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Exposure of U.S. Workers to Environmental Tobacco Smoke

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The concentrations of environmental tobacco smoke (ETS) to which workers are exposed have been measured, using nicotine or other tracers, in diverse workplaces. Policies restricting workplace smoking to a few designated areas have been shown to reduce concentrations of ETS, although the effectiveness of such policies varies among work sites. Policies that ban smoking in the workplace are the most effective and generally lower all nicotine concentrations to less than 1 µg/m^3; by contrast, mean concentrations measured in workplaces that allow smoking generally range from 2 to 6 µg/m^3 in offices, from 3 to 8 µg/m^3 in restaurants, and from 1 to 6 µg/m^3 in the workplaces of blue-collar workers. Mean nicotine concentrations from 1 to 3 µg/m^3 have been measured in the homes of smokers. Furthermore, workplace concentrations are highly variable, and some concentrations are more than 10 times higher than the average home levels, which have been established to cause lung cancer, heart disease, and other adverse health effects. For the approximately 30% of workers exposed to ETS in the workplace but not in the home, workplace exposure is the principal source of ETS. Among those with home exposures, exposures at work may exceed those resulting from home. We conclude that a significant number of U.S. workers are exposed to hazardous levels of ETS. — *Environ Health Perspect* 107(Suppl 2): 329–340 (1999). *http://ehpnet1.niehs.nih.gov/docs/1999/Suppl-2/329-340hammond/abstract.html*

Key words: environmental tobacco smoke, passive smoking, exposure, tobacco, nicotine, cigarettes, occupational exposure

Since the mid-1980s, the conclusion that exposure to environmental tobacco smoke (ETS) increases the risk of lung cancer in nonsmokers has been reached by a variety of agencies and government authorities including the U.S. Surgeon General, the National Research Council, the National Institute for Occupational Safety and Health, the U.S. Environmental Protection Agency, the California Environmental Protection Agency, and the International Agency for Research on Cancer. The Occupational Safety and Health Administration (OSHA) is charged with assuring each worker "safe and healthful working conditions." Section 6(b)(5) of the Occupational Safety and Health Act, which established OSHA, states that "the Secretary, in promulgating standards dealing with toxic materials or harmful physical agents under this subsection, shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life" (*1*).

The OSHA hearings of 1994 to 1995 on the proposed regulation for indoor air quality included discussion on the magnitude and risk of ETS exposure in U.S. workplaces. Some witnesses indicated that exposures to ETS in the home exceeded those in the workplace, whereas other witnesses maintained that the workplace exposures were comparable to exposures in the home. This comparison of workplace and home exposures is relevant to OSHA's proposed regulation, as much of the information on the adverse health effects of ETS comes from studies of effects of exposure at home.

This article reviews studies of nicotine concentrations in the workplace and presents new data. Concentrations measured in the workplace are compared with those found in the home.

Rationale for Selection of Studies Reviewed

Studies selected for this review provide data on workplace concentrations of nicotine, a highly specific marker for ETS. Although several indicators have been measured as markers for ETS (*2*), particles and nicotine have been used most widely. There are many sources of airborne particles, and the background concentration of particles varies in different environments, whereas nicotine is specific to smoking and hence to ETS. Consequently, this review focuses on studies of nicotine as a marker for ETS concentration and exposure.

The averaging time for measurement of nicotine concentration merits consideration in the context of the biologically relevant exposure metric; for example, the concentration of ETS averaged over a few minutes may be most relevant for acute health effects such as the onset or intensity of an asthma attack, whereas yearly average concentrations may be most relevant for chronic health effects. Available studies show that concentrations of indicators of ETS can be highly variable throughout a workday. For example, Muramatsu et al. (*3*) measured real-time concentrations of particles and 15-min average nicotine concentrations in an office through the workday and found that particle concentrations varied from approximately 20 to 200 µg/m^3. The 30-min average nicotine concentrations ranged from 2 to 26 µg/m^3 with a mean of 10 µg/m^3. For chronic health effects, e.g., cancer and heart disease, the short-term concentrations are less relevant than time-weighted average concentrations, and the short-term concentrations may not be indicative of risk because of their variability. Therefore, this review focuses on the more stable and relevant measurements of concentrations measured over longer periods of hours to days. The published literature of occupational exposure to ETS smoke was reviewed, and studies with data on airborne concentrations of nicotine in the workplace were included if the sampling time was over 1 hr.

Overview of the Larger Studies

Some of the earliest measurements of ETS exposures in the workplace were made on railroad workers during a study of diesel exhaust exposure. In the first of these measurements, over 500 full-shift personal

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Abbreviations used: ETS, environmental tobacco smoke; GSD, geometric standard deviation; NHANES III, the Third Health and Nutrition Examination Survey; OSHA, Occupational Safety and Health Administration.

samples were collected in 1981 to 1982 from workers at four U.S. railroads (*4*). Two years later, an additional 275 full-shift personal samples for ETS were collected from workers at one of the railroads (*5,6*). Few other studies measured ETS exposure before 1988, about the time that smoking restrictions in the workplace were becoming increasingly widespread. Because policies restricting or banning smoking in the workplace may have substantial effects on ETS concentrations (*7*), the studies reviewed are classified by the workplace smoking policy in place, if known.

One source of data on ETS in the workplace developed from the 1991 to 1992 WellWorks study of 25 workplaces in Massachusetts. The aggregated data from 359 samples collected at nonsmokers' work stations in that study were previously published (*7*). Here, we report the company-specific data for the first time. Most of these workplaces (22 of 25) included both office areas and a variety of nonoffice areas such as printing shops, laboratories, fire stations, and production areas. Passive samplers for nicotine were placed at the work stations of smokers and nonsmokers and left in place for 1 week. The average nicotine concentration was calculated assuming the samplers were exposed to ETS during a 45-hr workweek, except for the firefighters, for whom a 112-hr exposure period was assumed.

A more recent study of 1,600 individuals in 16 cities was conducted in 1993 to 1994 by researchers at Oak Ridge National Laboratory (Oak Ridge, TN), R.T. Reynolds, and Bellomy Research, Inc. (*8*). The study participants wore an active sampling system while at work for 1 day, and a second system for the remainder of the day while away from work. Multiple atmospheric markers for ETS were measured. Finally, the results of the only study of a nationally representative sample on ETS exposure, the Third Health and Nutrition Examination Survey (NHANES III), are considered in order to compare home and workplace exposures to ETS.

In the studies considered, some samples were collected by personal sampling and others by area sampling. Area sampling generally underestimates personal exposure to chemicals in the workplace. However, a recent study by Sterling et al. (*9*) evaluated the concentrations of nicotine in two office buildings as measured by 25 personal and 8 indoor area samples collected on the same days. The researchers reported that there was no significant difference between the two types of samples, and they concluded, "Overall... fixed-location monitoring appears to provide a close approximation to nonsmoking occupants' exposure to ETS, as determined through personal monitoring." Therefore, the results of personal and area sampling have been combined in this paper.

Nonoffice Workspace Concentrations

Railroad Workers

Particle-phase nicotine was measured on 33 composited samples; 376 personal full-shift (7–12 hr) samples were combined within each job grouping at each railroad, e.g., those for the freight engineers and firers were combined into three composite samples, one from each of three railroads (*4*). The particle-phase nicotine levels were converted to vapor-phase nicotine concentrations to make the results comparable to those from subsequent studies in which vapor-phase nicotine was measured. This conversion included two steps. First, vapor-phase nicotine concentrations were converted to ETS particle concentration by multiplying the concentration of nicotine in the composite samples by 92.4 μg ETS particles/μg particle-phase nicotine [the ratio determined experimentally in chamber studies using the same sampling and analytical methods (*4,10*)]. Second, the concentration of ETS particles was divided by 8.6 μg ETS particles/μg of vapor-phase ETS [the ratio determined experimentally in Schenker et al. (*5*)] to yield the concentration of vapor phase nicotine]. The average exposure concentrations of nicotine among the clerks, dispatchers, and ticket agents were 5 to 15 $\mu g/m^3$, whereas train crews and shop workers were generally exposed to 2 to 6 $\mu g/m^3$. In the winter, levels were much higher in the shop of railroad III (Table 1). These early data (1981–1982) on workplace exposure to ETS are limited by inclusion of samples from smokers and nonsmokers in the composites.

Two years after the original sampling, one of the railroads was visited again and vapor-phase nicotine concentrations were

Table 1. Exposure of railroad workers to ETS, 1981 to 1982 using personal samples from smokers and nonsmokers.[a]

Job group	Railroad I		Railroad II		Railroad III		Railroad IV	
	No. of samples composited	Nicotine, $\mu g/m^3$	No. of samples composited	Nicotine, $\mu g/m^3$	No. of samples composited	Nicotine, $\mu g/m^3$	No. of samples composited	Nicotine, $\mu g/m^3$
Clerks, ticket agents, dispatchers	14	15.3	13	10	9	5.2		
Signal maintainers	4	1.2	0	NM	10	1.2		
Engineers and firers								
Freight	14	1.9	13	2	10	2.4		
Passenger	21	2.7	0	NM	0	NM		
Yard	11	4.7	9	5.5	0	NM	16	7.8
Conductors and brakers								
Freight conductors	17	2.7	12	3.8	19	11.5		
Freight brakers	0	NM	7	2.3	9	6		
Passenger conductor and brakers	33	0.7	0	NM	0	NM		
Yard conductors and brakers	0	NM	7	8.7	0	NM		
Hostelers—all 3 railroads combined	8	0.8						
Repair shop								
Machinists, summer	18	4	9	3.3	5	2.7		
Machinists, winter	0	NM	23	3.1	12	10.9		
Electricians, summer	6	5.9	5	4	5	3		
Electricians, winter	0	NM	9	1.2	6	12.4		
Other shop workers (Railroads I and II combined)	6	2.2			6	4.7	10	17.8

NM, not measured. [a]Calculated from data of Hammond et al. (*4*) by dividing RSP[ETS] by 8.6 μg RSP[ETS]/μg nicotine to yield estimate of vapor phase nicotine (see text for details).

measured on that visit. Each sample was analyzed individually and the ETS exposures of smokers and nonsmokers were evaluated separately. Personal samples were taken for diesel exhaust and vapor-phase nicotine during the work shift over a period of 6 months in 1983 to 1984 on sampling trips of 2 to 4 days duration (*5,6*). Of the 275 personal samples of ETS exposures collected on 81 workers in a variety of jobs, 193 were collected from nonsmokers. These workers present three distinct environments from the point of view of ETS exposure: braker and predominantly carmen work outdoors shop workers are in a large repair facility with high ceilings and mechanical ventilation to prevent buildup of air contaminants; and, clerks and locomotive engineers work in relatively small enclosed spaces without mechanical ventilation.

The ETS exposures (measured as airborne nicotine concentration) of these groups of workers followed the patterns that might be expected given their working conditions (Figure 1). Thus, nonsmoking carmen, braker, and repair shop workers had the lowest ETS exposures, with medians and even 75th-percentile values of nicotine of 0.5 µg/m^3 or less; however, the engineers' exposures covered a wider range of concentrations, and the nonsmoking clerks had much higher ETS exposures. Two engineers, who were sampled on two days each, had no detectable exposure to nicotine on either day, whereas the other two had highly variable exposures ranging from 0.7 to 12.8 µg/m^3, with three of the four samples over 1 µg/m^3. The exposure to ETS appeared to depend on whether the cabmate smoked and on the extent of his/her smoking.

The variability of the individual exposures also implies that any individual worker has a substantial likelihood of having 1 day of exposure at a nicotine concentration of at least 1 µg/m^3; this was in fact observed in the 2 to 12 days of sampling on each worker in this study. Thus, among the outdoor workers, 20% of the braker and 33% of the carmen had at least 1 day of exposure at a nicotine concentration of 1 µg/m^3, whereas 46% of the repair shop workers and 50% of the engineers had at least 1 day with such exposures. By contrast, 92% of the clerks (all but one) had at least 1 day of exposure at a concentration over 1 µg/m^3 (Table 2). In most jobs, smokers had greater ETS exposure than nonsmokers (Figure 1), but among clerks the exposures of smokers and nonsmokers were comparable, at average nicotine concentrations of 5.0 and 6.9 µg/m^3, respectively. Although the average exposure concentrations of nonsmoking clerks, engineers, and carmen were greater than 2 µg/m^3, only the clerks had median exposure concentrations over 0.5 µg/m^3.

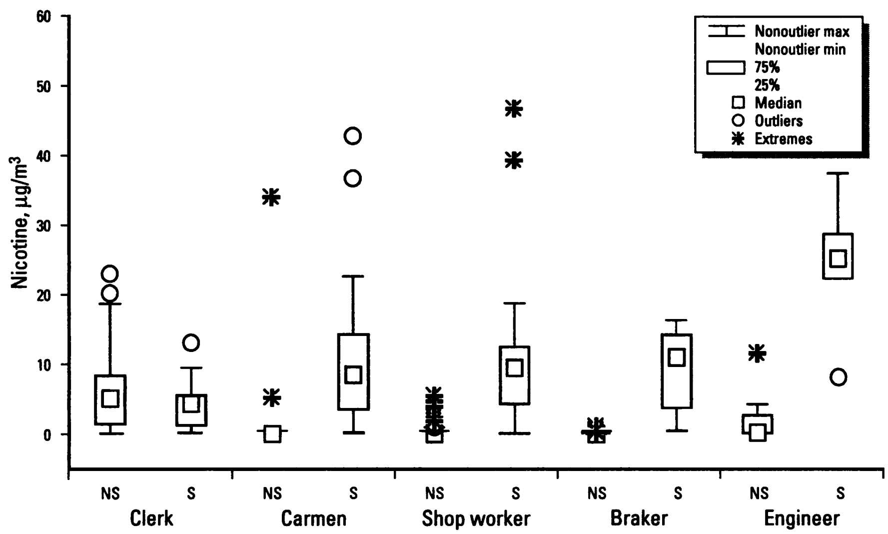

Figure 1. Exposure of railroad workers to ETS. Distribution by job and by smoking status of 275 full-shift personal samples collected in 1983 to 1984 at one railroad. S, smokers; NS, nonsmokers. The bars encompass the 25th to 75th percentiles of the data, the squares are the median values, the circles are outliers, and the asterisks are extreme data values. Data from Schenker et al. (*5,6*).

Restaurant, Cafeteria, Bar, and Casino Workers

Several studies have examined nicotine concentrations in public places such as

Table 2. Exposure of railroad workers to ETS, 1983 to 1984.

	Concentration of nicotine, µg/m^3										
Job and smoking status	No. of samples	No. of workers	Average	Standard deviation	Geometric mean	Geometric standard deviation	Minimum	Median	75th Percentile	Maximum	% of nonsmoking workers with exposure ≥1 µg/m^3 on at least 1 day
Clerks											
Smokers	12	5	5.0	4.3	2.0	8.4	<0.1	5.0	6.2	14.7	
Nonsmokers	31	13	6.9	6.7	4.3	6.0	<0.1	5.7	8.8	25.7	92
Engineers											
Smokers	5	3	27.2	12.0	24.4	1.8	9.1	28.4	32.1	41.8	
Nonsmokers	8	4	2.4	4.5	2.7	3.7	<0.1	0.4	2.1	12.8	50
Shop											
Smokers	31	7	11.9	11.4	7.4	3.7	<0.1	10.6	13.7	52.2	
Nonsmokers	124	17	0.4	0.9	0.4	2.8	<0.1	0.1	0.5	6.2	47
Brakemen											
Smokers	12	3	11.7	9.6	7.0	3.7	0.5	12.4	15.5	35.0	
Nonsmokers	18	10	11.4	0.4	0.3	3.6	<0.1	<0.1	0.1	1.3	20
Carmen											
Smokers	24	13	12.3	12.1	9.1	2.6	<0.1	9.6	15.7	25.1	
Nonsmokers	10	6	4.5	11.9	0.6	9.7	<0.1	0.2	0.3	38.1	33

restaurants, cafeterias, bars, bingo parlors, and casinos. Although the primary motivation for most of these studies was to evaluate the ETS exposure of the public, employees in these establishments are also exposed to ETS. Efforts to restrict smoking in restaurants, either by division into smoking and nonsmoking sections or by outright ban, have led to several surveys of the concentration of nicotine in restaurants, most with 20 to 50 samples, but with one having over 100 samples (Table 3). In most of these studies, nicotine concentrations ranged widely, from less than 1 to over 20 µg/m^3, with some measurements over 40 µg/m^3. The arithmetic mean concentrations were generally between 3 and 9 µg/m^3. The nicotine concentrations measured in cafeterias were somewhat higher than in restaurants, with averages between 6 and 14 µg/m^3; maximum values generally were over 10 and as high as 84 µg/m^3. All eight samples collected in 1991 to 1992 in the cafeterias of the WellWorks companies that banned smoking were less than 1 µg/m^3, whereas two-thirds of the 37 samples from the companies that allowed or only restricted smoking were over 5 µg/m^3 (Figure 2); break areas other than smoking lounges had higher concentrations of nicotine in the companies that restricted smoking compared to those that allowed smoking.

One study examined concentrations of nicotine at the University of Massachusetts Medical Center cafeteria between 11:30 AM and 2:30 PM on 4 days in 1987; four or five measurements were made in each of three areas, the smoking section and two areas of the nonsmoking section, one within 5 to 25 ft and the other over 30 ft from the smoking section (*11*). The number of smokers was counted every 15 min and averaged, and the cigarette butts were collected and counted. The concentrations of nicotine were highly variable in the smoking section, averaging 25 to 40 µg/m^3 on the 3 spring days, and 98 µg/m^3 on the winter day when the doors to the patio were kept closed. Concentrations were much lower in the nonsmoking area more proximal to the smoking section about 2 to 5 µg/m^3—and were mostly 0.5 µg/m^3 in the more remote nonsmoking section (Table 4). On the final day of sampling, 3 weeks after the start of a policy restricting smoking in the building to the smoking lounge, waiting rooms, and the smoking section of the cafeteria, the prevalence of smokers increased by one-third, the number of butts collected doubled, and the concentration of nicotine in the smoking section increased by about 25% despite the warmer weather.

Although nicotine concentrations have been measured in far fewer bars than restaurants, the concentrations are generally much higher, often with average values over 10 and maximum values over 50 µg/m^3 (Table 3). Samples taken for three nightclub musicians measured an average exposure concentration over 3 nights of 37 µg/m^3, with a range of 28 to 50 µg/m^3 (*12*).

Table 3. Concentrations of nicotine, µg/m^3, measured in restaurants, cafeterias, and bars.

	Year sampled	No. of Samples	Concentration of nicotine, µg/m^3 Average	Standard deviation	Geometric mean	Minimum	Median	Maximum	Reference
Restaurants		7	3.4			LD		16.1	(*36*)
		34	5.40	6.40	3.50	0.50	4.10	37.20	(*22*)
		36			4.10	1.00		36.00	(*37*)
Personal		21	4.30			0.30	2.90	24.00	(*38*)
Area		21	6.30			0.30	4.20	24.80	(*38*)
	1987–1988	2	4.10			2.00	4.10	6.20	(*39*)
		170			5.10	LD		23.80	(*35*)
		46	8.40		8.4?	LD		43.00	(*40*)
Busboy, personal	1986–1987	1	45.0		45.0		45.0		(*18*)
Patron, personal	1994	1	13.80		13.8		13.8		(*41*)
Cafeterias	1987	19—S area	47.86	23.72		6.00	38.00	150.00	(*11*)
		17—NS area	3.40	2.31		<0.1	2.00	16.00	(*11*)
		15 NS area	0.52	0.14		<0.1	<0.1	2.00	(*11*)
	<1990	62	7.50	12.90	3.20	LD	3.40	84.50	(*34*)
						2.30		4.40	(*22*)
		2-S area	14.00			<1.6		43.7	
		2 NS area	6.20			<1.6		10.90	
	1994	S area	11.40						(*41*)
		NS near S	14.50						
		NS remote	10.20						
Bars, taverns and cocktail lounges									
3 bars	1987–1988	5	7.36	4.42	5.67	1.10	7.00	13.10	(*39*)
Tavern			59.20			6.10		108.60	(*42*)
1 tavern on 2 nights		2	65.50			60.00		71.00	(*43*)
2 bars			12.90			4.10		21.60	(*34*)
8 cocktail lounges			17.60			1.80		90.60	(*36*)
Nightclub musicians at 3 clubs		17	37.1	6.9	36.4	28	34.9	50	(*12*)
Bingo, casino, and bowling alleys									
Bingo (personal), CA	1986	6				4.4	65.5	85.4	(*44*)
Bingo (personal) MA	1994	1	1	7.8			7.8		(*41*)
Casino (personal), CA	1994	1		8			8		(*44*)
Casino (personal), MA	1986	6				3.3	8.02	11.6	(*44*)
Betting		2	10.7		10.7		10.7		
Bowling alley		4	10.7		10.7		10.7		

LD, less than the limit of detection; S, smoking; NS, nonsmoking.

In the late 1970s, bingo game locales were one of the types of sites selected for measuring ETS, using respirable particles as an indicator (*13*). Nicotine concentrations were also quite high in six personal samples collected at the bingo games in 1986 in California, the median being 65.5 µg/m³ and the maximum 85.4 µg/m³. The single personal sample collected during a bingo game in Massachusetts in 1994 had a much lower nicotine concentration (Table 3).

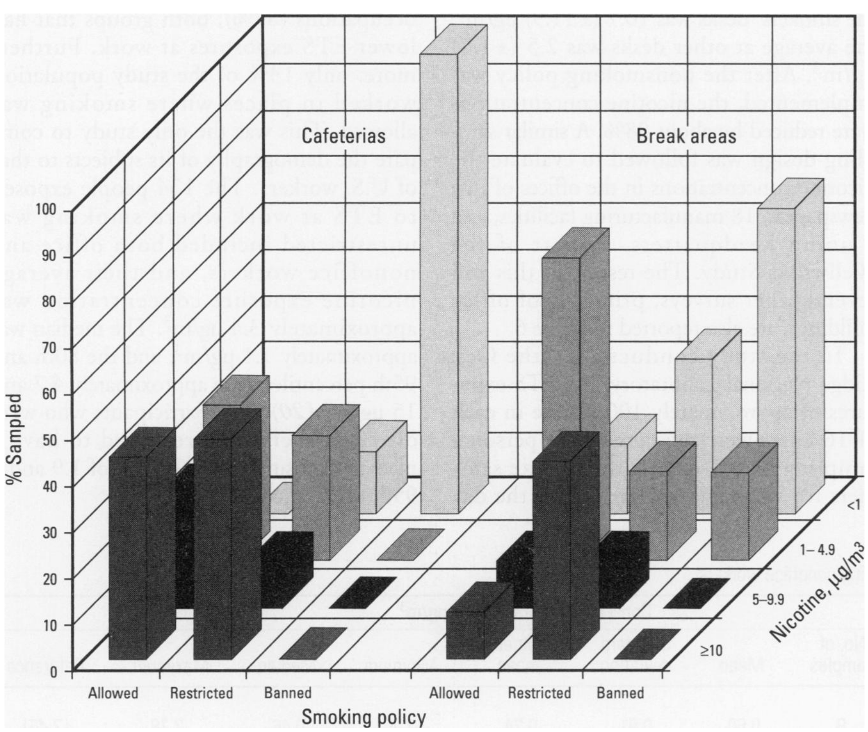

Figure 2. ETS in cafeterias and break areas of the WellWorks companies. Distribution of nicotine concentration as a function of smoking policy. These data do not include smoking sections or smoking lounges. Note that although the samples were in place for a full week, they were assumed to be exposed to ETS for 45 hr. Because these areas are probably occupied for less time each week, values may be underestimations of concentrations during times of maximum occupancy.

Table 4. Concentration of nicotine, µg/m³, in cafeteria at University of Massachusetts Medical Center.[a]

	Concentration of nicotine, µg/m³				
	Sampling date				
	01/29/87	03/16/87	03/18/87	04/22/87	4-Day average, µg/m³
Smoking section					
Average, µg/m³	98.0	29.3	27.4	36.8	47.9
SD	59.5	22.8	11.3	7.6	23.7
Number of samples	5	4	5	5	19
Nonsmoking section 5–25 ft from smoking section					
Average, µg/m³	4.5	4.0	3.5	1.6	3.4
SD	7.7	4.5	7.0	2.7	2.3
Number of samples	4	5	4	4	17
Nonsmoking section > 30 ft from smoking section					
Average, µg/m³	<0.1	1.8	<0.1	0.2	0.5
SD	0.0	0.3	0.0	0.2	0.1
Number of samples	4	3	4	4	15
Number of cigarette butts	141	105	93	240	
Number of smokers, average	6.9	7.2	6.7	9.4	

SD, standard deviation. [a]Data from Hepworth (*11*).

Airline Workers

The ETS exposures of four flight attendants were measured by personal sampling in the breathing zone on each of four transcontinental flights in 1988 (*14*). Each flight attendant was assigned to the smoking section for two flights and to the nonsmoking section for two flights. No significant difference was found in the ETS exposures as a result of these assignments, probably because the galleys were located near the smoking rows, and flight attendants had to move through the smoking section as they carried meals from the galleys to the passengers in the nonsmoking sections. Nicotine concentrations ranged from 0.1 to 10.5 µg/m³, with a median of 4.2 and a mean of 4.7 ± 4.0 µg/m³ (Table 5). Area sample measurements in the smoking sections on those four flights (average 16.5 ± 17.1 µg/m³) were lower than measurements made earlier and reported by other researchers, e.g., 22.4 ± 28.4 µg/m³ (*15*) and 24 ± 21 µg/m³ (*16*), and slightly higher than the average of 13.4 µg/m³ reported by Nagda et al. (*17*). In 1989, Nagda et al. (*17*) conducted the only random survey on a large sample ($n = 69$) of flights during the last year that smoking was allowed on U.S. domestic flights.

Other Nonoffice, Nonhospitality Workers

Measurements of nicotine concentrations made in workplaces other than offices, restaurants, and bars are reported in Table 5. ETS was monitored over 1 week at several locations in the fire stations of two cities of moderate size. Similar average nicotine concentrations were found for these two fire departments: 5.4 and 5.8 µg/m³, which were among the highest concentrations measured. Personal sampling, measured in 1986 to 1987 on two workers in a barber shop and five workers in a hospital while smoking was still allowed revealed higher average nicotine exposure concentrations of 8.8 and 25.8 µg/m³, respectively (*18*). Weekly average concentrations in manufacturing and printing areas generally 1 to 4 µg/m³, although maximum concentrations were usually over 10, and were over 20 µg/m³ in one-third of the work sites where smoking was permitted.

Office Concentrations

Forty-three personal samples of ETS exposure among 18 clerks who worked for the railroad were collected during five sampling trips in 1983 to 1984. These samples were full shift in duration; most subjects were sampled on 2 consecutive days and some were resampled on subsequent sampling trips. Five of the participants were smokers and 13 were nonsmokers. The 31 samples collected from nonsmoking clerks ranged from less than detectable (i.e., < 0.2 μg/m^3) for two samples to a maximum of 26 μg/m^3, with a mean nicotine concentration of 6.9 ± 6.7 μg/m^3 and a median concentration of 5.7 μg/m^3 (Table 2, Figure 1). All but 1 of the 13 nonsmokers (92%) was exposed on at least 1 day to concentrations over 1 μg/m^3, the median concentrations found in homes of smokers. The high variability in daily average exposures is illustrated by examining the exposures of four subjects (three nonsmokers) sampled for 4 or more days; the daily average exposure concentrations for each of these workers ranged over 50-fold; each worker experienced a daily average exposure concentration over 10 μg/m^3 at least once.

Passive samples were collected from nonsmokers' desks before and after a large office building instituted a nonsmoking policy on 1 January 1988 (*19*). The samplers were left in place for a week, thus smoothing some of the daily variability; exposure was assumed to occur for 9 hr/day, 45 hr/week. Six samples were collected at smokers' desks, and 13 at other desks. While the average nicotine concentration at the smokers' desks was 10.7 (± 11.9) μg/m^3, the average at other desks was 2.5 (± 1.7) μg/m^3. After the nonsmoking policy was implemented, the nicotine concentrations were reduced by about 98%. A similar sampling design was followed to evaluate the nicotine concentrations in the offices of two newspapers, 18 manufacturing facilities, and a union headquarters, as part of the Wellworks Study. The results of this and several other surveys, primarily of office buildings, are also reported in Table 6.

In the study conducted by the Oak Ridge National Laboratory, the ETS exposures of approximately 100 people in each of 16 cities were measured with personal sampling over 1 day, with separate samplers for work and for the rest of the day (*8*). Strengths of the study include the large numbers of people sampled in a diverse geographic area and the characterization of multiple markers of ETS. However, despite its size, the study was not designed to be representative, and women were oversampled, as were persons in professional, managerial, sales, and technical occupations (87%), both groups that had lower ETS exposures at work. Furthermore, only 13% of the study population worked in places where smoking was allowed. This was the only study to compare the demography of its subjects to that of U.S. workers. The 134 people exposed to ETS at work where smoking was unrestricted included both office and nonoffice workers, and their average nicotine exposure concentration was approximately 3.4 μg/m^3. The median was approximately 1.1 μg/m^3, and the 80th and 95th percentiles were approximately 4.7 and 15 μg/m^3 (*20*). The participants who were office workers were reported to have a median exposure concentration of 1.9 and a 95th percentile of 14.9 μg/m^3.

Table 5. Occupational exposures to nicotine among nonsmoking nonoffice workers.

Company type	Year sampled	No. of Samples	Concentration of nicotine, μg/m^3 Mean	Standard deviation	Geometric mean	Minimum	Median	Maximum	Reference
Smoking allowed									
Specialty chemicals	1991–1992	8	0.60	0.91	0.24	< 0.05	0.46	2.78	(*7,45*)
Railroad workers, personal	1983–1984	152	0.80	3.30	0.18	< 0.1	0.10	38.10	(*5,6*)
Tool manufacturing	1991–1992	13	1.59	1.05	1.16	0.15	1.85	3.40	(*7,45*)
Textile finishing, B	1991–1992	11	1.74	1.69	1.10	0.31	0.93	5.09	(*7,45*)
Labels and paper products	1991–1992	1	2.31				2.31		(*7,45*)
Die manufacturer	1991–1992	12	2.70	1.27	2.46	1.23	2.41	5.42	(*7,45*)
Scintering metal	1991–1992	12	2.88	2.59	2.11	0.62	2.24	9.72	(*7,45*)
Newspaper, B	1991–1992	5	2.96	1.37	2.68	1.23	2.78	4.63	(*3,45*)
Miscellaneous	< 1990	282	4.30	11.80	1.70	< 1.6	< 1.6	126.00	(*34*)
Textile finishing, A	1991–1992	11	4.33	8.82	1.77	0.46	1.39	30.71	(*7,45*)
Flight attendants (personal)	1988	16	4.70	4.00	2.32	0.10	4.20	10.50	(*14*)
Fire fighters, A[a]	1991–1992	16	5.39	3.81	4.08	1.20	4.84	13.42	(*7,45*)
Fire fighters, B	1991–1992	24	5.83	6.77	3.83	0.71	3.65	27.50	(*7,45*)
Barber shop, personal	1986–1987	2	8.80			4.00		13.70	(*18*)
Hospital, personal	1986–1987	5	24.80	22.80	16.80	6.30	10.00	53.20	(*18*)
Smoking restricted									
Work clothing	1991–1992	9	0.17	0.32	0.06	< 0.05	< 0.05	0.93	(*7,45*)
Filtration products	1991–1992	10	0.32	0.87	0.08	< 0.05	< 0.05	2.78	(*7,45*)
Film and imaging	1991–1992	6	0.82	0.83	0.39	< 0.05	0.70	2.16	(*7,45*)
Fiber optics	1991–1992	13	1.34	2.79	0.63	0.20	0.64	10.57	(*7,45*)
Newspaper, A	1991–1992	4	4.86	6.65	2.62	0.93	1.85	14.81	(*7,45*)
Valve manufacturer	1991–1992	10	5.80	7.85	3.62	1.16	3.26	27.31	(*7,45*)
Rubber products	1991–1992	2	5.85	5.36	4.18	2.06	5.85	9.64	(*7,45*)
Smoking prohibited									
Infrared and imaging systems	1991–1992	1	< 0.05				< 0.05		(*7,45*)
Hospital products	1991–1992	5	0.08	0.17	< 0.05	< 0.05	< 0.05	0.39	(*7,45*)
Weapons systems	1991–1992	12	0.08	0.20	< 0.05	< 0.05	< 0.05	0.63	(*7,45*)
Aircraft components	1991–1992	12	0.20	0.18	0.13	< 0.05	0.21	0.61	(*7,45*)
Radar communications components	1991–1992	13	0.31	0.36	0.14	< 0.05	0.26	1.08	(*7,45*)
Computer chip equipment	1991–1992	10	0.51	0.33	0.41	0.15	0.39	1.08	(*7,45*)

[a]Omits one data point, 101 μg/m^3.

The concentrations of nicotine found in offices are summarized in Table 6, with the data classified by smoking policy. Most office buildings had averages greater than 2 µg/m^3, and more than half the workplaces that allowed smoking had averages over 5 µg/m^3. Three buildings—a travel agency, a newspaper office, and a union headquarters—had nicotine averages over 15 µg/m^3.

Model of Office Exposure

One approach to examining the reasonableness of these measurements is to predict concentrations of nicotine in offices where smoking occurs. A simple model, based on the mass balance equation, predicts the steady-state airborne nicotine concentration (Equation 1).

Considering a 1,000 ft^2 office with a 10-ft ceiling (room volume = 282 m^3) occupied by seven people and supplied with air as recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers at 20 f^{t3}/min/person, the ventilation rate is given in Equation 2.

If one assumes that two of the seven occupants smoke (prevalence of 29%) and that each one smokes two cigarettes per hour, then the smoking intensity is four cigarettes/hr/283 m^3 = 0.0141 cigarettes/m^3/hr, only about half the 0.0244 cigarettes/m^3/hr value stated as typical of the office smoking environment by Guerin et al. (*21*) in citing the work of Thompson et al. (*22*). Equation 3 is the predicted steady-state nicotine concentration if each cigarette emits 1,800 mg of nicotine and the adsorption loss is 2.2 (*23*).

This steady-state concentration is achieved only after a sufficient period of smoking; at the beginning of the work day, the airborne concentration of nicotine would be close to zero and then increase

Table 6. Occupational exposures to nicotine among nonsmoking office workers.

			Concentration of nicotine, µg/m^3						
Work site description	Year sampled	No. of Samples	Average	Standard deviation	Geometric mean	Minimum	Median	Maximum	Reference
Smoking allowed									
2 office buildings	1987–1988	3	1.70	2.30	0.80	LD	0.60	4.30	(*39*)
Bldg 2, personal	1994	12	1.80			1.10	1.70	2.30	(*9*)
Bldg 1, personal	1994	13	2.00			0.30	1.60	4.70	(*9*)
Telephone company	1987	13	2.50	1.70	2.08	0.90	1.90	6.70	(*19*)
Social worker office, personal	1986–1967	1	2.50		2.50		2.50		(*18*)
Multiple sites, personal	1993–1994	< 136					1.90	> 14.9[a]	(*8*)
Labels and paper products	1991–1992	7	2.71	1.93	1.42	< 0.05	2.62	6.02	(*7,45*)
Tool manufacturing	1991–1992	7	3.46	4.92	3.46	0.77	1.39	14.51	(*7,45*)
Multiple work sites	< 1990	194	3.50	8.30	1.70	< 1.6		71.50	(*34*)
Die manufacturer	1991–1992	4	4.98	4.20	3.21	0.69	5.09	9.07	(*7,45*)
Textile finishing, B	1991–1992	2	5.09	2.84	4.68	3.09	5.09	7.10	(*7,45*)
Scintering metal	1991–1992	7	5.84	8.86	1.63	0.31	0.93	20.22	(*7,45*)
Attorney office,personal	1986–1987	1	5.90		5.90		5.90		(*18*)
Multiple work sites		28	6.00			4.10		7.80	(*46*)
Specialty chemicals	1991–1992	7	6.17	7.83	1.96	< 0.05	3.70	22.38	(*7,45*)
Railroad clerks, personal	1983–1984	31	6.89	6.72	3.20	< 0.1	5.70	25.70	(*5,6*)
Multiple work sites	< 1990	33	7.20				LD	41.90	(*47*)
Multiple work sites—naturally ventilated	< 1990	17	10.00				LD	41.90	(*47*)
Stock broker, personal	1986–1987	1	7.20		7.20		7.20		(*18*)
Multiple work sites	< 1989	32			3.80	1.20		24.30	(*37*)
Multiple work sites	< 1990	156			4.80	LD		69.70	(*35*)
Multiple work sites	< 1988	28			7.20	< 1.2		69.70	(*33*)
Textile finishing, A	1991–1992	3	9.67	0.93	9.64	8.80	9.57	10.65	(*7,45*)
Newspaper, B	1991–1992	19	15.77	14.48	8.05	0.15	10.80	47.69	(*7,45*)
Union headquarters[b]	1991–1992	15	21.95	12.37	17.24	1.08	17.05	45.06[b]	(*7,45*)
Travel agent, personal	1986–1987	2	48.35	2.33	48.32	1.05	48.35	50.00	(*18*)
Smoking restricted									
Telephone company	1988	19	0.27	0.20	0.21	< 0.1	0.20	0.70	(*19*)
Filtration products	1991–1992	6	0.44	0.68	0.13	< 0.05	0.10	1.70	(*7,45*)
Fiber optics	1991–1992	4	0.49	0.37	0.39	0.15	0.42	0.98	(*7,45*)
Work clothing	1991–1992	4	0.62	0.52	0.50	0.31	0.39	1.39	(*7,45*)
2 office buildings	1987–1988	2	1.00			LD	1.00	2.00	(*39*)
Film and imaging	1991–1992	7	2.67	2.18	1.97	0.62	1.85	6.33	(*7,45*)
Valve manufacturer	1991–1992	8	4.23	4.48	2.49	0.54	2.50	13.73	(*7,45*)
Newspaper, A	1991–1992	7	7.87	5.94	5.23	0.62	7.56	16.67	(*7,45*)
Smoking prohibited									
Hospital products	1991–1992	9	0.10	0.16	0.06	< 0.05	< 0.05	0.39	(*7,45*)
Radar communications	1991–1992	4	0.35	0.32	0.21	< 0.05	0.31	0.77	(*7,45*)
Office building	1987–1988	2	0.20			LD	0.20	0.40	(*39*)
Computer chip equipment	1991–1992	1	0.62				0.62		(*7,45*)
Infrared and imaging system	1991–1992	8	0.66	0.76	0.27	< 0.05	0.39	1.93	(*7,45*)
Aircraft components	1991–1992	5	0.85	0.98	0.38	< 0.05	0.37	2.43	(*7,45*)
Weapons systems	1991–1992	3	2.83	4.90	0.17	< 0.05	< 0.05	8.49	(*7,45*)

LD, less than the limit of detection. [a]95th percentile, as given in this article. [b]Omits one data point, 130 µg/m^3.

toward steady state over time. Therefore, the 8-hr time-weighted average nicotine concentration, $[\text{nicotine}]_{8\ \text{hr TWA}}$, is less than the steady-state concentration. The time-weighted average can be estimated from the predicted steady state in Equation 4.

This predicted value of 11 µg/m^3 can be compared to the average values measured in the offices reported in Table 6; these averages generally ranged between 2 and 25 µg/m^3; the median of these average values was approximately 6 µg/m^3. The general comparability between the predicted and measured values provides assurance about the validity of the available nicotine data and suggests that the measurements are not skewed toward the lower or upper ends of the distribution of nicotine concentrations.

Comparing Office and Nonoffice Area Concentrations of Nicotine

In the 22 workplaces in which nicotine was measured in both the office and the nonoffice areas, nicotine concentrations were generally lower in the non-office areas than in the office areas (Tables 5, 6). This reduction is probably due to several factors: the larger room sizes and higher ceilings of most of these work areas; greater ventilation of many of these areas to remove other air contaminants; lower density of workers on the shop floor; and less time available for smoking by workers. In addition, some nonoffice samples were collected in areas where smoking was not allowed for safety reasons (e.g., near flammable solvents). The average concentration in the offices was between 3 and 22 µg/m^3, but the average nonoffice exposure concentrations in these more industrial settings were between 0.6 and 4.3 µg/m^3.

Effect of Smoking Policies on Nicotine Concentrations

Offices

Workplaces in which smoking was restricted to designated areas had lower average nicotine concentrations that ranged from 0.3 to 7.9 µg/m^3. The distribution appeared bimodal, however, with 47% having averages less than 1.0 and 39% with values greater than 2.2 µg/m^3. This bimodal distribution probably reflects the variable efficacy of smoking policies that allow smoking on the premises but restrict it to designated areas. Variation in enforcement of policies may contribute, as may infiltration of ETS from areas where in which smoking is allowed to areas where in which it is not allowed. The lowest value was measured at a site 7 weeks after the policy restricting smoking had been implemented. Workers at this site had high awareness of the policy (*19*). Finally, six of the seven workplaces where smoking was prohibited on the premises had average concentrations in offices under 1 µg/m^3. One company had an average of 2.8 µg/m^3, the average of a measurement of 8.5, with two other measurements under 1 µg/m^3. The median and geometric mean concentrations measured in offices where smoking was banned were all under 1 µg/m^3, as were concentrations for half the companies that restricted smoking. However, none of the offices of companies that allowed smoking had geometric mean or median concentrations under 1 µg/m^3. In the seven studies in which multiple workplaces were included, the average concentrations of all seven were greater than 2 µg/m^3, and half had averages over 5 µg/m^3.

The maximum concentrations of nicotine measured in offices in which smoking was allowed were above 5 µg/m^3 for all but the two buildings measured in 1994 (Table 6); half the companies had maximum values over 20 µg/m^3, and several had maxima over 40 µg/m^3. Even where smoking was restricted to specific areas, half the work sites had maximum concentrations over 5 µg/m^3, and a third had values over 10 µg/m^3. By contrast, no companies that banned smoking had maximum values over 10 µg/m^3, and only one had a any measurements over 3 µg/m^3.

Nonoffice Workspaces

The variable efficacy of restricting smoking to designated areas in offices was also found in other work areas. Where smoking was restricted, three workplaces had average nicotine levels less than 1 µg/m^3, whereas three others had average nicotine concentrations around 5 to 6 µg/m^3. The same two companies with restrictions on smoking that had the highest nicotine concentrations in the offices also had higher nicotine concentrations in the nonoffice locations. All 13 workplaces that allowed smoking had at least one concentration measurement over 2 µg/m^3, as did six of the seven companies that had restricted smoking. This was not true for the six companies that had banned smoking. Half those workplaces that allowed smoking had maximum concentrations of 10 µg/m^3 or more, as did a similar proportion of those that restricted smoking. Although 4 of the 14 work sites that allowed smoking had highest concentrations over 20 µg/m^3, only 1 work site that restricted smoking had a level as high. Average nicotine concentrations were less than or equal to 0.5 µg/m^3 in the production areas of the six companies that prohibited smoking, and the maximum values measured were 1.1 µg/m^3 in two of these companies, whereas levels in the other four companies were under 1 µg/m^3.

Figure 3 and Table 7 demonstrate the effect of smoking restrictions at the 25 workplaces surveyed in the WellWorks study (*7*). A substantial percentage of workers were exposed to over 5 µg/m^3 of nicotine when smoking was allowed. A quarter of office workers were exposed to 20 µg/m^3 or more, whereas the upper 10% of nonoffice workers were exposed to over 7 µg/m^3 when smoking was allowed. Although half the office workers were exposed to 9 µg/m^3 or more of nicotine where smoking was allowed, only about 10% of office workers were exposed at this level where smoking was restricted, and none where smoking was banned. In offices where smoking was

$$[\text{nicotine}]_{\text{steady state}} = \frac{(\#\text{smokers})(\#\text{cigarettes smoke/hr/smoker})(\mu\text{g nicotine emitted/cigarette})}{(\text{volume of room, m}^3)(\text{ventilation rate, air change/hr})(\text{adsorption loss})} \quad \textbf{Equation 1}$$

$$\text{air changes per hr} = \frac{(7\text{ people})(20\text{ ft}^3/\text{min/person})(60\text{ min/hr})}{(10{,}000\text{ ft}^3)} = 0.84\text{ air exchanges/hr} \quad \textbf{Equation 2}$$

$$[\text{nicotine}]_{\text{steady state}} = \frac{(2\text{ smokers})(2\text{ cigarettes/hr/smoker})(1800\ \mu\text{g nicotine/cigarette})}{(283\text{ m}^3)(0.84\text{ airchanges/hr})(2.2)} = 13.8\ \mu\text{g/m}^3 \quad \textbf{Equation 3}$$

$$[\text{nicotine}]_{8\text{ hr TWA}} = 0.81 * [\text{nicotine}]_{\text{steady state}} = 0.81(13.8\ \mu\text{g/m}^3) = 11.2\ \mu\text{g/m}^3 \quad \textbf{Equation 4}$$

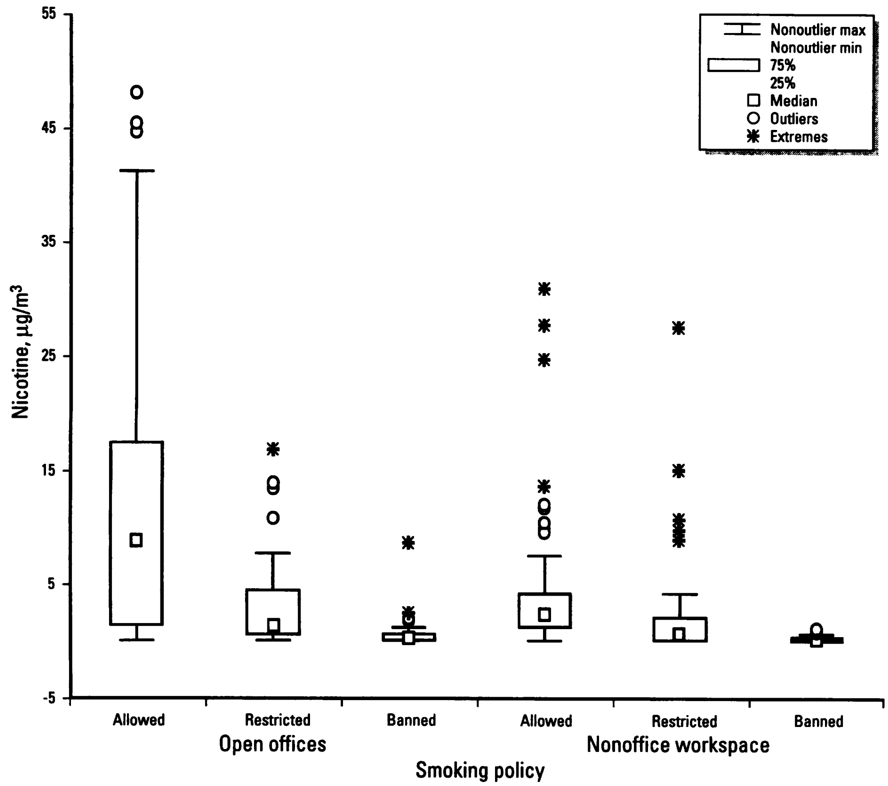

Figure 3. Effect of smoking policy. Distribution of nicotine concentrations in workplaces as a function of smoking policy, and by office or other workplaces. Data from the 25 companies sampled as part of the WellWorks study (*7*).

Table 7. Effect of smoking policy on nicotine concentrations in the workplace.

	Concentration of nicotine, µg/m^3		
	No Smoking Policy	Smoking Restricted	Smoking Banned
Offices			
No. of workplaces			
25th percentile	1.5	0.5	<0.1
Median	8.6	1.3	0.3
75th percentile	19.5	3.7	0.5
90th percentile	34.4	9.1	1.7
% <1 µg/m^3	13	45	82
% >1 µg/m^3	87	55	18
Nonoffices			
No. of workplaces			
25th percentile	1.1	<0.1	<0.1
Median	2.3	0.7	0.2
75th percentile	4.1	2	0.3
90th percentile	7.2	4	0.6
% <1 µg/m^3	22	63	96
% >1 µg/m^3	78	37	4

banned, over 90% of office workers were exposed to less than 2 µg/m^3, and 82% to less than 1 µg/m^3.

Comparison to ETS Levels Found in Homes

The average concentration of nicotine found in the homes of smokers has been measured in several studies (Table 8). The studies that involved at least 10 homes and were sampled for 14 hr to 1 week reported average nicotine concentrations between 1 and 6 µg/m^3. Only the study of 47 homes of smokers in New York state is based on a random sample; the weekly average concentration in winter and spring of 1986 was 2.2 µg/m^3 (*24*). The largest study of nonoccupational exposure to ETS, presumably with most exposure occurring in the home, was conducted by Jenkins et al. (*8*), who reported a 16-hr average exposure concentration of 2.1 µg/m^3 for 86 men and 2.9 µg/m^3 for 220 women exposed in the home. In studies of 13 smokers' homes in North Carolina, Henderson et al. (*25*) reported a 14-hr average concentration on weekdays (5 PM–7 AM) of 3.7 µg/m^3, whereas weekly samples in many of these same homes, collected a year later, had an average concentration of 1.5 µg/m^3 (*26*), quite similar to the values reported by Jenkins et al. in 1996 (*8*) and Leaderer and Hammond in 1991 (*24*). In contrast, Marbury et al. (*27*) reported an average weekly concentration of 5.8 µg/m^3 in the homes of 25 smokers in Minnesota. The 95th percentile concentration in the Jenkins study of 306 men and women was 8 µg/m^3, whereas the maximum concentrations were 9 µg/m^3 in the New York state study, 6 µg/m^3 in North Carolina, and nearly 30 µg/m^3 in Minnesota. The median weekly concentrations in the New York State and North Carolina studies were between 1 and 1.5 µg/m^3, as were the medians of home concentrations determined by personal samples collected for 16 hr by Jenkins et al. (*8*). The median concentration in the Minnesota homes was 3 µg/m^3 (*27*). These values are in contrast to workplace data that show median concentrations generally between

Table 8. Nicotine concentrations in homes.

	Concentration of nicotine, µg/m^3							
	Year sampled	No. of samples	Mean	Standard deviation	Minimum	Median	Maximum	Reference
North Carolina homes, weekly	1988	13	1.50	1.10	1.00	1.40	4.40	(*26*)
Personal, each sampled 3 times	1988	15						(*26*)
Males, personal,[a] 16 hr	1993–1994	86	2.13			1.29	>8.08[b]	(*8*)
New York homes, weekly	1986	47	2.20		0.10	1.00	9.40	(*24*)
Females,personal,[a] 16 hr	1993–1994	220	2.93			1.14	>7.81[b]	(*8*)
North Carolina homes, 14 hr (5 PM–7 AM)	<1987	13	3.74			3.3	6.5	(*25*)
Minnesota homes, weekly	circa 1989–	25	5.80		0.10	3.00	28.60	(*27*)

[a]16 hr average; "away from work." [b]95th percentile, as given in this article.

2 and 10 µg/m^3 in areas in which smoking is allowed (Tables 2, 3, 5, 6).

An examination of the concentrations of eight ETS surrogates reported by Jenkins et al. (*8*) in the Oak Ridge Study demonstrates that workplace concentrations are at least comparable to home concentrations in settings in which smoking is allowed (Figure 4). The mean and 80th percentile concentrations of seven of these eight surrogates (all but solanesol) were equal to 90 to 146% of the home concentrations, whereas the 95th-percentile workplace concentrations exceeded the 95th-percentile home concentrations by factors of 1.5 to 2.2 for all surrogates except solanesol. In constrast, the median concentrations at the workplace were generally less than those in the home. Thus, within this data set, a much wider range of ETS concentration exists in workplaces that allow smoking than in homes with active smokers. For example, the ratio of the 95th-percentile nicotine concentration to the median is 14 among those exposed in workplaces where smoking is allowed compared to only 5 among those exposed at homes with smokers. The greater variability of ETS levels in the workplace and the much higher 95th-percentile workplace concentrations may be due to the potential for many more smokers to occupy a single room or area in the workplace than in the home as well as the great variation in room size and ventilation systems.

The most representative data available for comparing home and workplace exposure to ETS were collected in NHANES III, a nationally representative sample of the U.S. population evaluated from 1988 through 1991 (*28*). ETS exposure was assessed by questionnaire (home and workplace only; exposure in other settings was not evaluated in the questions) and analysis of serum cotinine [see Pirckle (*28*) for details]. Half the 2,672 adult workers in this study reported they were not exposed either at home or at work, whereas almost one-third of workers were exposed only at work, 12% only at home, and 9% both at home and at work (Table 9). The geometric mean cotinine concentration for those exposed only at work was approximately half that of those exposed only in the home, indicating that workplace exposure is a major contributor to total ETS exposure. Although workers spend three times as much time away from the work as at work, cotinine levels indicate that the geometric mean exposure (expressed as concentration multiplied by duration) outside the workplace is only twice that of the workplace. Workers exposed to ETS both in the home and at work had serum cotinine concentrations approximately equal to the sum of the concentrations found in those exposed only at work and those exposed only in the home.

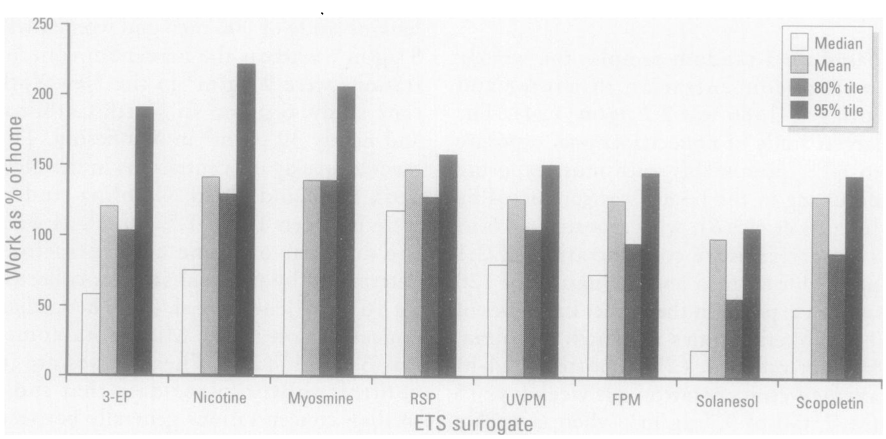

Figure 4. Comparison of ETS levels measured in the home and in the workplace. The ratio of workplace to home concentrations of eight ETS surrogates with an examination of this ratio for the median, the mean, and the 80th, and 95th percentiles. 3-EP, 3-ethenylpyridine; FM, fluorescence of a methanol extract of ETS particulate matter; RSP, respirable suspended particles; UVPM, a measure of the ultraviolet absorbance of a methanol extract of ETS particulate matter. Calculated from data in Jenkins et al. (*8*).

Table 9. Serum cotinine in nontobacco using adults who work.[a]

Reported ETS exposure[b]	*n*	% of workers	Cotinine, GM, ng/ml
No home or work exposure	1,332	50	0.132
Work only	779	29	0.318
Home only	315	12	0.651
Work and home	246	9	0.926

[a]Data from Pirkle et al., (*28*). 1996. [b]Observations made 22 June 1998.

Exposure Metric of Interest

For risk assessment purposes, emphasis is placed on characterizing the form of the distribution of exposures to ETS in the workplace. For the skewed distributions that have been observed, the geometric mean or the median are appropriate descriptors of the typical exposure. However, the arithmetic mean is the appropriate measure to use in evaluating cumulative exposure, which is relevant for both cancer and heart disease. Public health concern extends not only to the average worker's exposure but to the proportion of workers receiving exposures associated with unacceptable risk. This concern reflects the intent of the Occupational Safety and Health Act, to try to protect all workers so that none are exposed above the levels that have been established to present significant health hazards. The purpose of the Occupational Safety and Health Act, as stated in Section 2(b) of the Act, is "to assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources" (*1*).

To begin to address the hazard posed by ETS exposure in the workplace, information about the risks at comparable exposure levels in other locations can be used, along with direct assessment of risks associated with ETS exposure in the workplace. For this purpose, the exposure data provide a key link for translating risks observed in the home, the principal locus for studies of lung cancer, heart disease, and asthma, to the workplace. A full risk assessment is beyond the scope of this review.

The largest study of lung cancer among nonsmokers evaluated home exposure with two metrics, pack years exposure to spousal smoking and years exposed to spouse and others in the home (*29*). Because the lowest exposure group contained less than half the control subjects exposed to ETS in the home, the median exposure of those exposed in the home is higher than the exposure of those in the lowest exposure category. Lung cancer rates were elevated in all categories of those exposed, including those in the lowest exposed group. Therefore, median home concentrations of ETS are considered to confer increased risk of lung cancer.

Because one-fourth of the time in a week is spent on the job (40 hr/168 hr), parity between home and occupational exposure occurs when occupational concentration is 3 times the home concentration. If ETS exposure at the median level found in the homes of smokers is assumed to be hazardous, and the a median home concentration is between 1 and 1.4 $\mu g/m^3$ (Table 8), an equivalent weekly exposure would be gained at an occupational-only concentration of 4 $\mu g/m^3$ nicotine.

The data summarized in Tables 1 to 6 demonstrate that nearly every assessment of ETS in the workplace has found some exposure concentrations over that level. Within the 16-city study data (*8*), the median home exposure concentration in areas where smoking was taking place was 1.4 $\mu g/m^3$, but 20% of those who worked in areas where smoking was allowed without restriction were exposed to over 3 times that concentration, or 4.5 $\mu g/m^3$ or more. Five percent of workers at workplaces where smoking was allowed in that study were exposed to nicotine concentrations over 10 times the median home concentration [see Table 13 in Jenkins et al. (*8*): 95th percentile = 14.1 $\mu g/m^3$]. The NHANES III study indicated that 38% of workers reported being exposed to ETS at work, so 7% of all workers may have weekly occupational exposure to ETS comparable to concentrations of exposures in the homes of smokers.

The inherent temporal variability of ETS exposures may place some workers at risk, particularly for acute effects, even though mean or median values meet a criterion for acceptability. Kromhout et al. (*30*) demonstrated that for most occupational exposures the day-to-day variability in each worker's exposure, σ_w, is generally greater than the variability between workers in the same job grouping, σ_b. This may be seen in the exposures of railroad clerks to nicotine; for the three nonsmoking clerks with four daily measurements of airborne nicotine exposures, the within-worker variability, σ_w, was 12.8, 5.8, and 7.6; in contrast, the between-worker variability, σ_b, was only 1.3.

Spear (*31*) has shown that large variability in a worker's daily exposure to air contaminants leads to a reduced probability of detecting a high exposure on any one day, even among those exposed above some occupational exposure limit. For example, if 10% of workers had yearly mean exposures in excess of the limit and the geometric standard deviation (GSD) for exposure in that workplace and job was 3.0, an indication of high variability, the probability that the air sample collected on any one day exceeds the occupational exposure limit is between 10 and 18%; if GSD = 1.5, a situation in which daily exposures are not very variable, then this probability is between 11 and 28%. Thus, any one measurement on one individual in a workplace is unlikely to exceed the occupational exposure limit, even when 10% of the workers are overexposed. Spear further shows that even if half the workers are overexposed, a single sample still has less than a 50% probability of being over that level. When the individual data are highly variable, capturing the highest exposures is quite difficult, as is estimating annual mean exposures.

Summary

Workplace smoking policies clearly make a substantial difference in the concentration of ETS in the workplace. Nicotine concentrations were much higher in both the office and nonoffice areas of work sites where smoking was allowed than in those workplaces that either restricted smoking to relatively few areas or banned it completely. However, policies that restricted smoking had uneven efficacy, which probably reflects differing implementations of policy, whereas complete smoking bans were quite effective.

Only one study, the study of railroad workers (*5,6*) included measurements of the personal exposures of workers on more than one day. In that study, each office worker sampled on four workshifts had over a 50-fold range in daily exposure to ETS. This high variability in exposure increases the likelihood that workers will be overexposed to this complex mixture of toxic air contaminants over a year period, even as it decreases the likelihood of measuring a high exposure on any one day (*32*). This caveat must be borne in mind as results of workplace measurements are examined.

Several studies have now been performed to measure workplace exposure to ETS. The mean concentrations in offices were generally between 2 and 6 $\mu g/m^3$ nicotine; in restaurants between 3 and 8 $\mu g/m^3$, in bars between 10 and 40 $\mu g/m^3$, and in other, diverse blue collar occupations, between 1 and 6 $\mu g/m^3$, although some workplaces had higher means in all these locations. However, nearly all of these studies also reported much higher maximum concentrations; e.g., most offices studied had at least one sample with nicotine concentration over 10, whereas several offices had measured concentrations of over 40 $\mu g/m^3$ (*7,18,32–34*). These results are in agreement with predictions from modeling the range of office exposures (*23*). These measurements are in contrast to nicotine concentrations in the homes of smokers, where the adverse health effects of ETS have been most clearly established, and generally average between 1 and 3 $\mu g/m^3$ nicotine, with highest levels under 10 $\mu g/m^3$ except in the Minnesota study which reported a maximum of 29 $\mu g/m^3$. Average workplace concentrations of nicotine in areas where smoking is allowed are commonly greater than concentrations in the homes of smokers, and the upper 5% of such workplace concentrations are over twice as great as the upper 5% of these home concentrations (*8*) (Figure 4).

According to the NHANES III study, the only nationally representative sample reported to date (*28*), nearly 40% of U.S. workers report being exposed to ETS in the workplace. Furthermore, the workplace is the principal source of ETS exposure for three-quarters of these workers not exposed at home. Measurements of serum cotinine in these workers confirmed the measurements of airborne nicotine in the workplace, namely, that the workplace leads to significant ETS exposure compared to the home Despite the increase in policies restricting smoking in the workplace, a large fraction of U.S. workers continue to be exposed to significant levels of ETS.

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