using approaches similar to those used for other airborne pollutants. The concentration of ETS to which an individual is exposed depends on factors such as the type and number of cigarettes burned, the volume of the room, the ventilation rate, and the proximity to the source. These factors, along with the duration of exposure and individual characteristics such as ventilatory rate and breathing pattern, dictate the dosage received by an individual.

Ideally, the health effects of exposures to ETS might be assessed by quantifying the time-dependent exposure dose for each of the several thousand compounds in cigarette smoke and defining the dose-response relationships for these compounds in producing disease, both as isolated compounds and in various combinations. The magnitude of this task, given the number of compounds in smoke, and the limited knowledge of the precise mechanisms by which these compounds cause disease have led to a simpler approach, one that attempts to use measures of exposure to individual smoke constituents as estimates of whole smoke exposure. The accuracy with which

TABLE 6.—Summary of mainstream smoke size distribution studies

Study	Cigarette	Method	Dilution ratio	Count median diameter (μm)	Mass median diameter (μm)	Geometric standard deviation	Concentration (number/cm³)
Keith and Derrick (1960)	Blended	"Conifuge"	295	0.23	Not reported	1.6	5.3×10^9
Porstendörfer and Schraub (1972)	Not reported	CNC/diffusion tube	Not reported	0.22	Not reported	Not reported	Not reported
Okada and Matsunama (1974)	Blended	Light scattering	1500	0.18	0.29	1.5	3×10^{10}
Hinds (1978)	Commercial	Cascade impactor	10	Not reported	0.52	1.35	Not reported
		Cascade impactor	50	Not reported	0.44	1.44	Not reported
		Cascade impactor	100	Not reported	0.39	1.43	Not reported
		Aerosol certifuge	100	Not reported	0.38	1.33	Not reported
		Aerosol certifuge	320	Not reported	0.38	1.37	Not reported
		Aerosol certifuge	500	Not reported	0.38	1.35	Not reported
		Aerosol certifuge	700	Not reported	0.37	1.31	Not reported
McCusker et al. (1983)	2R1	SPART analyzer	1.26×10^5	0.36	0.42	1.38	4.2×10^9
Chang et al. (1985)	2R1	EAA	6	0.25	0.30	1.27	4.2×10^9
			10	0.24	0.26	1.18	3.6×10^9
			18	0.22	0.26	1.26	7×10^8

NOTE: CNC = Condensation nucleus counter; SPART = Single particle aerodynamic relaxation time analyzer; EAA = Electrical aerosol analyzer.

measurements of a single compound reflect exposure to whole smoke is limited by the changes in the composition of ETS with time and the conditions of exposure. For this reason, exposures to JTS are often assessed using several measures as markers, including markers of the vapor phase and the particulate phase as well as reactive and nonreactive constituents. Although biological markers show promise as measures of exposure because they measure the absorption of smoke constituents, they too have limitations (discussed in Chapter 4). An individual's exposure is a dynamic integration of the concentration in various environments and the time that the individual spends in those environments.

In specifying an individual's exposure to specific components of ETS, consideration must be given to the time scale of exposure appropriate for the response of interest. Immediate exposures of seconds or hours would be most relevant for irritant and acute allergic responses. Time-averaged exposures, of hours or days, may be important for acute contemporary effects such as upper and lower respiratory tract symptoms or infections; chronic exposures occurring over a year or a lifetime might be associated with increased prevalence of chronic diseases and risk of cancer.

The spatial dimensions or the proximity of the individual to the source of smoke is important in assessing that individual's exposure to ETS. ETS is a complex, dynamic system that changes rapidly once emitted from a cigarette. Physical processes such as evaporation and dilution of the particles, scavenging of vapors on surfaces, and chemical reactions of reactive compounds are continuously occurring and modify the mixture referred to as ETS. An individual located a few centimeters or a meter from a burning cigarette may be exposed to a high concentration of ETS, ranging from 200 to 300 mg/m^3, and may inhale components of the mostly undiluted smoke plume and of the exhaled mainstream smoke. Ayer and Yeager (1982) reported cigarette plume concentrations of formaldehyde and acrolein in the core smoke stream emitted from the cigarette of up to 100 times higher than known irritation levels. Hirayama, as reported by Lehnert (1984), cites the importance of this "proximity effect" in assessing exposure. Distances on the order of a meter to tens of meters from a burning cigarette are relevant for exposures in offices, restaurants, a room in a house, a car, or the cabin of a commercial aircraft. At these distances, the mixing of ETS throughout the airspace and the factors that affect concentration are of importance in determining exposure for people in the space. In many rooms, mixing is not completely uniform throughout the volume, and significant concentration gradients can be demonstrated (Ishizu 1980). These concentration gradients will affect an individual's exposure by modifying the effectiveness of ventilation in diluting or removing pollutants. The airborne mass concentration may vary by

a factor of 10 or more within a room. Short-term measurements in rooms with smokers can yield respirable particulate concentrations of 100 to 1,000 $\mu g/m^3$ (Repace and Lowrey 1980). Multihour measurements average out variations in smoking, mixing, and ventilation and yield concentrations in the range of 20 to 200 $\mu g/m^3$ (Spengler et al. 1981, 1985, 1986). Finally, on a systems scale, as in a house or building, concentrations are influenced by dispersion and dilution through the volume. Most time-integrated samples are taken on this larger scale.

Using a piezobalance, Lebret (1985) found significant variation in respirable suspended particulate (RSP) levels between the living room, kitchen, and bedroom in homes in the Netherlands during smoking or within one-half hour of smoking. Ju and Spengler (1981) studied the room-to-room variation in 24-hour average concentrations of respirable particles in various residences. Although differences between some rooms were statistically significant, absolute differences were relatively small, with a maximum difference of a factor of 2.

Moschandreas and colleagues (1978) released sulfur hexafluoride, a tracer gas, in the living rooms of several residences and observed uniform concentrations in adjacent rooms within 30 to 90 minutes. RSP, which is slightly reactive, and nonreactive gases would be expected to rapidly migrate through adjacent rooms. Therefore, in a setting such as the work environment, where the duration of exposure is several hours or more, ETS would be expected to disseminate throughout the airspace in which smoking is occurring. Smoke dissemination may be reduced when air exchange rates are low, as may occur when internal doors are closed.

Time-Activity Patterns

Individual time-activity patterns are a major determinant of exposure to ETS. The population of the United States is mobile, spending variable amounts of time in different microenvironments. Individual activity patterns depend on age, occupation, season, social class, and sex. For example, Letz and colleagues (1984) surveyed the time-activity patterns of 332 residents of Roane County, Tennessee, and found that 75 percent of the person-hours were spent at home, 10.8 percent at work, 8.5 percent in public places, 2.9 percent in travel, and 2.8 percent in various other places. As expected, occupation and age were strong determinants of time-activity patterns. Housewives and unemployed or retired individuals spent 84.9 percent of their time at home, and occupational groups worked 21 to 24 percent of the hours. Students tended to spend the largest percentage of their time in public places, presumably schools, ranging from 14.7 percent for the youngest group to 19.17 percent for the oldest group of students.

TABLE 7.—Mean percent and standard deviation of time allocation in various locations by work or school classification subgroup

Location	Homemaker	Student	Outdoor worker	Office/ Service	Industrial/ Construction	Total, all participants
Home	84.34 (2.02)[1]	60.91 (13.92)	49.97 (12.24)	68.74 (8.72)	57.28 (7.05)	64.21 (13.99)
Outside	5.52 (3.27)	8.62 (5.53)	19.81 (8.55)	2.47 (2.49)	10.59 (10.74)	8.08 (7.07)
Motor vehicle	4.28 (3.19)	5.11 (3.74)	8.67 (6.15)	4.69 (2.33)	7.64 (7.52)	5.51 (4.29)
Other indoors	6.01 (3.27)	23.61 (10.61)	21.55 (5.32)	24.99 (10.24)	24.80 (12.86)	21.58 (11.37)
Cooking	4.69 (1.88)	0.34 (0.79)	0.00 (0.00)	2.32 (2.30)	0.52 (0.86)	1.24 (1.98)
Near smokers	2.84 (4.32)	5.20 (7.88)	2.75 (3.38)	11.73 (15.19)	12.03 (10.05)	6.89 (9.71)
Number	8	32	4	12	8	66[2]

[1] Numbers in parentheses are the standard deviation.
[2] Two unemployed participants were included in the total, but not given a separate category.
SOURCE: Data from Quackenboss et al. (1982).

The time allocations for various population subgroups in Portage, Wisconsin, are summarized in Table 7 (Quackenboss et al. 1982). The data are consistent with the findings of Letz and colleagues (1984) and show that the variability of individual nonsmokers' exposure to smokers can be quite marked between the various occupational subgroups.

Infants have unique time-activity patterns; their mobility is limited and the locations where they spend their time depend primarily on their caretakers. The time-location patterns for 46 infants is illustrated in half-hour segments in Figure 1 (Harlos et al. in press). Although infants spend most of their time in their bedrooms, they are in contact with a caretaker while traveling or in the living room or the kitchen for approximately half of the day. These infant time-activity patterns presumably correspond to the family patterns and may significantly influence the infants' potential exposure.

Although most people spend approximately 90 percent of their time in just two microenvironments (home and work) (Szalai 1972), important exposures can be encountered in other environments. For instance, commuting or being "in transit" accounts for about 0.5 to 1.5 hours per day for most people. Therefore, additional information

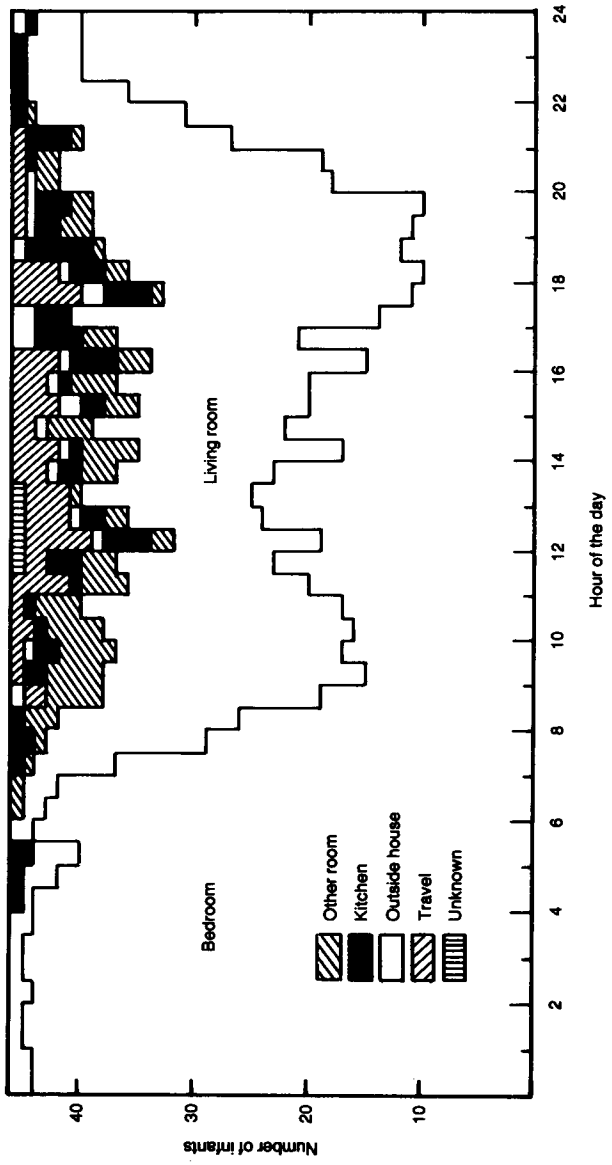

FIGURE 1.—Time location patterns for 46 infants
SOURCE: Harlos et al. (in press).

on the time spent and the ETS concentration in various microenvironments may be useful in defining exposure. This exposure information can be obtained by questionnaire and validated by personal monitoring programs. The characterization of concentra-

tions or exposures or both in microenvironments should use time scales appropriate for the health effect of interest. These variations in location and time-activity patterns can make the reconstruction of detailed ETS exposure difficult in studies of long-term health effects.

The limitations in utilizing this time-activity approach in characterizing exposures to other environmental pollutants also apply for ETS exposures. They include the following: the extent to which overall population estimates can be generalized to individual patterns is poorly understood; concentrations in various microenvironments are only partially characterized; the variation in time and activity patterns and their effects on concentration levels are not established, extrapolation to longer time scales either prospectively or retrospectively has not been validated, the differences within structures, i.e., room to room variations, are not well established.

Temporal and Spatial Distribution of Smokers

Exposure to ETS can occur in a wide variety of public and private locations. Approximately 30 percent of the U.S. adult population currently are cigarette smokers. Nationwide, 40 percent of homes have one or more smokers (Bureau of the Census 1985). In a survey of more than 10,000 children in six U.S. cities, the percentage of children living with one or more smoking adults varied from a low of 60 percent to a high of 75 percent (Ferris et al. 1979). Lebowitz and Burrows (1976) reported that 54 percent of children in a study in Tucson had at least one smoker in the home; Schilling and colleagues (1977) reported that 63 percent of homes in a Connecticut study had a smoker in the home. These data indicate that the population potentially exposed to ETS in the home is greater than might be inferred from aggregated national statistics on the prevalence of smoking. A variation in the percentage of homes with smokers may be observed among different regions. Furthermore, within house holds, smoking does not take place uniformly in time or space. Smoking patterns may change with activity, location, and time of day. These variables all serve to modify a nonsmoker's exposure to ETS.

Exposure to ETS at home may also correlate with ETS exposures outside the home, possibly because nonsmokers married to smokers may have a greater tolerance for ETS-polluted environments or may be in the company of more smokers because of the spouses' tendency to associate with other smokers. Wald and Ritchie (1984) used a biological marker and questionnaires to show that nonsmokers married to smokers reported a duration of exposure to ETS greater outside the home than was reported by nonsmokers married to nonsmokers (10.7 hours and 6.0 hours, respectively).

Smoking prevalence varies widely among different groups (e.g., teenage girls, nonworking adults, and adults employed in various

occupations); this variation modifies the exposure of nonsmokers to ETS. Smokers are present in nearly all environments, including most workplaces, restaurants, and transit vehicles, making it almost impossible for a nonsmoker to avoid some exposure to ETS. The number of cigarettes consumed per hour by the smoker may vary at different times in the day, and the rate and density of smoking will also differ by the type of indoor environment and activity in such locales as schools, autos, planes, offices, shops, and bars.

Although there have been numerous measurements of ETS concentrations in various indoor settings, these data do not represent a comprehensive description of the actual distribution of ETS exposures in the U.S. population. Spengler and colleagues (1985) and Sexton and colleagues (1984) demonstrated by the personal monitoring of respirable particles and the use of time-activity questionnaires that exposures to ETS both at home and at work are significant contributors to personal exposures. However, additional data on the distribution of smokers in the nonsmokers' environment, as well as the distribution of ETS levels in that environment, are needed in order to characterize the actual ETS exposure of the U.S. population.

Determinations of Concentration of Environmental Tobacco Smoke

Environmental tobacco smoke is a complex mixture of chemical compounds that individually may be in the particulate phase, the vapor phase, or both. ETS concentration varies with the generation rate of its tobacco-derived constituents, usually given as micrometer per hour. The generation rate for ETS has been approximated by the number of cigarettes smoked or the number of people present in a room who are actively smoking. Room-specific characteristics such as ventilation rate, decay rate, mixing rate, and room volume also modify the concentration. Because ETS particles have MMDs in the 0.2 to 0.4 μm range, convective flows dominate their movement in air, they remain airborne for long periods of time, and they are rapidly distributed through a room by advection and a variety of mixing forces. Under many conditions, the ventilation rate of a space will dominate chemical or physical removal mechanisms in determining the levels of ETS particles.

Nonreactive ETS components distribute rapidly through an airspace volume, and their elimination depends almost solely on the ventilation rate. For example, Wade and colleagues (1975) simultaneously measured carbon monoxide, a nonreactive gas, and nitrogen dioxide, a reactive gas, in a house and determined their half-lives to be 2.1 and 0.6 hours, respectively. This study demonstrates the need for caution in extrapolating from one vapor phase compound to another. Reactive gases and vapors may be rapidly lost to surfaces

may react with other chemical species. Their removal may be dominated by their reaction or absorption rates. Furthermore, the decay of ETS-derived substances can be a function of the chemical as well as the physical characteristics of room surfaces. For example, Walsh and colleagues (1977) found that sulfur dioxide removal was greater for rooms with neutral and alkaline carpets than for rooms having carpets with acidic pH. Reactions with furnishings and other materials may occur for some ETS components as well.

Microenvironmental Measurements of Concentration

As was discussed earlier, the complex chemical makeup of ETS makes the measurements of individual levels for each compound present in ETS impossible with existing resources; thus, some individual constituents have been measured as markers of overall smoke exposure. Because many of these constituents are also emitted from other sources in the environment, the contribution of ETS to the levels of these constituents is quantified by determining the enrichment of specific compounds found in smoke-polluted environments relative to the concentration measured in nonsmoking areas. Various ETS components have been measured for this purpose, including acrolein, aldehydes, aromatic hydrocarbons, carbon monoxide, nicotine, nitrogen oxides, nitrosamines, phenols, and respirable particulate matter. A summary of the levels found and the conditions of measurement are presented in Tables 8 through 15. The major limitation of using most of these gases, vapors, and particles is their lack of specificity for ETS. The presence of sources, other than tobacco smoke, of these compounds may limit their utility for determining the absolute contribution made by ETS to room concentrations. Levels of nicotine and tobacco-specific nitrosamines, however, are specific for ETS exposure.

Obviously, no single measurement can completely characterize the nonsmoker's exposure to ETS, and many studies have measured several of these components in order to characterize the exposure. Markers should be chosen both because of their accuracy in estimating exposure and because of their relevance for the health outcome of interest.

One widely reported marker of ETS is respirable suspended particulate (RSP) matter. Although lacking specificity for tobacco smoke, the prevalence and number of smokers correlates well with RSP levels in homes and other enclosed areas.

A study of the RSP levels in 80 homes in six cities (Figure 2) (Spengler et al. 1981) showed that indoor concentrations were higher on average and had a greater range than the outdoor concentrations. From these data, it is evident that even one smoker can significantly elevate indoor RSP levels.

TABLE 8.—Acrolein measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels	
					Mean	Range
Badre et al. (1978)	Cafes	Varied	Not given	100 mL samples		0.03–0.10 mg/m³
	Room	18 smokers	Not given	100 mL samples	0.185 mg/m³	
	Hospital lobby	12 to 30 smokers	Not given	100 mL samples	0.02 mg/m³	
	2 train compartments	2 to 3 smokers	Not given	100 mL samples		0.02–0.12 mg/m³
	Car	3 smokers	Natural, open	100 mL samples	0.03 mg/m³	
		2 smokers	Natural, closed	100 mL samples	0.30 mg/m³	
Fischer et al. (1978) and Weber et al. (1979)	Restaurant	50–80/470 m³	Mechanical	27 × 30 min samples	7 ppb	
	Restaurant	60–100/440 m³	Natural	29 × 30 min samples	8 ppb	
	Bar	30 –40/50 m³	Natural, open	28 × 30 min samples	10 ppb	
	Cafeteria	80–150/574 m³	11 changes/hr	24 × 30 min samples	6 ppb (5 ppb nonsmoking section)	

TABLE 9.—Aromatic hydrocarbons measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels		Nonsmoking controls	
					Mean	Range	Mean	Range
					Benzene (mg/m³)			
Badre et al. (1978)	Cafes	Varied	Not given	100 mL samples		0.05–0.15		
	Room	18 smokers	Not given	100 mL samples	0.109			
	Train compartments	2 to 3 smokers	Not given	100 mL samples		0.02–0.10		
	Car	3 smokers	Natural, open	100 mL samples	0.04			
		2 smokers	Natural, closed	100 mL samples	0.15			
					Toulene (mg/m³)			
	Cafes	Varied	Not given	100 mL samples		0.04–1.04		
	Room	18 smokers	Not given	100 mL samples	0.215			
	Train compartments	2 to 3 smokers	Not given	100 mL samples	1.87			
	Car	2 smokers	Natural, closed	100 mL samples	0.50			
					Benzo[a]pyrene (ng/m³)			
Elliott and Rowe (1975)	Arena	8,647–10,786 people	Mechanical	Not given	7.1			
		12,000–12,844 people	Mechanical	Not given	9.9			
		13,000–14,277 people	Mechanical	Not given	21.7			
				Separate non-activity days			0.69	
Galuskinova (1964)	Restaurant	Not given	Not given	20 days in summer	6.2			
				18 days in the fall		28.2–144		

TABLE 9.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels		Nonsmoking controls	
					Mean	Range	Mean	Range
Just et al. (1972)	Coffee houses	Not given	Not given	6 hr continuous	0.25–10.1		4.0–9.3 (outdoors)	
					Benzo[e]pyrene (ng/m³)			
					3.3–23.4		3.0–5.1 (outdoors)	
					Benzo[ghi]perylene (ng/m³)			
					5.9–10.5		6.9–13.8 (outdoors)	
					Perylene (ng/m³)			
					0.7–1.3		0.1–1.7 (outdoors)	
					Pyrene (ng/m³)			
					4.1–9.4		2.8–7.0 (outdoors)	
					Anthanthrene (ng/m³)			
					0.5–1.9		0.5–1.8 (outdoors)	
					Coronene (ng/m³)			
					0.5–1.2		1.0–2.8	
					Phenols (μ/m³)			
					7.4–11.5			
					Benzo[a]pyrene (ng/m³)			
Perry (1973)[1]	14 public places	Not given	Not given	Samples, 5 outdoor locations	<20–760			<20–43

[1] The correctness of the data is doubtful (Grimmer et al. 1977).

TABLE 10.—Carbon monoxide measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm)		Nonsmoking controls (ppm)	
					Mean	Range	Mean	Range
Badre et al. (1978)	6 cafes	Varied	Not given	20 min samples		2–23	(outdoors)	0–15
	Room	18 smokers	Not given	20 min samples	50		0 (outdoors)	
	Hospital lobby	12 to 30 smokers	Not given	20 min samples	5			
	2 train compartments	2 to 3 smokers	Not given	20 min samples		4–5		
	Car	3 smokers	Natural, open	20 min samples	14		0 (outdoors)	
		2 smokers	Natural, closed	20 min samples	20		0 (outdoors)	
Cano et al. (1970)	Submarines 66 m^3	157 cigarettes per day	Yes		<40 ppm			
		94–103 cigarettes per day	Yes		<40 ppm			
Chappell and Parker (1977)	10 offices	Not given	Values not given	17 × 2–3 min samples	2.5 ± 1.0	1.5–4.5	2.5 ± 1.0 (outdoors)	1.5–4.5
	15 restaurants	Not given	Values not given	17 × 2–3 min samples	4.0 ± 2.5	1.0–9.5	2.5 ± 1.5 (outdoors)	1.0–5.0
	14 nightclubs and taverns	Not given	Values not given	19 × 2–3 min samples	13.0 ± 7.0	3.0–29.0	3.0 ± 2.0 (outdoors)	1.0–5.0
	Tavern	Not given	Artificial	16 × 2–3 min samples	8.5			
			None	2 × 2–3 min samples		35 (peak)		
	Office[a]	1440 ft^3	Natural, open	2–3 min samples		10.0 (peak)		
				30 min after smoking	1.0			

TABLE 10.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm)		Nonsmoking controls (ppm)	
					Mean	Range	Mean	Range
Coburn et al. (1965)	Rooms	Not given	Not given	Not given		4.3–9.0		
				Nonsmokers' rooms			2.2 ± 0.98	0.4–4.5
Cuddeback et al. (1976)	Tavern 1	10–294 people	6 changes/hr	8 hr continuous	11.5	10–12	2 (outdoors)	
				2 hr after smoking	~1			
	Tavern 2	Not given	1–2 changes/hr	8 hr continuous	17	~3–22	Values not given	
				2 hr after smoking	~12		Values not given	
U.S. Dept. of Transportation (1971)[1]	18 military planes	165–219 people	Mechanical	6–7 hr continuous		<2–5		
	8 domestic planes	27–113 people	Mechanical	1¼–2½ hr continuous	≤2			
Elliott and Rowe (1975)[2]	Arena 1	11,806 people	Mechanical	Not given	9.0		3.0 (nonactivity day)	
	Arena 2	2,000 people	Natural	Not given	25.0		3.0 (nonactivity day)	
				Nonsmoking arena			9.0	
Fischer et al. (1978) and Weber et al. (1979)	Restaurant	50–80/470 m²	Mechanical	27 × 30 min samples	5.1	2.1–9.9	4.8 (outdoors)	
	Restaurant	60–100/440 m²	Natural	29 × 30 min samples	2.6	1.4–3.4	1.5 (outdoors)	
	Bar	30–40/50 m²	Natural, open	28 × 30 min samples	4.8	2.4–9.6	1.7 (outdoors)	
	Cafeteria	80–150/574 m²	11 changes/hr	24 × 30 min	1.2	0.7–1.7	0.4 (outdoors)	
				Nonsmoking room			0.5	0.3–0.8

TABLE 10.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm)		Nonsmoking controls (ppm)	
					Mean	Range	Mean	Range
Godin et al. (1972)	Ferryboat	Not given	Not given	11 grab samples	18.4 ± 8.7		3.0 ± 2.4 (nonsmoking room)	
	Theater foyer	Not given	Not given	Grab samples	3.4 ± 0.8		1.4 ± 0.8 (auditorium)	
Harke (1974)[3]	Office[4]	~72 m^3	236 m^3/hr	30 min samples		<2.5–4.6		
	Office[5]	~78 m^3	Natural	30 min samples		<2.5–9.0		
Harke and Peters (1974)[6]	Car	2 smokers (4 cigs)	Natural	Samples		42 (peak)	(Nonsmoking runs) 13.5 (peak)	
			Mechanical	Samples		32 (peak)	(Nonsmoking runs) 15.0 (peak)	
Harmsen and Effenberger (1957)[1]	Train	1–18 smokers	Natural	Not given		0–40		
Perry (1973)[1]	14 public places	Not given	Not given	One grab sample	<10			
Portheine (1971)[7]	Rooms	Not given	Not given	Not given		5–25		
Sebben et al. (1977)	9 nightclubs	Not given	Varied	77 × 1 min samples	13.4	6.5–41.9		
				Outdoors			9.2	3.0–35.0
	14 restaurants	Not given	Not given	Spot checks	9.9 ± 5.5		Values not given	
	45 restaurants	Not given	Not given	Spot checks	8.2 ± 2.2		7.1 ± 1.7 (outdoors)	
	33 stores	Not given	Not given	Spot checks	10.0 ± 4.2		11.5 ± 6.9 (outdoors)	
	3 hospital lobbies	Not given	Not given	Spot checks		4–8	Values not given	

TABLE 10.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm)		Nonsmoking controls (ppm)	
					Mean	Range	Mean	Range
Seiff (1973)	Intercity bus	Not given	15 changes/hr, 23 cigarettes burning continuously		33 ppm			
			3 cigarettes burning continuously		18 ppm			
Slavin and Hertz (1975)	2 conference rooms	Not given	8 changes/hr	Continuous, morning		8 (peak)	1–2 (separate nonsmoking day)	
			6 changes/hr	Continuous, morning		10 (peak)	1–2 (separate nonsmoking day)	
Szadkowski et al. (1976)	25 offices	Not given	Not given	Continuous	2.78 ± 1.42		2.59 ± 2.23 (separate nonsmoking offices)	

[1] The Drager tube used is accurate only within ± 25 percent.

[2] The MSA Monitaire Sampler used is accurate only within ± 25 percent.

[3] Three cigarettes and one cigar smoked in 20 minutes.

[4] About 40 cigarettes/day were smoked.

[5] About 70 cigarettes/day were smoked.

[6] Four filter cigarettes were smoked.

[7] No experimental description given.

TABLE 11.--Nicotine measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels ($\mu g/m^3$)		Nonsmoking controls	
					Mean	Range	Mean	Range
Badre et al. (1978)	6 cafes	Varied	Not given	50 min sample		25-52		
	Room	18 smokers	Not given	50 min sample	500			
	Hospital lobby	12 to 30 smokers	Not given	50 min sample	37			
	2 train compartments	2 to 3 smokers	Not given	50 min sample		36-50		
	Car	3 smokers	Natural, open	50 min sample	65			
			Natural, closed	50 min sample	1010			
Cano et al. (1970)	Submarines 66 m^3	157 cigarettes per day	Yes		32 $\mu g/m^3$			
		94-103 cigarettes per day	Yes		15-35 $\mu g/m^3$			
Harmsen and Effenberger (1957)	Train	Not given	Natural, closed	30-45 min Samples		0.7-3.1		
Hinds and First (1975)[1]	Train	Not given	Not given	2½ hr samples	4.9		Values not given	
	Bus	Not given	Not given	2½ hr samples	6.3		Values not given	
	Bus waiting room	Not given	Not given	2½ hr samples	1.0		Values not given	
	Airline waiting room	Not given	Not given	2½ hr samples	3.1		Values not given	
	Restaurant	Not given	Not given	2½ hr samples	5.2		Values not given	
	Cocktail lounge	Not given	Not given	2½ hr samples	10.3		Values not given	
	Student lounge	Not given	Not given	2½ hr samples	2.8		Values not given	
Weber and Fischer (1980)[2]	44 offices	Varied	Varied	140 x 3 hr samples	0.9 ± 1.9	13.8 (peak)	Values not given	

TABLE 11.--Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (µg/m^3)		Nonsmoking controls	
					Mean	Range	Mean	Range
First (1984)	1 public building	Nonsmokers	Mechanical	Not given			5.5	
	8 public buildings	1 to 5 smokers	Natural and mechanical	Not given	13.2	27-30.0		
Muramatsu et al. (1984)	Office	Not given	Not given	Not given	19.4	9.3-31.6		
	Office	Not given	Not given	Not given	22.1	14.6-26.1		
	Laboratory	Not given	Not given	Not given	5.8	1.8-9.6		
	5 conference rooms	Not given	Not given	Not given	38.7	16.5-53.0		
	3 houses	Not given	Not given	Not given	11.1	7.6-14.6		
	Hospital lobby	Not given	Not given	Not given	3.0	1.9-5.0		
	4 hotel lobbies	Not given	Not given	Not given	11.2	5.5-18.1		
	5 restaurants	Not given	Not given	Not given	14.8	7.1-27.8		
	3 cafeterias	Not given	Not given	Not given	26.4	11.6-42.2		
	3 bus and railway waiting rooms	Not given	Not given	Not given	19.1	10.1-36.4		
	4 cars	Not given	Not given	Not given	47.7	7.7-83.1		
	8 trains	Not given	Not given	Not given	16.4	8.6-26.1		
	7 airplanes	Not given	Not given	Not given	15.2	6.3-28.8		

[1]Background levels have been substracted.
[2]Control values (unoccupied rooms) have been subtracted.

TABLE 12.--Nitrogen oxides measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels		Nonsmoking controls (ppb)	
					Mean	Range	Mean	Range
Fischer et al. (1978) and Weber et al. (1979)	Restaurant	50-80/470 m^3	Mechanical	27 x 30 min samples	NO_2: 76 NO: 120	59-105 36-218	63 (outdoors) 115 (outdoors)	
	Restaurant	60-100/440 m^3	Natural	29 x 30 min samples	NO_2: 63 NO: 80	24-99 14-21	50 (outdoors) 11 (outdoors)	
	Bar	30-40/50 m^3	Natural, open	28 x 30 min samples	NO_2: 21 NO: 195	1-61 66-414	48 (outdoors) 44 (outdoors)	
	Cafeteria	80-150/574 m^3	11 changes/hr	24 x 30 min samples Other--non-smokers mom	NO_2: 58 NO: 9	35-103 2-38	34 (outdoors) 4 (outdoors) NO_2: 27l NO: 5	15-44 2-9
Weber and Fischer (1980)[1]	44 offices	Varied	Varied	348-354 samples	NO_2: 24 ± 22 NO: 32 ± 60	115 (peak) 280 (peak)	Values not given values not given	

[1] Control values (unoccupied rooms) have been subtracted.

TABLE 13.--Nitrosamines measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ng/L)	
					Mean	Range
Brunnemann and Hoffmann (1978)	Train bar car	Not given	Mechanical	90 min continuous	0.13	
	Train bar car	Not given	Natural	90 min continuous	0.11	
Brunnemann et al. (1978)	Bar	Not given	Not given	3 hr continuous	0.24	
	Sports hall	Not given	Not given	3 hr continuous	0.09	
	Betting parlor	Not given	Not given	90 min continuous	0.05	
	Discotheque	Not given	Not given	2¾, hr continuous	0.09	
	Bank	Not given	Not given	5 hr continuous	0.01	
	House	Not given	Not given	4 hr continuous	<0.005	
	House	Not given	Not given	4 hr continuous	<0.003	

TABLE 14.--Particulates measured under realistic conditions

Study	Type of premises	Occupancy (active smokers per 100 m^3)	Ventilation	Monitoring conditions (min)	Levels ($\mu g/m^3$) Mean SD	Nonsmoking controls ($\mu g/m^3$) Mean SD
Repace and Lowrey (1980)	Cocktail party	0.75	Natural	15	351 ± 38	24
	Lodge hall	1.26	Mechanical	50	697 ± 28	60[1]
	Bar and grill	1.78	Mechanical	18	589 ± 28	63[1]
	Firehouse bingo	2.77	Mechanical	16	417 ± 63	51[1]
	Pizzeria	2.94	Mechanical	32	414 ± 58	40[1]
	Bar/cocktail lounge	3.24	Mechanical	26	334 ± 120	50[1]
	Church bingo game	0.47	Mechanical	42	279 ± 18	30
	Inn	0.74	Mechanical	12	239 ± 9	22[1]
	Bowling alley	1.53	Mechanical	20	202 ± 19	49[1]
	Hospital waiting room	2.15	Mechanical	12	187 ± 52	58[1]
	Shopping plaza restaurant					
	Sample 1	0.18	Mechanical	18	153 ± 8	59[1]
	Sample 2	0.18	Mechanical	18	163 ± 4	36[1]

TABLE 14.—Continued

Study	Type of premises	Occupancy (active smokers per 100 m³)	Ventilation	Monitoring conditions (min)	Levels (μg/m³) Mean	Levels (μg/m³) SD	Nonsmoking controls (μg/m³) Mean	Nonsmoking controls (μg/m³) SD
	Barbeque restaurant	0.89	Mechanical	10	136	± 17	40[1]	
	Sandwich restaurant A							
	Smoking section	0.29	Mechanical	20	110	± 36	40[1]	
	Nonsmoking section	0	Mechanical	20	55	± 5	30	
	Fast-food restaurant	0.42	Mechanical	40	109	± 38	24[1]	
	Sports arena	0.09[2]	Mechanical	12	94	± 13	55[1]	
	Neighborhood restaurant/bar	0.40	Mechanical	12	93	± 17	55[1]	
	Hotel bar	0.59	Mechanical	12	93	± 2	30	
	Sandwich restaurant B							
	Smoking section	0.13	Mechanical	8	86	± 7	55	
	Nonsmoking section	0	Mechanical	21	51			
	Roadside restaurant	1.12	Mechanical (9.5 ach[3])	18	107[4]		30	
	Conference room	3.54	Mechanical (4.3 ach[3])	6	1947[4]		55	
Repace and Lowrey (1982)	Dinner theater	0.14	Mechanical	44	145	± 43	47	± 10
	Reception hall	1.19	Mechanical	20	301	± 30	33[1]	
	Bingo hall	0.93[2]	Natural	2	1140		40[1]	
		0.93[2]	Mechanical (1.39 ach[3])	6	443[4]		40[1]	

[1] Sequential outdoor measurement (5 minute average).

[2] Estimated.

[3] Air changes per hour.

[4] Equilibrium level as determined from concentration vs. time curve.

TABLE 14.--Continued

Study	Type of premises	occupancy	Ventilation	Monitoring conditions	Levels (µg/m³) Mean	Levels (µg/m³) Range	Nonsmoking controls (µg/m³) Mean	Nonsmoking controls (µg/m³) Range
Cuddeback et al. (1976)	Tavern	Not given	6 changes/hr	4 x 8 hr continuous	310	233–346		
	Tavern	Not given	l-2 changes/hr	8 hr continuous	986			
U.S. Dept. of Transportation (1971)	18 military planes	165-219 people	Mechanical	72 x 6-7 hr samples		<10–120		
	8 domestic planes	27-113 people	Mechanical	24 x l¼,-2½ hr samples	Not given			
Dockery and Spengler (1981)	Residences	Not given	Varied	24 hr samples	32			
Elliott and Rowe (1975)	Arena 1	11,806 people	Mechanical	During activities	323		42 (nonactivity day)	
	Arena 2	2,000 people	Natural	During activities	620		92 (nonactivity day)	
	Arena 3 (smoking prohibited)	11,000 people	Mechanical	During activities	148		71 (nonactivity day)	
Harmsen and Effenberger (1957)	Trains	15-120 people	Natural	Not given		46-440 particles/cm		
				Nonsmokers cars				20-75 particles/cm³
Just et al. (1972)	4 coffee houses	Not given	Not given	6 hr averages	1150	500-1900	570 (outdoors)	100-1900
Neal et al. (1978)	Hospital unit	Not given	Mechanical	48 hr samples	21 ± 14	3-58	73 ± 25	
	Hospital unit	Not given	Mechanical	48 hr samples	40 ± 21	13-79	72 ± 25	

TABLE 14.-- Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (µg/m^3) Mean	Levels (µg/m^3) Range	Nonsmoking controls (µg/m^3) Mean	Nonsmoking controls (µg/m^3) Range
Spengler et al. (1981)	Residences	2+ smokers	Natural	24 hr samples	70 ± 43		21 ± 12 (outdoors)	
		1 smoker	Natural	24 hr samples	37 ± 15		21 ± 12 (outdoors)	
Weber and Fischer (1980)	44 offices	Varied	Natural and mechanical	429 X 2 min samples	133 ± 130[1]	962[1] (peak)		
Quant et al. (1982)	Office No. 1	0.82[2]	Mechanical	Five l0-hr workday	45	39-54		5-15
	Office No. 2	0.68[2]	Mechanical	avereges; continuous	45	37-60		l5-20
	Office No. 3	1.46[2]	Mechanical	monitoring	68	42-89		l5-20
Brunekreef and Boleij (1982)	26 houses	1 to 3 smokers	Natural	2 mo averages	153[3]	60–340	55	20-90
First (1984)	1 public building	Nonsmokers	Mechanical	2 min			20	
	8 public buildings	1 to 5 smokers	Natural and mechanical	2 min	260	40-660		
Hawthorne et al. (1984)	11 residences	Nonsmokers	0.18-0.98	6-15 min			9-40	
	8 residences	Nonsmokers	026-1.98	5-15 min			12-46	
	2 residences	Smokers	0.27-1.47	5-15 min	96-106			
Nitschke et al. (1985)	Outdoor			168 hr			11	11-28
	19 residences	Nonsmokers	Natural	168 hr			26	6-88
	11 residences	Smokers	Natural	168 hr	59	10-144		
Spengler et al. (1985)	Outdoor			24 hr			18	
	73 residences	Nonsmokers	Natural	24 hr			28	
	24 residences	Smokers	Natural	24 hr	74			
Sterling and Sterling (1984)	1 office	Smokers	Not given	Not given	26	16-38		
	22 offices	Smokers	Not given	Not given	32			

'Values above background.

'Habitual smokers per 100 m^3.

***Weighted mean.**

TABLE 15.--Residuals measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels Mean	Levels Range	Nonsmoking controls Mean	Nonsmoking controls Range
					Acetone (mg/m^3)			
Badre et al. (1978)[1]	6 cafes	Varied	Not given	100 mL samples		0.91-5.88		
	Room	18 smokers	Not given	100 mL samples	0.51			
	Hospital lobby	12 to 30 smokers	Not given	100 mL samples	1.16			
	2 train compartments	2 or 3 smokers	Not given	l00 mL samples		0.36-0.76		
	Car	3 smokers	Natural, open	100 mL samples	0.32			
	Car	2 smokers	Natural, closed	100 mL samples	1.20			
					Sulfates ($\mu g/m^3$)			
Dockery and Spengler (1981)	Residences	Not given	Varied	24 hr samples	4.81			
					sulfur dioxide (ppb)			
Fischer et al. (1978)	Restaurant	50-80/470 m^3	Mechanical	27 x 30 min samples	20	9-32	12 ppb	
	Restaurant	60-100/440 m^3	Natural	29 x 30 min samples	13	5-18	6	
	Bar	30-40/50 m^3	Natural, open	28 x 30 min samples	30	13-75	8	
	Cafeteria	80-150/574 m^3	11 ch/hr	24 x 30 min samples	15	1-27	12	
				Other nonsmokers' room			7	3-13
					Aldehydes ($\mu g/m^3$)			
Just et al. (1972)	4 coffes houses	Not given	Not given	6 hr continuous	12.0-15.3			

[1]See original paper for nine other residuals.

SOURCE: Sterling et al. (1982).

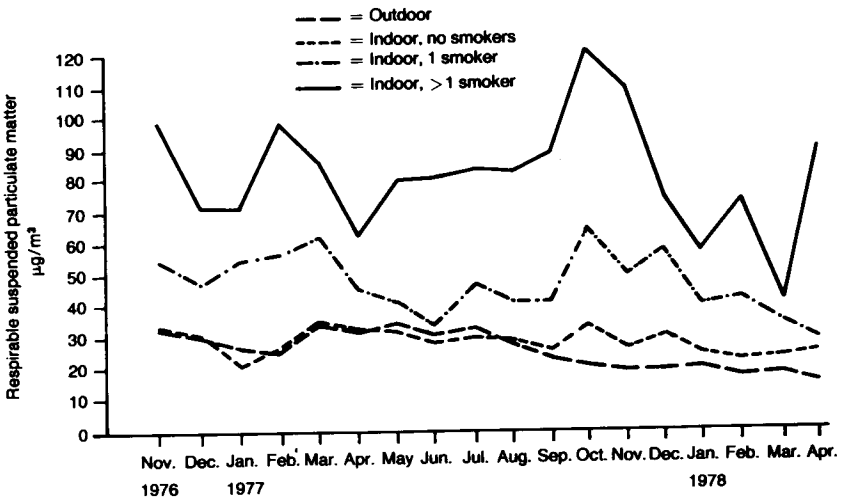

FIGURE 2.—Monthly mean mass respirable particulate concentrations (µg/m³) across six cities

SOURCE: Spengler et al. (1981).

TABLE 16.—Respirable particulate levels as a function of number of smokers

Smoker status	Number	Mean (µg/m³)	Standard deviation
No smokers	35 homes/1,186 samples	24.4	11.6
1 smoker	15 homes/494 samples	36.5	14.5
2 smokers	5 homes/153 samples	70.4	42.9
2+ smokers	4 homes/? samples	51.8	12.3

SOURCE: Spengler et al. (1981).

Spengler and colleagues (1981) collected respirable suspended particulate samples in 55 homes in six cities. The average concentrations observed between May 1977 and April 1978 are shown in Table 16. The quantity of tobacco smoked was not reported, nor was the number of hours each smoker spent in the home. The researchers concluded that the mean RSP levels increased by 20 $\mu g/m^3$ per smoker.

Dockery and Spengler (1981) further analyzed these data and considered the number of cigarettes smoked in the home. They concluded that the mean RSP concentration increased by 0.88 $\mu g/m^3$

for every cigarette smoked per day in the house. A one-pack-a-day smoker in the home thus raises indoor respirable particulate levels by 17.6 $\mu g/m^3$. Air conditioning increased the contribution of each cigarette by 1.23 $\mu g/m^3$, to a total of 2.11 $\mu g/m^3$ per cigarette in fully air-conditioned homes. These values are annual averages; air-conditioned homes, in which air is recirculated during the warmer months, have higher levels.

Repace and Lowrey (1980) measured RSP concentration using a piezobalance in several public and private locations, including restaurants, cocktail lounges, and halls, in both the presence and the absence of smoking. They then developed an empirical model utilizing the mass-balance equation. Using both measured and estimated parameters as input to the model, they validated the model for predicting an individual's exposure to the RSP constituent of ETS. The model takes the form: $C_{eq} = 650\ D_s/n_v$; where Ceq equals the equilibrium concentration of the RSP component of ($\mu g/m^3$), D_s equals the density of active smokers (number of burning cigarettes per 100 m^3), and n_v equals the ventilation rate (in air changes per hour). The ventilation rate is a complex parameter that takes into account all the room-specific constants affecting the removal of HI'S, such as ventilation, decay, and mixing.

Measurements in a large number of locations using measures of smoke generation such as the number of people smoking or the number of cigarettes being smoked have shown a definite relationship of smoke generation to particulate levels. First (1984) cautioned against the use of RSP measurements as a measure of ETS in public places because of its nonspecificity for ETS, and noted that other sources may contribute enough to the levels to invalidate the determination of the ETS contribution. However, there are few other sources of PSP in most U.S. homes, and therefore, the relationships of RSP measurements to ETS levels are generally quite accurate in this setting.

Nicotine appears to be a promising tracer for ETS because of its specificity for tobacco and its presence in relatively high concentrations in tobacco smoke. It can also be measured in biological fluids to provide an indication of acute exposure to tobacco smoke. Cotinine, nicotine's major metabolite, can be used as an indicator of more chronic exposure. These biological markers are discussed in a separate chapter of this Report. Recent studies have indicated that nicotine may be primarily associated with the vapor phase of ETS and therefore not a surrogate for the particulate phase as once thought (Eudy et al. 1986). However, the possible usefulness of this compound in estimating exposure to ETS warrants further evaluation. The nicotine content of sidestream smoke does not differ significantly from brand to brand when normalized on a per gram of tobacco basis (Rickert et al. 1984). The use of nicotine as a marker for

ETS must also give consideration to its loss to surfaces and its subsequent revolatilization and readmission to the room volume.

Carbon monoxide, a marker for gas phase components, has been measured extensively as a surrogate for ETS. There are many sources of carbon monoxide other than cigarettes, indoors (e.g., stoves, grills) and outdoors (e.g., automobile). This nonspecificity for ETS seriously limits its usefulness for environmental measurements.

In summary, no single compound definitively characterizes an individual's exposure to ETS. Additional research is currently under way to quantify the relationships among various constituents and ETS levels. Because of the complex nature of ETS, investigators may need to measure several markers or to separately record source variables (such as number of cigarettes smoked) in order to estimate exposure to ETS.

Monitoring Studies

Personal monitors can measure the concentrations of ETS in an individual's breathing zone. Personal monitoring is preferable to area monitoring because it integrates the temporal and spatial dimensions of an individual's exposures. At the present time, all of the studies that have used personal monitors to measure ETS constituents have utilized active samplers that provide integrated exposures over differing time periods.

The markers assessed in personal monitoring studies have the same lack of specificity found in area monitoring studies. However, in many of the personal monitoring studies, time-activity diaries were kept to permit greater resolution in attributing exposure to specific sources.

In Topeka, Kansas, 45 nonsmoking adults carried personal RSP monitors for 18 days, and area monitors were placed inside and outside their homes (Spengler and Tosteson 1981). The indoor RSP levels were consistently higher than outdoor levels, and the personal exposures levels were higher than either. The group was divided into those who reported ETS exposure and those who did not (Figure 3). Reported exposure to ETS clearly shifts the distribution to the right. On the average, reported ETS exposure increased an individual's personal concentration by 20 $\mu g/m^3$.

Personal RSP monitors were carried by 101 nonsmoking volunteers for 3 days in Kingston-Harriman, Tennessee (Spengler et al. 1985). The study population was divided into two groups: those who lived with a smoker and those who did not. ETS exposure was reported by 28 of the participants, with the remaining participants reporting none. The RSP distribution for the ambient samples is shown in Figure 4. Clearly, exposure to ETS significantly increases an individual's personal concentration profile.

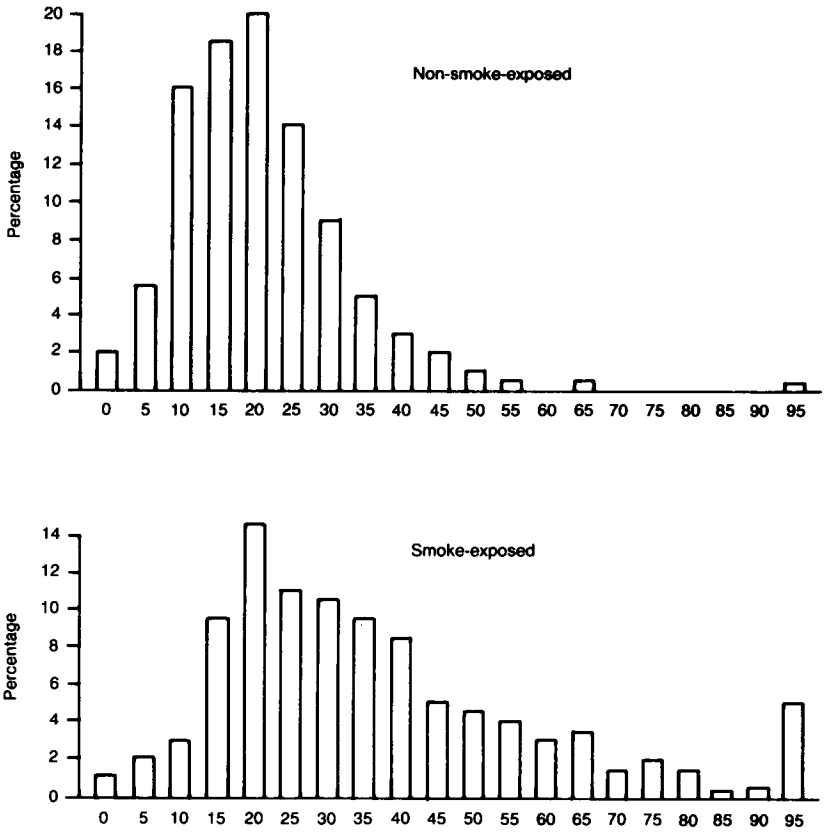

FIGURE 3.—Percentage distribution of personal respirable particulate concentrations, non-smoke-exposed and smoke-exposed samples, Topeka, Kansas

SOURCE: Spengler and Tosteson (1981).

Sexton and colleagues (1984) monitored personal RSP exposure for 43 nonsmokers in Waterbury, Vermont, every other day for 2 weeks. The participants kept activity logs and had simultaneous indoor and outdoor RSP samples collected at their homes. The proportion of time individuals spent exposed to ETS was the single most important determinant of their personal exposure. Volunteers who reported greater than 120 minutes of exposure to ETS had a mean RSP exposure of 50.1 $\mu g/m^3$, whereas those volunteers who reported no exposure to ETS had a mean exposure of 31.7 $\mu g/m^3$.

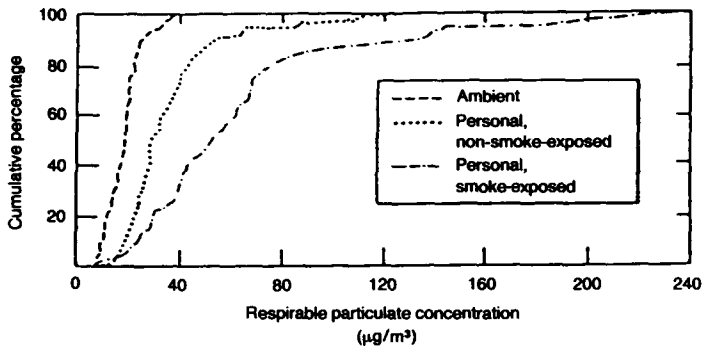

FIGURE 4.—Cumulative frequency distributions of central site ambient and personal smoke-exposed and non-smoke-exposed respirable suspended particulate concentrations

SOURCE: Spengler et al. (1985).

Nicotine, a tobacco-specific compound, should make an excellent tracer for ETS if its usage can be properly validated. Some considerations in its usage are detailed in the section on area sampling. Currently, no published reports are available that utilize this compound for the type of detailed personal monitoring studies carried out for RSP. However, a lightweight personal nicotine monitor has recently been developed (Muramatsu et al. 1934) that may aid this type of research. Theresearchers measured average nicotine concentrations ranging from 3.0 $\mu g/m^3$ in a hospital lobby to 38.7 $\mu g/m^3$ in a conference room and 47.7 $\mu g/m^3$ in an automobile. No information on the duration of exposure or representativeness of these levels to the general population was given. However, this study does provide information as to the range of exposures an individual may encounter and demonstrates that high nicotine levels can be encountered in various settings. It will be necessaryto quantify the relationship between nicotine, a vapor phase component of ETS, and other components of interest such as RSP in order to fully utilize this tracer.

Certain organic gases have been measured as possible indicators of ETS exposure or of specific effects such as irritation. These include formaldehyde and acrolein (Weber and Fischer 1980) and aromatic compounds such as benzene, toluene, xylene, and styrene (Higgins et al. 1983). The U.S. Environmental Protection Agency's recent TEAM study utilized personal monitors, employing Tenax cartridges, to develop profiles of individual exposures to volatile organics (Wallace

et al. in press). The TEAM study has found significantly increased exposure to benzene for individuals exposed to ETS. Again, the nonspecificity of these materials for ETS limits their applicability.

Other materials such as carbon monoxide and nitrogen dioxide have been measured in personal monitoring studies attempting to assess individuals' exposure to ETS. Their nonspecificity and lack of sensitivity for low-level ETS exposure make them inappropriate for population-based studies.

Personal monitoring techniques are currently available that will allow the assessment of individual exposures to various components of ETS. Although not widely used in the past, they can provide valuable input in developing exposure models and in validating other monitoring schemes. Their usefulness is primarily that they sample all of the microenvironments in which individuals find themselves and therefore automatically compensate for the nonuniform temporal and spatial distributions of ETS that affect individual exposure profiles.

Conclusions

1. Undiluted sidestream smoke is characterized by significantly higher concentrations of many of the toxic and carcinogenic compounds found in mainstream smoke, including ammonia, volatile amines, volatile nitrosamines, certain nicotine decomposition products, and aromatic amines.
2. Environmental tobacco smoke can be a substantial contributor to the level of indoor air pollution concentrations of respirable particles, benzene, acrolein, N-nitrosamine, pyrene, and carbon monoxide. ETS is the only source of nicotine and some N-nitrosamine compounds in the general environment.
3. Measured exposures to respirable suspended particulates are higher for nonsmokers who report exposure to environmental tobacco smoke. Exposures to ETS occur widely in the nonsmoking population.
4. The small particle size of environmental tobacco smoke places it in the diffusion-controlled regime of movement in air for deposition and removal mechanisms. Because these submicron particles will follow air streams, convective currents will dominate and the distribution of ETS will occur rapidly through the volume of a room. As a result, the simple separation of smokers and nonsmokers within the same airspace may reduce, but will not eliminate, exposure to ETS.
5. It has been demonstrated that ETS has resulted in elevated respirable suspended particulate levels in enclosed places.

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