TABLE 10.—Carbon monoxide measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm) Mean	Levels (ppm) Range	Nonsmoking controls (ppm) Mean	Nonsmoking controls (ppm) 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) Mean	Levels (ppm) Range	Nonsmoking controls (ppm) Mean	Nonsmoking controls (ppm) Range
Coburn et al. (1965)	Rooms	Not given	Not given	Not given		4.3–9.0		
				Nonsmokers' rooms			2.2 ± 0.96	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 m^2	Mechanical	27 × 30 min samples	5.1	2.1–9.9	4.8 (outdoors)	
	Restaurant	60–100/440 m^2	Natural	29 × 30 min samples	2.6	1.4–3.4	1.5 (outdoors)	
	Bar	30–40/50 m^2	Natural, open	28 × 30 min samples	4.8	2.4–9.6	1.7 (outdoors)	
	Cafeteria	80–150/574 m^2	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) Mean	Levels (ppm) Range	Nonsmoking controls (ppm) Mean	Nonsmoking controls (ppm) 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 $\pm$ 25 percent.

[2] The MSA Monitaire Sampler used is accurate only within $\pm$ 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 ($\mu g/m^3$) Mean	Range	Nonsmoking controls 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 × 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 ($\mu g/m^3$)		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	2.7–30.0		
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 subtracted.

[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 × 30 min samples	NO_2: 76	59–105	63 (outdoors)	
					NO: 120	36–218	115 (outdoors)	
	Restaurant	60–100/440 m^3	Natural	29 × 30 min samples	NO_2: 63	24–99	50 (outdoors)	
					NO: 80	14–21	11 (outdoors)	
	Bar	30–40/50 m^3	Natural, open	28 × 30 min samples	NO_2: 21	1–61	48 (outdoors)	
					NO: 195	66–414	44 (outdoors)	
	Cafeteria	80–150/574 m^3	11 changes/hr	24 × 30 min samples	NO_2: 58	35–103	34 (outdoors)	
					NO: 9	2–38	4 (outdoors)	
				Other—non-smokers room			NO_2: 27	15–44
							NO: 5	2–9
Weber and Fischer (1980)[1]	44 offices	Varied	Varied	348–354 samples	NO_2: 24 ± 22	115 (peak)	Values not given	
					NO: 32 ± 60	280 (peak)	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	$2\frac{3}{4}$ 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 m²)	Ventilation	Monitoring conditions (min)	Levels ($\mu g/m^3$) Mean	SD	Nonsmoking controls ($\mu g/m^3$) Mean	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 ($\mu g/m^3$)		Nonsmoking controls ($\mu g/m^3$)	
					Mean	Range	Mean	Range
Cuddeback et al. (1976)	Tavern	Not given	6 changes/hr	4 × 8 hr continuous	310	233–346		
	Tavern	Not given	1–2 changes/hr	8 hr continuous	986			
U.S. Dept. of Transportation (1971)	18 military planes	165–219 people	Mechanical	72 × 6–7 hr samples		<10–120		
	8 domestic planes	27–113 people	Mechanical	24 × 1¼–2½ 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^3		
				Nonsmokers' cars				20–75 particles/cm^3
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/m³)		Nonsmoking controls (µg/m³)	
					Mean	Range	Mean	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 × 2 min samples	133 ± 130[1]	962[1] (peak)		
Quant et al. (1982)	Office No. 1	0.82[2]	Mechanical	Five 10-hr workday averages; continuous monitoring	45	39-54		5-15
	Office No. 2	0.68[2]	Mechanical		45	37-50		15-20
	Office No. 3	1.46[2]	Mechanical		68	42-89		15-20
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	0.18-0.96	5-15 min			9-40	
	8 residences	Nonsmokers	0.26-1.98	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	15-36		
	22 offices	Smokers	Not given	Not given	32			

[1] Values above background.
[2] Habitual smokers per 100 m².
[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	100 mL samples		0.36–0.75		
	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 × 30 min samples	20	9–32	12 ppb	
	Restaurant	60–100/440 m^3	Natural	29 × 30 min samples	13	5–18	6	
	Bar	30–40/50 m^3	Natural, open	28 × 30 min samples	30	13–75	8	
	Cafeteria	80–150/574 m^3	11 ch/hr	24 × 30 min samples	15	1–27	12	
				Other nonsmokers' room			7	3–13
					Aldehydes ($\mu g/m^3$)			
Just et al. (1972)	4 coffee 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).

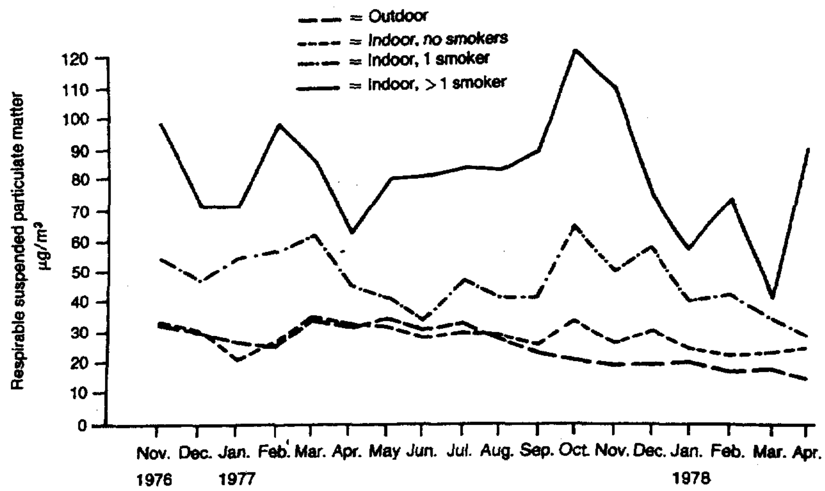

FIGURE 2.—Monthly mean mass respirable particulate concentrations (μg/m³) across six cities

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 μg/m³ 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 μg/m³ 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 C_{eq} equals the equilibrium concentration of the RSP component of ETS ($\mu g/m^3$), 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 ETS, 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 RSP 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.

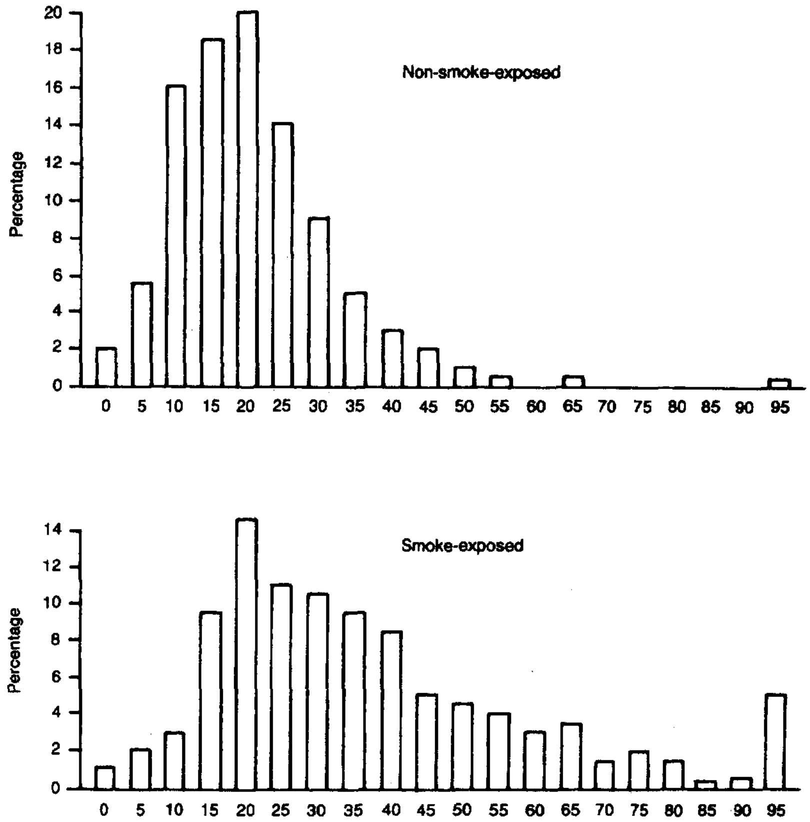

FIGURE 3.—Percentage distribution of personal respirable particulate concentrations, non-smoke-exposed and smoke-exposed samples, Topeka, Kansas

SOURCE: Spengler and Tosteson (1981).

Sexton and colleagues (1984) monitored personal RSP exposure for 48 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 $\mu g/m^3$.

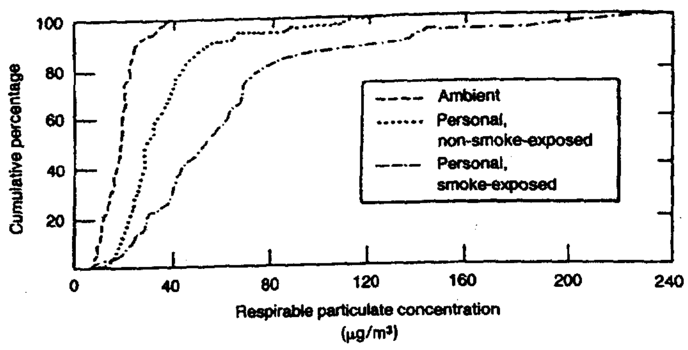

FIGURE 4.—Cumulative frequency distributions of central site ambient and personal smoke-exposed and non-smoke-exposed respirable suspended particulate concentrations

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. 1984) that may aid this type of research. The researchers 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 necessary to 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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