Indoor Air Pollution From Cigar Smoke

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INTRODUCTION Smoking in enclosed spaces exposes occupants to indoor air pollution from the by-products of tobacco combustion in confined spaces where airborne contaminant removal is slow and uneven. This chapter investigates the factors determining the indoor environmental tobacco smoke exposure from cigar smoking. Mathematical models allow the prediction of the levels of indoor pollutants, such as environmental tobacco smoke (ETS).

The physical design of the cigar, leaf type and composition, and wrapper type may all affect the cigar emissions (Schmeltz et al., 1976) (Chapter 3). For a given composition, the mass of a cigar consumed during smoking is the primary determinant of the quantity of its emissions. The greater mass of tobacco in cigars relative to cigarettes leads to a prolonged smoking time and greater total emissions when a single cigar is smoked compared to a single cigarette. An alternate means of comparing emissions from cigars with those of cigarettes is to compare the emission per minute or per gram of tobacco burned. Both the emission rates and the number of minutes a tobacco product is smoked need to be considered when comparing the contribution of cigars and cigarettes to ETS. The emissions of cigars differ from those of cigarettes due to differences in construction and engineering and differences in tobacco leaf (Chapter 3). The number of puffs taken to smoke a large cigar is dependent on the size of the cigar and may be as high as 100, whereas for a cigarette, it is approximately 10 (Rickert et al., 1985).

MATHEMATICAL MODELS FOR CIGAR ETS CONCENTRATIONS ETS concentrations of indoors can be predicted with reasonable accuracy by application of a mass balance model (Leaderer, 1990). This model shows that the average concentration, Z_{ave}, of ETS pollutants in indoor air is directly proportional to the pollutant mass emission rate and inversely proportional to the rate at which a unit volume of indoor air is cleared of ETS (Ott et al., 1992; Leaderer, 1990; Repace, 1987a,b).

Ott et al.(1992) have shown that the time-averaged ETS concentration Z_{ave} (in units of $\mu g/m^3$), is given by:

$$Z_{ave} = g_c n_{ave} / \phi v \qquad (1)$$

where g_c is the cigar emission rate in units of $\mu g/min$, n_{ave} is the average number of cigars being smoked during the averaging time ΔT, where the generation rate need not be uniform, i.e., the number of cigars being smoked at any instant may vary. We define $n_{ave} = t_s / \Delta T$ where t_s is the total duration of smoking (Repace et al., 1996). The quantity $\phi = q\phi_v$ is the effective air exchange rate in units of hr^{-1}, ϕ_v is the air exchange rate due to ventilation alone, and v is the space volume in units of m^3. The term q is an empirically-derived factor ($q \geq 1$) expressing the increase in removal over ventilation alone due to such processes as surface sorption of particulate matter (Repace, 1987). The estimation accuracy of this equation improves as the correction term $\Delta Z/\phi\Delta T$ becomes small compared to Z_{ave}, where ΔZ is the difference between the initial and final observed concentrations (Ott et al., 1996).

For each individual cigar (Repace, 1987), the change over time of the ETS pollutant concentration during smoking, assuming a uniform generation rate, is given by Z(t), the concentration at time t where e is the base of natural logarithms:

$$Z(t) = Z_{eq}(1 - e^{-\phi t}) \qquad (2)$$

After a long time period, the pollutant concentration approaches an equilibrium value Z_{eq}, but most cigars typically are extinguished before reaching their equilibrium value. The equilibrium value is a function of the emissions space volume and ventilation rate and is defined by the equation.

$$Z_{eq} = g_c / \phi \nu \qquad (3)$$

Once smoking has ended, at a time t_s, the concentration will decay as:

$$Z(t) = Z(t_s)\, e^{-\phi(t - t_s)} \qquad (4)$$

where $Z(t_s)$ is given by Equation 2 with $t = t_s$. Equations 2 through 4 are illustrated in Figure 1.

Equations 1 through 4 allow the results from field surveys and chamber experiments to be generalized, estimating concentrations for pollutants from ETS in a variety of indoor settings. These predictions require determination of the values of n_{ave}, g_c, ν, and ϕ. It is possible to determine ϕ by experiment and to measure or estimate ν, and to determine ϕ_v from either measurement or estimation from tables of ventilation rates (Repace, 1987). The emission factor, g_c, must be measured for the ETS constituent of interest.

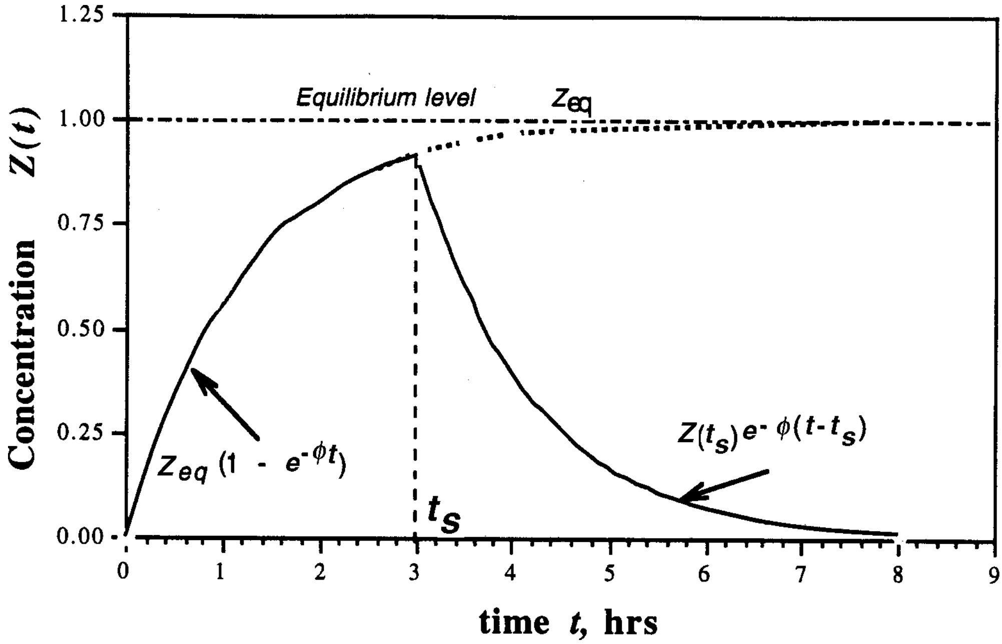
CIGAR EMISSIONS: MACHINE SMOKING

The chemical composition of cigar smoke is described elsewhere in this monograph (Chapter 3).

Sidestream smoke is the major contributor to ETS for cigarettes (Adams et al., 1987; Surgeon General (SG), 1986); there is little available data on the relative amounts of sidestream and exhaled mainstream smoke for cigars. On a per-cigar basis, large cigars deliver substantially higher amounts of carbon monoxide (CO) and other sidestream gas-phase constituents than little cigars or cigarettes, and substantially higher amounts of sidestream ammonia (Schmeltz, et al., 1976). Armitage et al. (1978) collected the exhaled mainstream and sidestream smoke of seven male habitual smokers of both little cigars and cigarettes and reported that the sidestream nicotine emissions averaged 30.9 percent $\pm$ 5.4 percent of total cigar nicotine, while exhaled mainstream smoke averaged 12.7 percent $\pm$ 9.0 percent. The cigar butt retained 20.1 percent $\pm$ 8.8 percent, while the smoker retained the remainder, in an amount similar to cigarette smoking.

Figure 1.

Growth and decay of the concentration (in normalized units) of an ETS pollutant as a function of time (in hours) as predicted by the mass balance model (solid line), respectively given by Equations 2 and 4 in the text. In this example, the air exchange rate ϕ = 0.84 hour^{-1}, is equivalent to the ASHRAE Standard for an office, and is slightly higher than the average closed window air exchange rate for a home. Smoking begins at time t = 0, and ends at time t_s = 3 hours. The figure represents the concentration from three cigars of 1 hour duration each smoked over a 3-hour period; the average number of cigars smoked during the 3-hour period, is thus 1, from Equation 1. The concentration at the end of the three hour smoking period is calculated by Equation 2 as $Z(3) = 0.93\ Z_{eq}$. The dashed curve shows the concentration which would occur if smoking continued; after a long time, the equilibrium concentration Z_{eq}, described by Equation 3 in the text, is approached. The actual decay of concentration after smoking ceases is given by Equation 4.



CIGAR EMISSIONS: HUMAN SMOKING

Machine smoking in chambers under standard conditions can provide a comparison of the relative emissions of various tobacco products. However, in order to understand how differences among tobacco products affect ETS concentrations, we must also measure emissions and concentrations when cigars are smoked by human smokers who, unlike machines, smoke idiosyncratically.

Emissions of RSP, CO, and Nicotine from Cigars

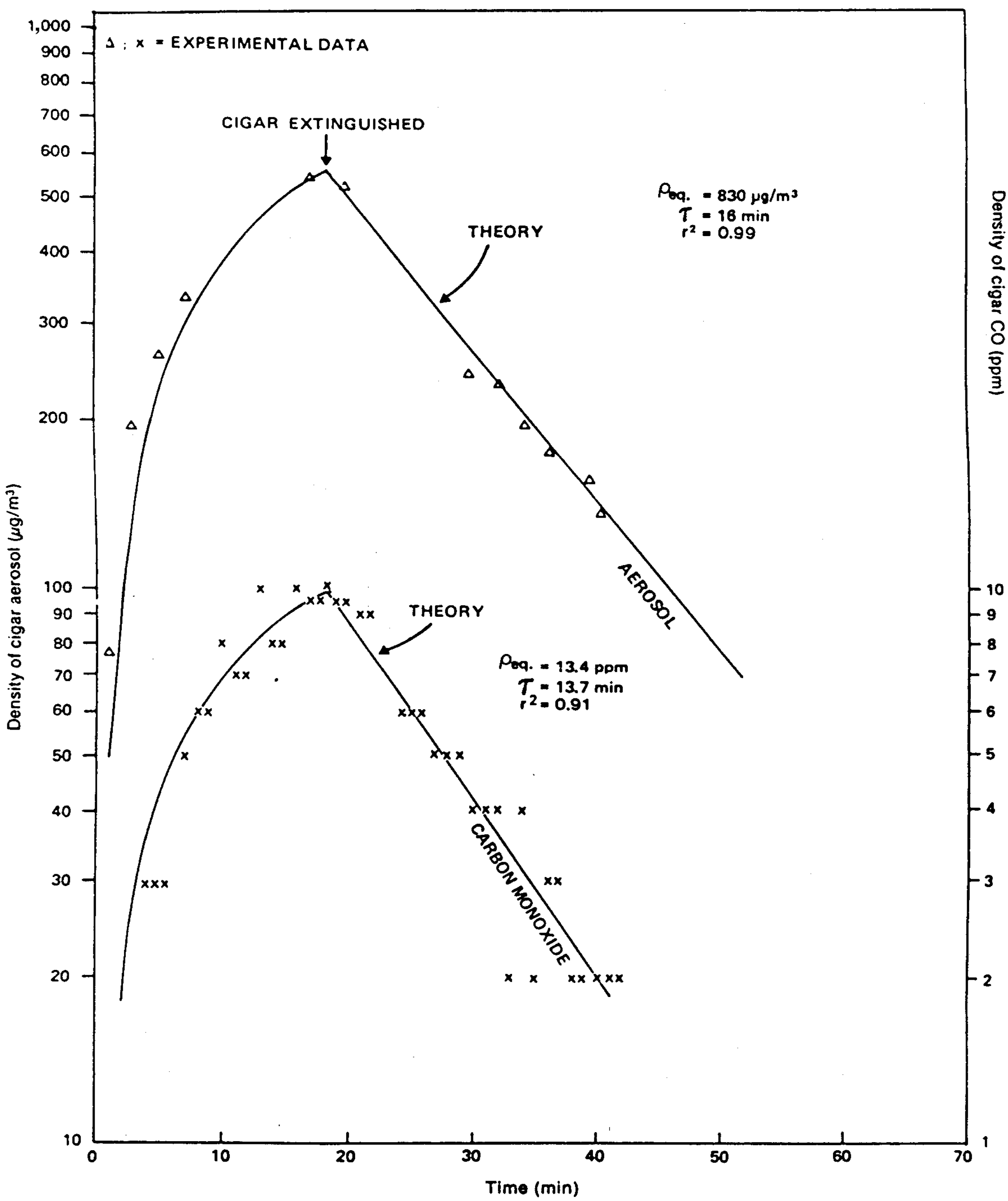
Repace and Lowrey (1982) measured Respirable Suspended Particles RSP (particles less than 3.5 microns in aerodynamic diameter) and CO emissions of a popular-priced, mass-market cigar (Marsh-Wheeling Stogie, length ≈5-1/2", ring size ≈38, mass ≈7 g) smoked in a well-mixed volume $v = 51\ m^3$ in a mechanically ventilated office building. The logarithms of the RSP and CO concentrations plotted versus time show a straight-line decay pattern from which the air exchange rate can be calculated (Figure 2).

The cigar was smoked by a regular cigar smoker for 20 minutes, yielding a predicted equilibrium of $Z_{eq} = 830\ \mu g/m^3$ for RSP and 13.4 ppm (15,340 $\mu g/m^3$) for CO, calculated using Equation 3. The total calculated RSP emissions were $G_{RSP} = 51 m^3 \times 830\ \mu g/m^3 \times 20\ min / 16\ min = 52.9\ mg$, and the RSP emission rate was $g_{RSP} = G_{RSP}/t_s = 52.9\ mg/20\ min = 2.65\ mg/min$. For CO, the total emissions were $G_{CO} = (51\ m^3 \times 15{,}340\ \mu g/m^3 \times 20\ min) / 13.7\ min = 1142\ mg$, using $\tau = 1/\phi = 13.7\ min$ ($\phi = 4.38\ hr^{-1}$) yielding a CO emission rate of $g_{CO} = G_{CO}/t_s = 57.12\ mg/min$. Neither the fraction of the cigar smoked nor the after-smoking weight was recorded.

In 1978, by comparison, a single king-sized Marlboro was smoked by a smoker for $t_s = 5.33$ mins in a $v = 29\ m^3$ unventilated but well-mixed bedroom with the windows and door closed (Repace and Lowrey, 1980). The value of $Z_{eq} = 1773\ \mu g/m^3$ for ETS-RSP was calculated using Equations 2 and 4, and the mean residence time for the RSP was $\tau = 16.39$ mins ($R^2 = 0.80$). Using Equation 3 (with $\phi = 1/\tau$), the total RSP emissions were calculated to be $G_{RSP} = 29\ m^3 \times 1773\ \mu g/m^3 \times 5.33\ min / 16.39\ min = 16.72\ mg$ per cigarette, and the RSP emission rate was $g_{RSP} = G_{RSP}/t_s = 3.14\ mg/min$. The cigarette RSP emission rate is actually higher than the cigar, although the total RSP emissions of the cigar are much greater due to the four-fold greater smoking duration and larger mass of tobacco in the cigar.

Leaderer and Hammond (1991) measured the emissions of 10 U.S. brands of cigarettes and 1 cigar (a cigarillo -- B. Leaderer, personal communication, 1997) as smoked by human smokers. From data presented in the paper, an estimated total of 440 U.S. cigarettes and 40 cigars were smoked in this study. The average smoking duration for the cigarettes was 7.5 mins; the average duration for the cigars was not specified, but appears to be the same as for the cigarettes. The RSP emissions of the 10 brands of cigarettes representing 48 percent of the sales-weighted U.S. market in 1987, averaged $G_{RSP}/M_{cig} = 27 \pm 3.4\ mg/g$, where an average of $M_{cig} = 0.63 \pm 0.023$ g of tobacco was smoked per cigarette. This results in an emission rate of 2.27 mg of RSP per minute. The total average cigar emissions were $G_{cigar} = 48 \pm 9.1\ mg/g$. The physical characteristics of the cigar were not specified; however, a cigarillo typically contains less than 1.3 g of tobacco. The

Figure 2.
Growth and decay of RSP and CO from a cigar smoked by a smoker in a mechanically ventilated 51 m³ office at the U.S. Naval Research Laboratory's main computer building in Washington D.C. in 1978. The effective air exchange rates of RSP and CO are similar (about 4 ach) due to the effect of three mixing fans. By contrast, when the ventilation and mixing fans were not used, the effective air exchange rate for RSP was 1 ach, and for CO, 0.43 ach (Repace and Lowrey, 1982).



steady-state chamber nicotine concentration for the cigars was essentially the same as for the cigarettes, whereas the RSP emissions were 28 percent higher for the cigar.

Klepeis et al. (in press) report cigar smoking in two locations: a residence and an office. These experiments consisted of the smoking of a cigar by a person in both locations, and by a smoking machine in the latter. The effects on real-time pollutant concentrations of various cigar durations, smoking styles, and ventilation rates were measured.

In some of the experiments, two-minute average RSP concentrations were measured with a TSI Model 8510 piezobalance. For one experiment, particle-bound polycyclic aromatic hydrocarbon (PAH) concentrations were measured with an EcoChem PAS 1002i Realtime PAH monitor (West Hills, CA).

The ventilatory air exchange rate was determined using Equation 4 by observing the exponential decay of CO concentration after smoking had stopped, thus including only the removal from air flow in and out of the room. In contrast, the effective air exchange rate for RSP or PAH, which includes mechanisms of RSP or PAH removal such as deposition and ventilation, was measured by observing the exponential decay of RSP and PAH concentrations. Together with the room volume and the observed pollutant time series, these decay rates provided a means to calculate CO and RSP emission factors for each cigar.

In the residence, Klepeis et al. (in press) report results for a single cigar smoked by a human smoker on two separate days in a 97 m^3 parlor. Measurements of the particle size distribution showed that the bulk of the cigar aerosol mass was in the particle-size range 0.1 to 2.5 μm. A regular cigar smoker smoked the cigar for 1 to 2 hours. Once the levels had declined to near background, a different smoker smoked a cigarette for 9 minutes providing a comparison of the cigar and cigarette emissions under the similar conditions (Figure 3).

The upper curves of Figure 3 show the real-time PAH concentrations of the cigar and cigarette and the lower curves show the real-time RSP concentrations. The mass balance model predicts the pollutant concentration time series with reasonable accuracy (Figure 3, bottom) (Klepeis, et al., in press).

The ratio of CO to RSP concentrations is 1 ppm of CO per 165 $\mu g/m^3$ of RSP for a Santona cigar smoked on day 1 (Table 1). The ratio of particulate PAH to RSP concentrations is 1 $\mu g/m^3$ of particulate PAH per 238 $\mu g/m^3$ of RSP for a Paul Garmirian cigar smoked on day 2. By contrast, for a Marlboro cigarette, the ratio is 1 $\mu g/m^3$ of particulate PAH per 137 $\mu g/m^3$ of RSP. However, the total PAH emissions for the cigar are twice that of the cigarette due to the much longer smoking duration and mass of the cigar.

In a field study of a 521 m^3 sports tavern, investigators machine-smoked four Dutch Masters Corona Deluxe cigars in 11 minutes, two at a time. Figure 7 shows the results for CO (Mage and Ott 1996, Ott et al. 1996). This experiment used the decay of cigar CO to determine the ventilatory air exchange rate of the tavern, ϕ_v = 7.5 ach. Similarly, the decay rate of RSP (less background) yielded the effective air exchange rate for cigar RSP, ϕ = 7.63 ach. They used three CO monitors and two

Figure 3.
The time series, i.e., growth and decay of PAH and RSP concentration with time, measured in a naturally ventilated San Francisco residence while a Paul Garmarian cigar and a Marlboro cigarette were smoked sequentially by two different persons on March 9, 1997. The upper plot shows the source activity pattern (rectangles) and the PAH data, while the bottom plot shows the simultaneously measured RSP data and the RSP time series predicted by the mass balance model (Klepeis et al., in press).

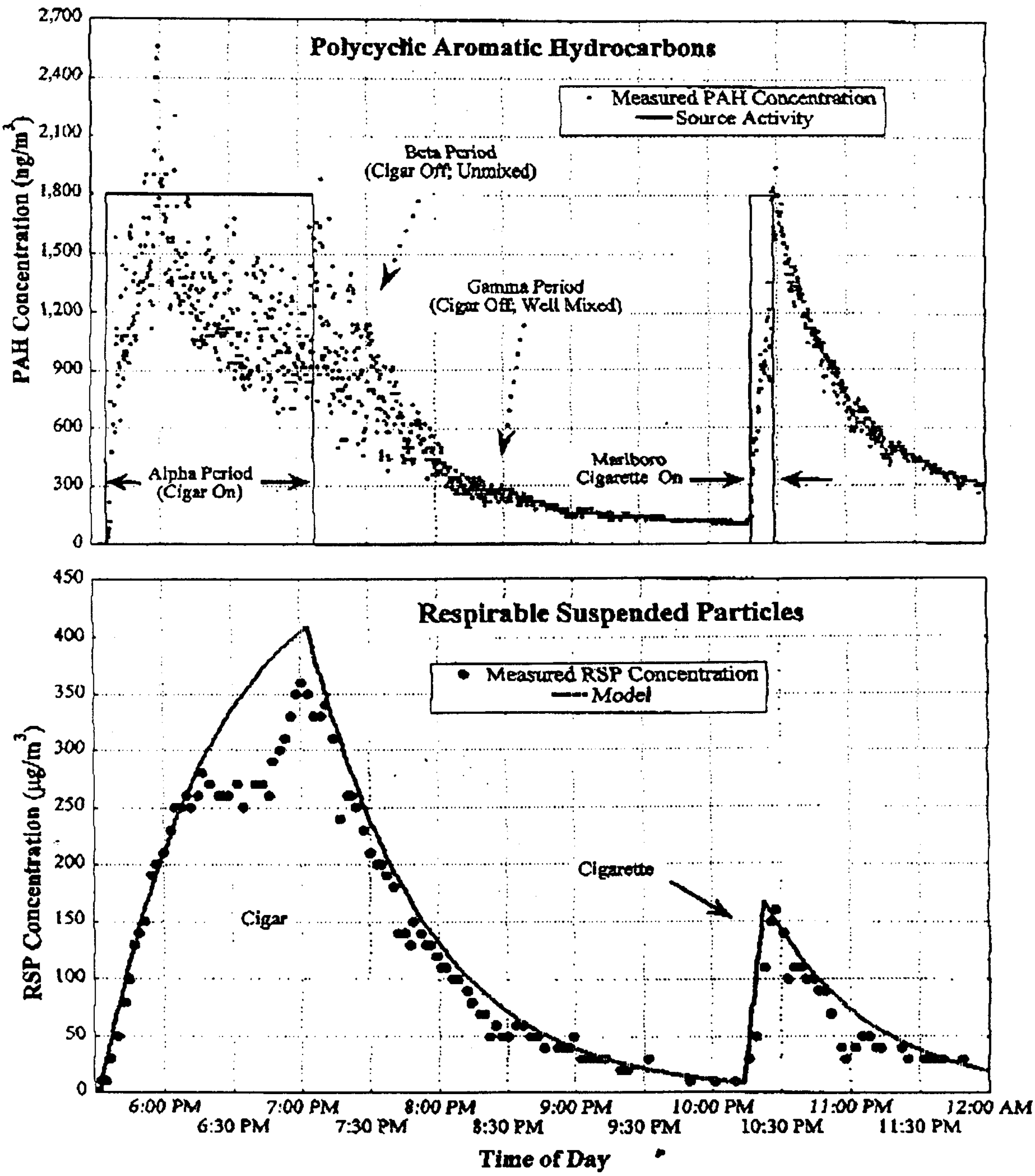


Figure 4.

Relative Emissions, Cigars versus Cigarettes: For each of the measured compounds, large cigars produce greater total emissions than cigarettes. For CO, RSP, PAH, and Cadmium, the emissions ratios are for ETS. For all others except benzene, they are for sidestream smoke. For benzene, they are for mainstream smoke. (Brunnemann et al. 1977; Appel et al. 1990; Brunnemann, Stahnke, and Hoffmann 1978; Brunnemann, Yu, and Hoffmann 1979; Brunnemann Adams and Hoffmann 1979; Brunnemann and Hoffmann 1978; Klepeis et al. in press; Brunnemann and Hoffmann, 1975.)

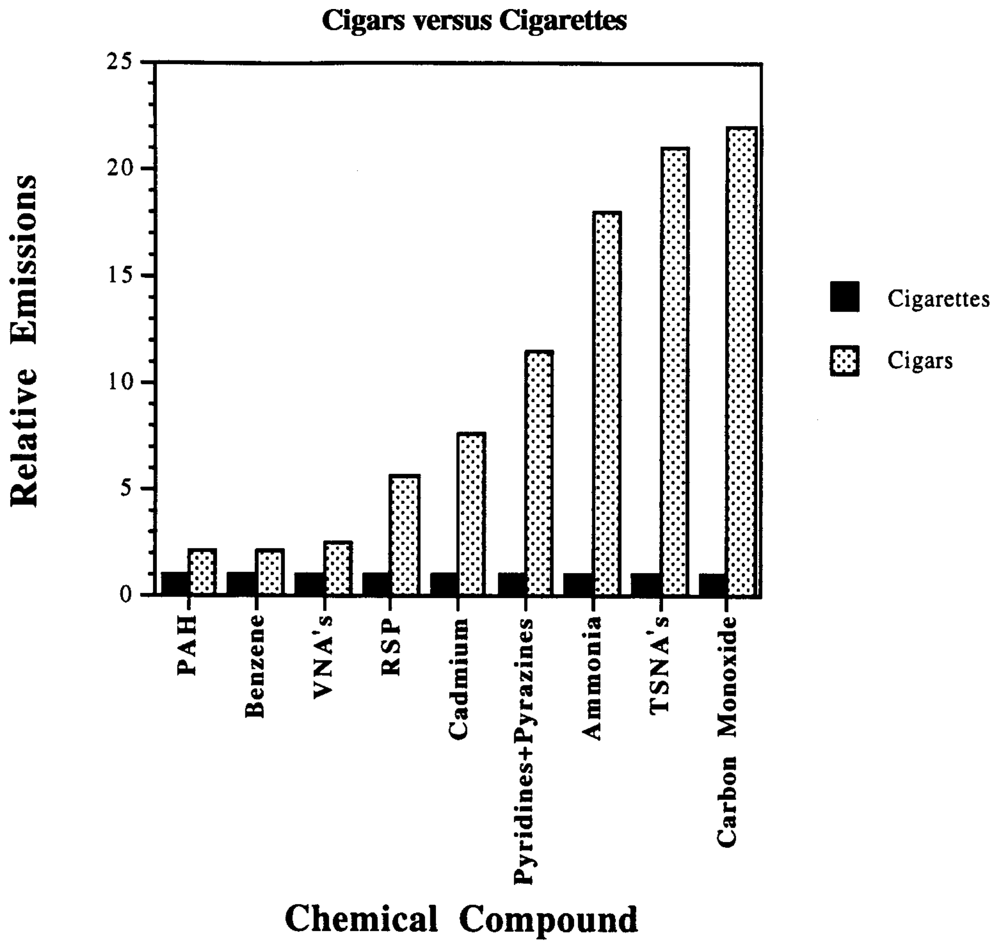


Table 1
CO, RSP, and Nicotine Emission Factors[1] Measured in Various Cigar and Cigarette Studies

[2]Experiment Description	Source Duration	[3]Ave Source Emission Rate	[4]Total ETS Source Emissions	[5]Mass Smoked	ETS emissions per Mass Smoked
Klepeis et al. (in press) 1 Sante Fe Fairmont cigar smoked by a machine in 49.6 m^3 office (4/6/96); 4.5 ach	7.8 min	140 mg CO/min	1.1 g CO	6 g	190 mg CO/g
1 Sante Fe Fairmont cigar smoked by a machine in a 49.6 m^3 office (4/7/96); 0.12 ach	24 min	50 mg CO/min	1.2 g CO	6.1 g	200 mg CO/g
1 AyC Grenadiers cigar smoked by a machine in a 49.6 m^3 office (4/27/96); 0.12 ach	10 min	87 mg CO/min	890 mg CO	4.9 g	180 mg CO/g
1 AyC Grenadiers cigar smoked by a machine in a 49.6 m^3 office (4/29/96); 4.5 ach	11.5 min	67 mg CO/min	780 mg CO	4.9 g	160 mg CO/g
1 Santona cigar smoked by a person in a 97 m^3 parlor of a (1.3 hrs) residence (3/1/97); 2.0 ach; 2.5 eff ach for RSP	76 min	14 mg CO/min 1.0 mg RSP/min	1.1 g CO 78 mg RSP	8.8 g	130 mg CO/g 8.9 mg RSP/g
1 Paul Garmirian cigar smoked by a person in a 97 m^3 parlor of a residence (3/9/97); 0.9 ach; 1.2 eff ach for RSP and 1.5 for PAH	90 min (1.5 hrs)	0.95 mg RSP/min 0.0042 mg PAH/min	86 mg RSP 0.38 mg PAH	10.8 g	8.0 mg RSP/g 0.035 mg PAH/g
1 Marlboro cigarette smoked by a person in a 97 m^3 parlor of a residence (3/9/97); 1.3 eff ach for RSP and 2.0 for PAH	7 min	1.9 mg RSP/min 0.022 mg PAH/min	16 mg RSP 0.18 mg PAH	0.4 g	40 mg RSP/g 0.45 mg PAH/g
Repace and Lowrey (1982) 1 Marsh Wheeling Stogie smoked by a person in a 51 m^3 office; 3.8 ach for RSP; 4.4 ach for CO (mechanical ventilation).	20 min	57 mg CO/min 2.7 mg RSP/min	1.14g CO 53 mg RSP	not recorded	
Nelson (1994) 50 top brands of cigarettes smoked by a person in an unventilated room (analyzed by Repace et al., in press)			13.8 ± 3.1 mg ETS RSP per cigarette 1.8 ± 0.28 mg ETS nicotine per cigarette		
Klepeis et al. (1996) Cigarette smoking in two airport lounges		11.9 mg CO/min 1.43 mg RSP/min			
CPRT (1990) 13 brands of cigars sold in Canada	not reported	not reported	not reported	not reported	10.3 ± 2.4 mg RSP/g 0.13 ± 0.08 mg nicotine/g
Mage and Ott (1996) 4 cigars smoked two at a time by separate machines in a 521 m^3 tavern (8/24/94); 7.2 ach; results are from two monitors, one in SW booth and one in NW booth	11 min (all sources)	SW, 240 mg CO/min NW, 250 mg CO/min	SW, 1.2 g CO per cigar NW, 1.3 g CO per cigar	not recorded	

Notes: [1]Calculations of emission factors are based on a single-compartment mass balance model, which assumes uniform mixing. [2]Experiment descriptions include the type of cigar or cigarette source, the location where smoking took place, the room volume, and the air exchange rate and/or effective air exchange rate, which includes all removal mechanisms (both are in units of air changes per hour). [3]Ave Source Emission Rate is the average emission rate over the time the source(s) was(were) on and over all the individual sources that were ever active. [4]Total Source Emissions is the total mass emitted over all sources. [5]Mass Smoked is the measured difference between the mass of the unsmoked cigar(s) or cigarette(s) source and the mass after smoking. [6]Emissions per Mass Smoked is Total Source Emissions divided by Mass Smoked. 1 ppm = 1.145 mg/m^3 at 25^{o}C and 1 ATM.

Source: Because of the exceptional and multi-source nature of this composite table, the general reference for the "Experiment description" column is: Klepeis et al. (in press). Specific references for horizontal data fields are noted in bold in the table.

RSP monitors, in three locations: a central table, a Southwest corner booth and a Northwest corner booth. The 30 minute average RSP concentration for the two monitors was 194 μg/m^3. The 30 minute average CO concentration for the three locations was 1.7 ppm (Mage and Ott, 1996).

Emissions of particulate phase Polycyclic Aromatic Hydrocarbons (PAH's) from Cigars

Available evidence suggests that cigar smoke contains many of the same carcinogenic PAH's that are found in cigarette smoke (SG,1979; IARC, 1986).

Real-time measurements of particle-bound PAH's (4 or more ringed compounds) are possible using a newly-developed photo-ionization monitor (EcoChem, West Hills, CA). Investigators have applied this new monitor to make real-time measurements of PAH aerosols from tobacco smoking and other sources in homes, automobiles, and outdoor ambient conditions (Buckley and Ott, 1996; Wilson et al., 1993; 1994; Ott et al., 1994).

Klepeis et al. (in press) used the EcoChem 1002i monitor in a 97 m^3 San Francisco parlor with a human smoking a Paul Garmirian cigar. The cigar caused the particle-bound PAH level to increase by as much as 2500 ng/m^3 above a near-zero background concentration, while a Marlboro cigarette increased the levels by 1700 ng/m^3 above background. Using a calibration factor of 1000 ng/m^3 per pA, they report that the total PAH emission for the cigar was 380 μg, while the cigarette emitted 180 μg. The emission rate and the total emissions per gram (22 μg/min, and 450 μg/g respectively) were higher for the cigarette than for the cigar (4.2 μg/min, and 35 μg/g respectively), but the cigar emitted twice as much total PAH as the cigarette because of its longer smoking time. The PAH concentrations of both the cigar and the cigarette shown in the upper part of Figure 3 generally track the RSP emissions shown in the lower part of the figure.

Figure 4 presents the total emission of various smoke constituents for cigars contrasted with that from cigarettes. For CO, RSP, PAH, and Cd, the emissions ratios are for ETS. For all others except benzene, they are for sidestream smoke.

MEASUREMENTS AT CIGAR SMOKING SOCIALS

Klepeis et al. (in press) report results from two field experiments in which an investigator wearing a concealed CO personal monitor attended public social events that featured cigar smoking. The hidden miniaturized monitoring instrument was a Langan L15 Personal Exposure Measurer™ equipped with a battery-powered data logger (Langan, 1992). The monitor was carried in the inside pocket of a jacket. Measurements were logged every minute in the first field study, and every 15 seconds in the second study.

The first cigar smoking social event, a "Cigar Smoker," was held in a private club in suburban San Francisco. Four different types of cigars were available at the entrance. The private club was a large house with two adjoining rooms (a large reception hall with a mezzanine and a food preparation area) measuring 1560 ft^2 (155 m^2) in total area, with a volume of 570 m^3. The event's sponsors opened all doors and windows to allow maximum flow of outdoor air.

The investigator wearing the monitor smoked the first cigar only partially and then mingled with the other guests. Because the monitor was carried for several hours while traveling to and from the party, it is possible to compare the in-vehicle and outdoor CO concentrations with those measured during the cigar smoker (Figure 5). As many as 89 persons were present (when 50 persons were present, there were 12 women and 38 men). Indoor CO concentrations during the smoker ranged between 5 and 11 ppm, yielding an indoor average of about 6 ppm. The highest CO concentrations occurred on the upstairs mezzanine of the main hall. If we adjust the observed CO concentrations by subtracting the ambient CO levels of 1.5 ppm measured outside the building on the sidewalks, the cigar smokers contributed about 4.5 ppm. The CO levels were similar to those measured during the rush-hour freeway drive to the event on Route 280, which is a major arterial roadway between San Francisco and San Jose, California. The high air exchange rate caused by the wide-open doors and windows probably reduced the interior CO concentrations considerably.

The second concealed monitoring field study (Klepeis et al., in press) took place at a cigar banquet held in a downtown San Francisco restaurant. This cigar banquet featured three premium cigars per person: [a Hoyo De Monterrey Epicure *#2,* (5", ring gauge 50) (Curtis, 1995) a Romeo Y Julieta Gold Label Churchill (7", ring gauge 47) (Curtis, 1995) and a Partagas Series "D" #4, (Robusto, 4-7/8", ring gauge 50) (Curtis, 1995, Resnick, 1996). Figure 6 shows the CO concentration time series from the point when the investigator departs from home in Redwood City, driving North on California Highway 101 to San Francisco. The CO averages about 4 ppm on this leg of the trip.

The CO concentration spikes to about 18 ppm in the confines of the parking garage, whereas it is only 1 ppm on the street. The guests received the first cigar when they entered the door, which was kept open during the entire social, and they gathered around the bar to socialize for about an hour prior to being seated for dinner. The indoor levels in the restaurant-bar during the first hour, due to about 24 smokers at the bar (including the investigator) were 13 to 17 ppm (Figure 6). At 7:45 PM the patrons were all seated for dinner at individual tables of 4 to 6 persons. After everyone was seated, waiters distributed the second imported cigar to all and began serving the three-course dinner. The investigator was seated with five other persons; all six smoked cigars during dinner; the investigator's cigar was only partially smoked. The third cigar was distributed just before dessert; the investigator did not smoke his. Overall, more than 100 cigars were smoked during this banquet; "laser lighters" rather than matches were used to ignite the cigars.

The indoor CO concentration averaged over the 3-hour-and-20-minute event was 10 ppm, and about 75 percent of the 40 persons present were smoking cigars at any instant of time. Based on measurements outdoors on downtown sidewalks before and after the event, ambient CO concentrations were found to be about 1 ppm, so the indoor CO concentration caused by cigar smoking was about 9 ppm. If the cigar dinner had lasted more than 8 hours, then indoor CO concentrations would have violated the National Ambient Air Quality Standard (NAAQS) adopted by the Environmental Protection Agency (EPA) to protect public health (9 ppm CO for 8 hours).

Figure 5.
The carbon monoxide (CO) personal concentration time series measured before, during and after attendance at a "cigar party" in the San Francisco Bay Area on January 1, 1997. The total volume of the establishment was about 570 m . At one point in the evening 89 persons were present of whom about two thirds were estimated to be smoking cigars. Notice that the background CO levels outdoors are between 1 and 2 ppm, and that the average CO concentration while driving from San Jose to the party (5.5 ppm; 5:00 PM - 6:20 PM) is similar to the average concentration while present at the party (5.8 ppm; 6:26 PM - 8:09 PM) (Klepeis et al. In press).

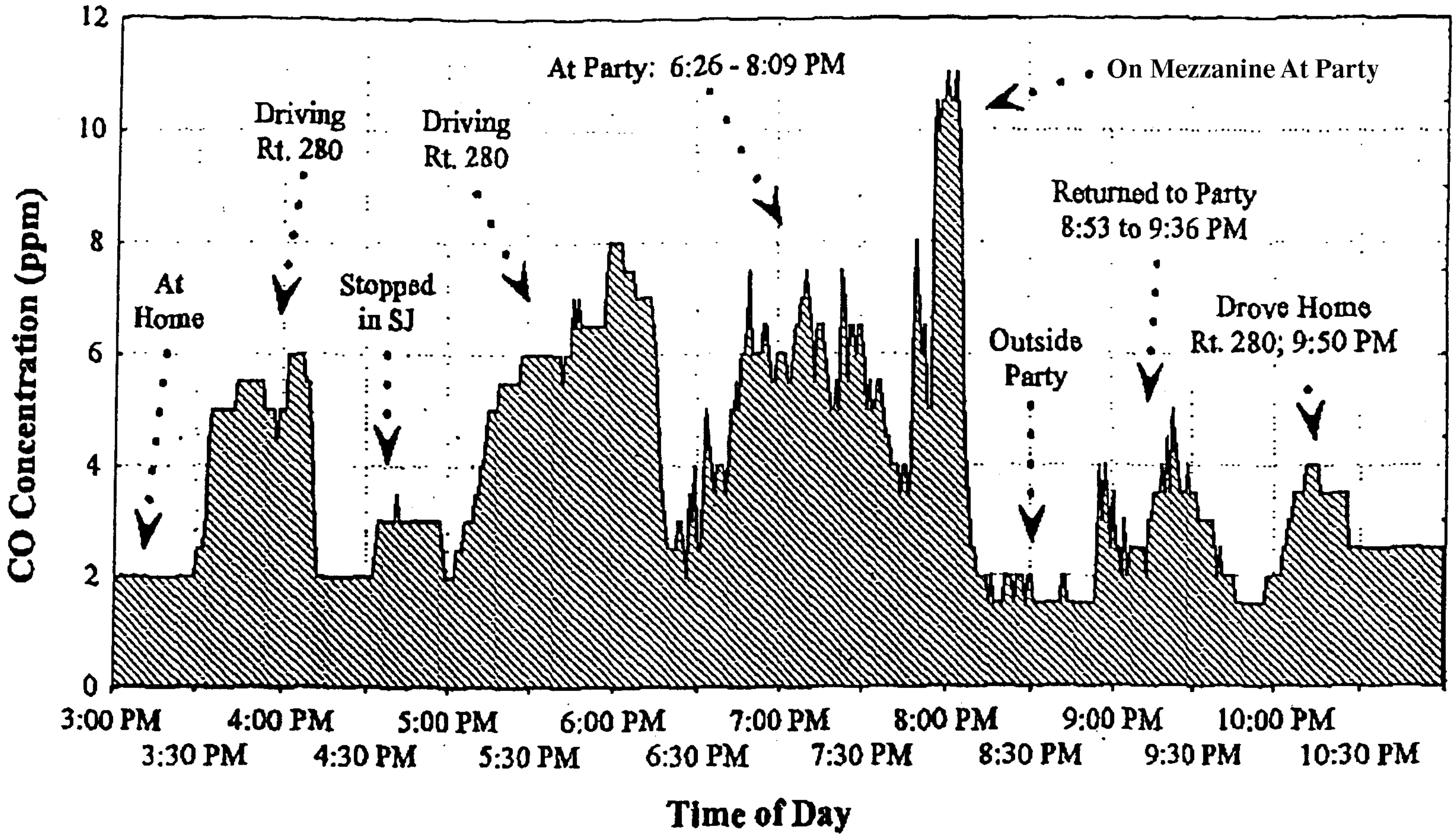


Figure 6.
CO concentrations measured using a concealed personal exposure monitor at a cigar dinner party in downtown San Francisco. The investigator carried the Langan L15 CO Personal Exposure Measurer concealed beneath his dinner jacket. Concentrations were logged every 15 seconds, and the background value (concentration that would occur in the absence of indoor sources) was estimated as 1 ppm (Klepeis et al. In press).

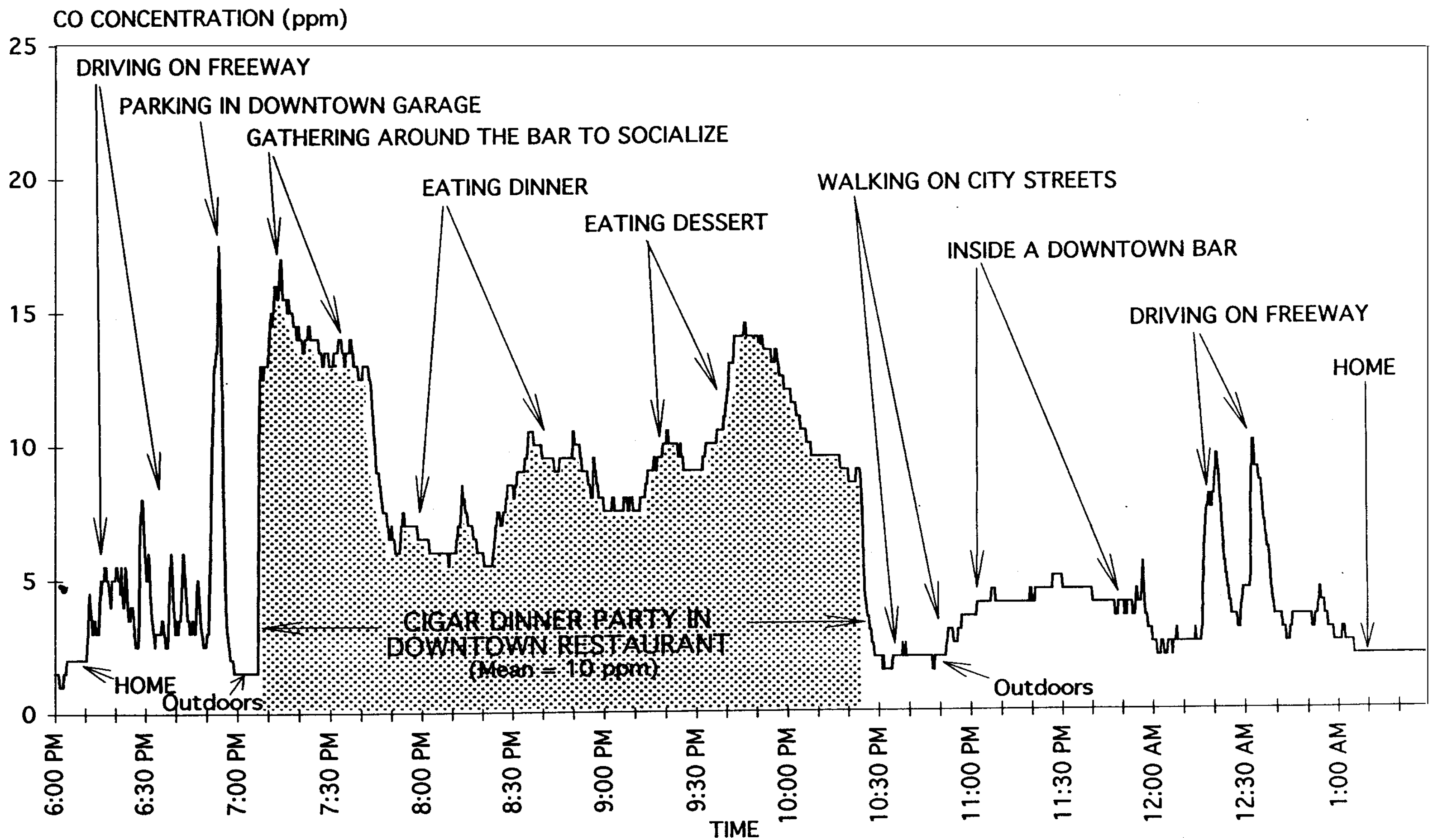


Figure 7(a).
CO concentration time series measured in a 548 m3 tavern at three locations after investigators machine-smoked four cigars in the central area. The air exchange rate was 7.5 air changes per hour. Despite the wide separation of the three monitors (approx. 6 - 7 m) the simultaneous CO exposures at all three locations are nearly within ± 10 percent of the overall average concentration (1.84 ppm), which is used by ASTM (ASTM E 741) as a criterion for uniformity of mixing (Mage and Ott, 1996).

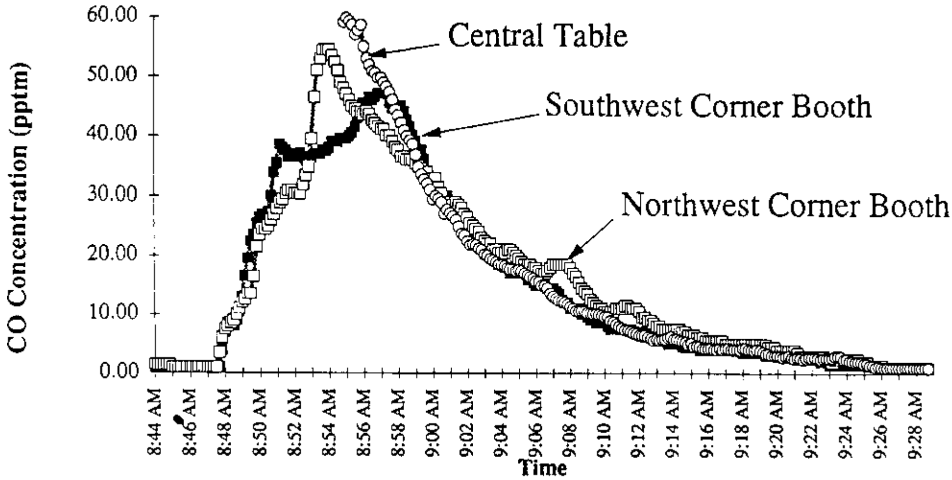
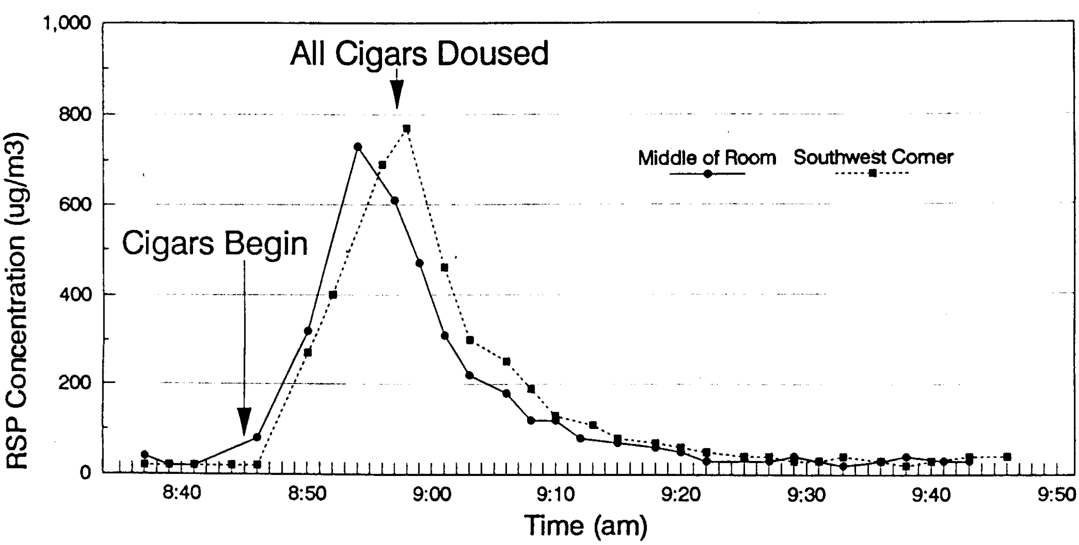


Figure 7(b).
RSP concentration time series measured in a 548 m3 tavern at three locations after investigators machine-smoked four cigars in the central area (Ott, Switzer, and Robinson, 1996). The RSP concentration ($PM_{3.5}$) was measured with two piezobalances in the middle of the room and at the southwest corner booth. Figures 7 (a) and 7(b) suggest that when averaged over a length of time long compared to the source duration, it doesn't matter where you are in the tavern, illustrating both the validity of the well-mixed assumption for the mass-balance model and the futility of spatial separation of smokers and nonsmokers as a putative public health measure.



CO concentrations recorded on the freeway while driving to and from this cigar banquet averaged 4.5 ppm, similar to values observed on the freeway while driving to the earlier cigar smoker social. This observation is the same as the average in-traffic CO concentration measured on 96 trips on a year-long study of an urban arterial highway in the San Francisco Bay Area (Ott et al., 1996). After leaving the restaurant, the investigator walked to a San Francisco bar where several cigarettes were being smoked but no cigars; indoor CO levels were about 4.5 ppm, much lower than at the cigar dinner.

These studies show that cigar smoking can considerably elevate indoor CO concentrations in a restaurant, even when the doors are wide open, and the ventilation system is operating.

DISCUSSION

Klepeis et al. (in press) report that the average emission rate and total emissions per source are not good emission factors for use in comparisons between different cigars and/or other tobacco sources, because they depend on smoking style, smoking duration, or the mass of the cigar smoked. Emission per mass smoked is a better basis for use in comparisons of cigar potencies, since it provides a normalized measure of the ability of a tobacco source to produce ETS-pollutant concentrations. Klepeis et al. (in press) report that CO emissions per mass smoked (Table 1) ranged from 130 mg CO/g to 200 mg CO/g for three different brands of cigars and two different smoking styles (i.e., by a machine and by a person) in five settings. Two different Santa Fe Fairmont cigars smoked by a machine gave CO emissions per mass smoked that were very similar (190 and 200 mg/g). The AyC Grenadiers cigars emitted CO in amounts of 160 and 180 mg/g when smoked by a machine. A Santona cigar smoked in a residential parlor generated CO mass emissions that were somewhat smaller (130 mg/g), which might be due to either the different smoking style or the different cigar brand (Table 1).

RSP emissions per mass smoked for two cigar experiments in a residential parlor were 8.0 and 8.9 mg RSP/g (Klepeis et al., in press). These RSP emission factors are comparable to the results found for the 13 brands of medium and large cigars smoked in a Canadian Report (CPRT, 1990) described above, which averaged 10.3 ± 2.39 mg RSP/g. By contrast, the RSP emissions per mass smoked for a cigarette in the same residence was 40 mg/g, which is five times larger than the emissions per mass smoked for the cigar.

Emissions of PAH per mass smoked were calculated for both the cigar and the cigarette in the second residential experiment of Klepeis et al.(in press) from Figure 3. Although the errors in estimation of the PAH background levels introduce additional uncertainty (about 20 to 30 percent error), cigarettes appear to generate more PAH than cigars (PAH emissions of 0.45 versus 0.035 mg/g).

Cigars appear to emit less RSP and PAH per mass burned than cigarettes, but cigars contain more tobacco than cigarettes and also tend to be smoked for much longer time periods (10 minutes or less for a cigarette versus an hour or more for cigars).

The Effects of Cigar Smoking On Indoor Air Pollution

Using the mathematical models presented earlier, the concentration of ETS in an enclosed space will be directly proportional to the smoker density ($g_c n_{ave}/v$) and inversely proportional to the effective air exchange rate ϕ. The effective air exchange rate for nonreactive gases is the same as the air exchange rate due to building ventilation plus infiltration, and for particles may be somewhat higher due to surface sorption or air cleaning (Repace, 1987).

Ventilation rates for mechanically ventilated buildings are recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 1990) and are typically incorporated into local building codes. In buildings without ventilation systems, closed-window air exchange rates are determined by the tightness of the building structure, and open-window ventilation rates may be comparable to or higher than in mechanically ventilated buildings. Typical closed-window residential air exchange rates are of the order of 0.75 ach. Typical mechanical air exchange rates designed for commercial buildings are a function of the density of human occupancy, and range from 0.84 air changes per hour (ach) for office buildings to 7 ach for restaurants.

If the ventilation rate ϕ_v is determined by the building structure and condition and the building volume is fixed, the concentration of ETS in a building will be determined by the number of smokers, their smoking rate, and the emission rate of the tobacco product.

The concentrations of certain ETS constituents can be compared to the National Ambient Air Quality Standards (NAAQS) for regulated outdoor air pollutants. The NAAQS for particulate matter $\leq$10 µm (PM_{10}) is 50 µg/m^3 on an annual basis, and on a 24-hour basis, 150 µg/m^3, with one exceedance allowed per year. Recently the U.S. EPA adopted a new fine particle standard. This proposed EPA NAAQS for $PM_{2.5}$, (particle size $\leq$ 2.5 µm) is 15 µg/m^3 averaged on an annual basis, or 65 µg/m^3 on a 24-hr average basis with one allowed violation (i.e., no more than one day at each monitor in a location may exceed the specified daily standard concentration).

The RSP level from a single Paul Garmirian cigar smoked in a San Francisco residence (Klepeis et al., in press) averaged 160 µg/m^3 over a 4.7- hour period (Table 1), or 31 µg/m^3 averaged over a 24-hour period. By comparison, the Marlboro cigarette smoked in the same San Francisco residence averaged 65 µg/m^3 over a period of 2.75 hours, or 7 µg/m^3 averaged over 24- hour period.

The current NAAQS for carbon monoxide is 9 ppm, an 8 hour time-weighted average (TWA)(USEPA, 1996). The average CO concentration measured during the cigar party (5.8 ppm) (Figure 3) is slightly greater than encountered on a California freeway (5.5 ppm), despite the fact that all the doors and windows were open.

On a per-cigarette basis, Ott et al. 1992, Rosanno and Owens 1969, and Rickert et al. 1984 report total CO emissions ranging from 40 to 70 mg per cigarette for sidestream smoke. On a rate basis, Ott et al. (1992) report an average CO emission rate of 9.4 mg CO/min for cigarettes, which is much lower than the 14 to 140 mg /min emission rates that Klepeis et al. (in press) found for cigars.

On a mass basis, Klepeis et al. (in press) report that CO emissions for cigars are between 100 and 200 mg/g (Table 1). If the mass of a cigarette smoked is about 0.4 g, as it was for one of the experiments of Klepeis et al. (in press), then the cigarette CO emissions per mass smoked would also be in the range of 100 to 175 mg /g. However, the larger total mass of a cigar results in the total CO emissions of cigars studied by Repace and Lowrey (1982) and Klepeis et al. (in press) (Table 1) averaging more than 1000 mg/cigar, placing the total cigar CO emissions about 1000/50 = 20 times that of a cigarette.

The cigar RSP emissions reported by Klepeis et al. (in press) and Repace and Lowrey (1982) for 3 cigars averaged about 77 mg per cigar. By contrast, (Table 1) data from Nelson (1994) as analyzed by Repace et al. (in press) show ETS-RSP emissions of about 14 $\pm$ 3 mg/cig for the top 50 brands of cigarettes; an RSP datum, 16 mg/cig reported by Klepeis et al.(in press) for a single Marlboro is consistent with these results. This suggests that total RSP emissions of large cigars are 5 to 6 times greater than cigarettes.

From the limited data available (Table 1) it appears that the total PAH emissions of a large Paul Garmirian cigar (380 µg) is only twice that of a Marlboro cigarette (180 µg) because the PAH emission rate for the Marlboro was 5 times as large as for the cigar. The total PAH emissions for the cigar, however, were twice as great as the cigarette because of the more than ten-fold larger smoking time for the cigar. (Table 1 and Figure 2).

Cigar size and the extended smoking time compensate for the cigar's lower emission rate for RSP and PAH and enhance the delivery of CO to the indoor environment. Smoking a single cigar can result in a much higher exposure of nonsmokers to CO, RSP, and PAH than smoking a single cigarette.

CONCLUSIONS

1. ETS from cigar smoke is a major and increasing source of exposure to indoor air pollution.
2. When smoked in confined indoor spaces at typical smoking and ventilation rates, cigars may produce concentrations of certain regulated ambient air pollutants, including CO and RSP, which can violate federal air quality standards and add to the level of these compounds already in the ambient air from other combustion sources.
3. Measurements of the CO concentrations at a cigar party in a hall and at a cigar banquet in a restaurant showed carbon monoxide levels comparable to those observed on a crowded California freeway.
4. The smoking of one cigar generates more Respirable Suspended Particles (RSP) and Polycyclic Aromatic Hydrocarbons (PAH) than the smoking of one cigarette due to the larger mass of tobacco contained in a cigar, but the amount of PAH and RSP generated per gram of tobacco burned appears to be somewhat lower for cigars compared to cigarettes.

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