Reprinted from **APCA JOURNAL**, *Vol. 32, No. 3, March 1982*

Indoor Byproduct Levels of Tobacco Smoke: A Critical Review of the Literature

T. D. Sterling, H. Dimich
Simon Fraser University
Burnaby, British Columbia

D. Kobayashi
Columbia University
New York, New York

The levels reported in diverse publications of byproducts of cigarette combustion (acrolein, aldehydes, aromatic hydrocarbons, carbon monoxide, nicotine, nitrogen oxides, nitrosamines, particulates, and others for which scattered information is available as HCN, ketones, nitriles) are summarized in tabular form. Summaries also include information on test conditions such as ventilation, size and types of premises, monitoring conditions, number of smokers, and rate of smoking. Current methodology emerging from a review of a wide variety of measuring practices is critically evaluated and discussed. Major findings are reviewed. In conclusion, the presently available data are useful for gaining a reasonably accurate perspective of the amount of combustion products contributed by cigarette smoking under different conditions, even though serious methodological problems persist.

Of all the many contributors to the indoor atmosphere, none has been studied so intensely as cigarette smoking. Repeated measurements have been obtained for eight major byproducts of cigarette combustion. Yet no easy and clear understanding emerges of the contribution of cigarette smoke to indoor pollution because of the large differences in conditions under which measurements have been obtained. Test conditions have differed with respect to ventilation (in fact a large number of studies were done in unventilated chambers), with respect to number of smokers and others present, with respect to size of premises, and with respect to other important variables.

Evaluated and summarized here is the information in the published literature about observed values of tobacco combustion byproducts (mostly for acrolein, aldehydes, aromatic hydrocarbons, carbon monoxide, nicotine, nitrogen oxides, nitrosamines, and particulates, with some information for other byproducts such as HCN, ketones, or nitriles) in relation to the major conditions under which these measures were obtained. Such a summary may be extremely important because, where conditions are similar, so are observed levels of measured byproducts. Thus estimates which can be obtained from realistic settings may be useful in studying ventilation and design questions for offices and other structures. Reference is also made to reports that fail to be specific about some relevant conditions, since additional useful information may still be obtainable from their investigators.

Discussion of Current Methodology

The wide variations present in measurements introduce uncertainty about the meaning and comparability of reported levels of combustion byproducts. Similarly, measured levels may have different interpretations depending on conditions and procedures. Discussed here are the key factors of experimental protocols which should be considered by investigators who need to use information contained in studies here summarized.

A detailed description of the measuring instruments, the sensitivity, range, and efficiency of the monitoring system—as well as mention of calibration, air temperature, barometric pressure, humidity readings, and the removal of water vapor and other interferences—should be included with any report. The humidity and temperature of the air affects the physical and chemical reactions of the components in air and thus their concentrations and mutual relationships (Orlien,[1] Penkala and Oliveira[2]).

Studies such as those of Russell, Cole, and Brown,[3] Harke, *et al.*,[4] Johansson,[5] and Neal, *et al.*,[6] provide adequate detailed descriptions of instrumentation and methodology. On the other hand, other studies such as those by Lawther and Commins,[7] Portheine,[8] McNall,[9] Shephard, *et al.*,[10,11] Dockery and Spengler,[12] and Dublin[13] give few indications of how the cigarette smoke components were measured.

Monitoring conditions include the volume and rate of the ambient air flow, and the number, period, and timing of the samples. The concentration of many tobacco smoke components are time-dependent to a certain degree due to the possibilities of adsorption on surfaces, coagulation in the air, and sedimentation due to gravity. The length of time between sample collection and analyses is also important due to the possibility of chemical reactions and light-induced decomposition. Harke, *et al.*[14] and Jermini, *et al.*[15] are two studies which mention the physical positioning of monitoring equipment and also whether monitoring is on a continuous or on a sample basis.

The proximity of the sampling instrument to recognized sources of airborne substances is important because the dispersal of such substances is not uniform. Harke[16] and Anderson and Dalhamn[17] have found some fluctuations resulting in extreme readings which have been attributed to the direct intake from the sources into the sampling instruments.

Another factor which ought to be considered in the interpretation of monitor readings is the dilution effect of the air which replaces the airborne components. While Penkala and Oliveira[2] and Grimmer, *et al.*,[18] accounted for this decrease

in the concentration of the components, many researchers (e.g. Hugod, *et al.*[19] and Seppanen[20]) have made no mention of this phenomenon.

The conditions of smoking in the monitored environment are pertinent matters which are often neglected in many studies, especially in the studies under realistic conditions. The description of the cigarette type (e.g., filter, nonfilter) and content and the butt length should be included, as well as the individual smoking behavior (depth of inhalation, number of puffs per cigarette, etc.) as the factors that may influence the ambient levels of the components. Studies by Harke, *et al.*[4] and by Harke[21] attempt to deal with these indicators.

In order to replicate experiments involving measurements of the ambient levels of components in cigarette smoke, standard smoking conditions must be established. The most frequently used conditions are puff volume (35 mL), puff duration (2 sec), puff frequency (one puff/min) and butt length (23 or 33 mm). Studies by Harke, *et al.*,[4] Hoegg,[22] and Shephard, *et al.*[10,11] are examples of the few that did report in these standard terms.

The cigarette smoke itself consists of a particulate phase—defined as those components of which greater than 50% will be retained in a Cambridge filter (medium—113) under standardized smoking conditions and a gas phase.[1] Semi-volatile components are found in both the particulate and the gas phases. Few researchers distinguish the phases; Grimmer, *et al.*[18,23] and Jermini, *et al.*,[15] in their measurements of aromatic hydrocarbons, are exceptions. If a particular substance is measured in the particulate phase only, volatization of that component may underestimate the amount. Conversely, Hugod, *et al.*[19] found that the levels of certain measured components (NO_2, acrolein, aldehydes, and HCN) were in slightly higher concentrations in the gas phase measurements conducted after particular components were removed by filtration. They suggest that some fraction of those components can be fixed to particles and therefore avoid determination by the applied chemical methods.

It is also important to determine whether the cigarettes were smoked by people under realistic conditions or by a smoking machine in an experimental setting. The determination is required because of the differences between mainstream and sidestream smoke. In realistic circumstances, ambient concentration depends on sidestream smoke and the exhaled mainstream smoke. The amount of smoke components retained in the body depends on the depth of inhalation and varies for each component. Thus the percentage of components exhaled into the environment varies from 1% to perhaps 70%.[24,25] It has been estimated that sidestream smoke forms approximately 6/7th of the total smoke in the ambient air.[1,26] However, the ratios of the levels of various smoke components in sidestream smoke compared to mainstream smoke vary from 1.2 to 46.[22] Many experimenters[4,15,19,27,28] have chosen to analyze the sidestream smoke only. On the other hand, Pimm, *et al.*[29] analyzed both sidestream and whole mainstream smoke, justifying their choice because smokers' retention of the mainstream portion is incomplete. Using an unventilated climate chamber, Johansson[5] found particulate levels of 660 $\mu g/m^3$ in ambient sidestream smoke, and 291 $\mu g/m^3$ in mainstream smoke. An average of 972 $\mu g/m^3$ of particulates was found in the whole smoke after ten cigarettes were machine smoked.

To evaluate properly the contribution of tobacco smoke in indoor atmospheres, references to nonsmoking conditions should be included. While under realistic conditions nonsmoking periods are often difficult to include, measures of a separate nonsmoking section or of outdoor levels are sometimes substituted (see Godin, *et al.*,[30] Sebben, *et al.*,[31] Fischer, *et al.*,[32] and Repace and Lowrey[33]). Background levels of substances are often included in experimental studies, (e.g., Penkala and Oliveira,[2] and Weber, *et al.*[27,28]) although the use of a separate run under identical sampling and environmental conditions of ventilation, occupancy, etc., before smoking is permitted is perhaps the best method (e.g., Pimm, *et al.*,[29] Weber-Tschopp, *et al.*,[27,28] and Weber, *et al.*[34]). For instance, Weber, *et al.*[34] found background levels of particulates to be less than 5 $\mu g/m^3$, whereas in separate control studies in which the environmental conditions and the number of people present were the same as in the smoking condition, values ranging between 2 and 14 $\mu g/m^3$ were found.

In some instances, reports mention the use of control conditions, but do not give the measured values.[10,11,19,23,25]

A description of the room furnishings is also informative. According to Jones and Fagan,[36] the concentration of particulate matter in particular is influenced by deposition, adsorption, and agglomeration, all of which are dependent on the nature of the environment. Items such as furniture, carpeting, and draperies must be considered together with the temperature and ventilation parameters. Good descriptions of the premises in which measurements are taken are offered by Harke[21] and Harke, *et al.*[4] Johansson[5] found that the accuracy of daily readings could be improved if the internal surfaces of the experimental chamber were washed daily with alcohol "in order to remove sedimented and adhered smoke particles" (p. 254).

It is essential that researchers eliminate or at least account for other potential sources which may contribute to levels of components which might otherwise be attributed to tobacco smoke. For example, Sebben, *et al.*[31] attribute the high levels of measured CO to the iron grill used in the particular restaurant. Other researchers have found that infiltration of outdoor CO from motor vehicle exhaust can completely overwhelm the contribution of any indoor source. Fischer, *et al.*[32] attribute potential indoor sources of NO_2 to grills and various cooking facilities. (It should be mentioned that NO_2 is present in only very small quantities in cigarette smoke.) Indoor levels of respirable suspended particulates can be affected tremendously by infiltration of outdoor particles, cooking (especially with gas stoves and ranges), dust raised by indoor traffic, and industrial contaminants brought home on worker's clothing (p. 468, Repace and Lowrey[33]). The density of people in the smoking environment should be quantified because of its influences on the tobacco smoke constituent levels. In realistic situations, this variable is largely dependent on the level of activity of the people as well as their number, since settled dust will be resuspended to varying degrees depending on that activity. Alternatively some researchers have found that inactive or resting occupants of the smoking area decrease levels of suspended components, especially particulate matter which may adhere to skin, hair, and clothing (p. 24, Hugod, *et al.*[19]).

A description of the outdoor traffic is helpful where outdoor levels have not been measured. For instance, the density of the traffic outside the restaurants measured by Chappell and Parker,[37] Fischer, *et al.*,[32] and Szadkowski, *et al.*[38] contributed to the measured indoor levels of CO. Godin, *et al.*[30] found that local traffic density accounted for 63% of the variance found for CO concentrations. In Chappell's study, it was reported that the typical city dweller was exposed to approximately 2.5 ppm while driving and walking while in five downtown offices the indoor CO levels ranged from 2.2 to 4.6 ppm. Chappell and Parker[37] (p. 160) conclude that, with the exception of places with poor ventilation, there is little difference between the CO levels inside and outside most public places and that in these environments, tobacco smoke contributes little to the background CO level generated from other combustion sources, primarily motor vehicles.

Summary of Indoor Tobacco Combustion Byproducts

Most of the data from experimental studies were obtained while cigarettes were smoked at abnormally high rates and in highly artificial conditions (e.g. special chambers). While these data are a useful archive for circumstances, they lack the generality that is projected by data obtained under realistic

Table I. Acrolein measured under realistic conditions.

Study	Type of premises	Occupancy	Ventilation	Monitoring Conditions	Levels Mean	Levels Range	Nonsmoking controls Mean	Nonsmoking controls Range
Badre, *et al.*, 1978 (53)	5 Cafes	Varied	Not given	100 mL samples		0.03–0.10 mg/m^3		
	Room	18 smokers	Not given	100 mL samples	0.185 mg/m^3			
	Hospital lobby	12 to 30 smokers	Not given	100 mL samples	0.02 mg/m^3			
	2 train compartments	2 to 3 smokers	Not given	100 mL samples		0.02–0.12 mg/m^3		
	Car	3 smokers	Natural, open	100 mL samples	0.03 mg/m^3			
		2 smokers	Natural, closed	100 mL samples	0.30 mg/m^3			
Fischer, *et al.*, 1978 (32)	Restaurant	50–80/ 470 m^3	Mechanical	27 × 30 min samples	7 ppb		Outdoor values not given	
and Weber, *et al.*, 1979b (62)	Restaurant	60–100/ 440 m^3	Natural	29 × 30 min samples	8 ppb		Outdoor values not given	
	Bar	30–40/ 50 m^3	Natural, open	28 × 30 min samples	10 ppb		Outdoor values not given	
	Cafeteria	80–150/ 574 m^3	11 changes/ hr	24 × 30 min samples	6 ppb		5 ppb (Nonsmoking section)	

conditions. Thus this review is limited to the major methodological considerations employed by studies under realistic conditions of smoking, where observers measured byproduct levels of combustion without manipulating smoking and/or ventilation rates.

Acrolein

After a survey of four eating establishments, Fischer, *et al.*[32] found the highest mean level of 10 ppb acrolein in a very crowded and poorly ventilated bar. The lowest level, 6 ppb, was found in a well ventilated student cafeteria. It was comparable to the level of 5 ppb found in the nonsmoking situation.

Aromatic Hydrocarbons

Perry[39] measured very high benzo(*a*)pyrene (B*a*P) concentrations lying between 54 ng/m^3 and 760 ng/m^3 with a special fluorescence technique. However the CO concentrations simultaneously determined in these rooms are lower than 10 ppm in all cases, a fact which casts doubt on the correctness of the data. According to Grimmer, *et al.*,[23] one would expect a CO concentration to be more than 350 ppm for a B*a*P concentration of 760 ng/m^3.

Elliott and Rowe[40] did provide a control situation by taking B*a*P measurements on separate nonactivity days in an arena. They found these levels to be 0.69 ng/m^3 in comparison to a maximal 21.7 ng/m^3 value found when 14,000 people were at an arena event. However the presence of the 8–14,000 people alone during the activity days may influence background levels; as well, the fluctuation in outdoor levels renders this type of control measurement not fully adequate. Just, *et al.*[41] were the only researchers to measure other aromatic hydrocarbons apart from B*a*P. As controls, outdoor measurements were made, yet very few differences were found.

Carbon Monoxide

This substance is the most frequently measured constituent of indoor tobacco smoke in studies conducted under realistic conditions. However, as noted previously, there are many other sources of indoor CO besides tobacco smoke. These sources should be accounted for in the experimental design.

The quality of CO monitoring varies greatly however. The successive readings for a Drager tube[39,42,43] and the MSA Monitaire sampler[40] vary around 25% at best. Although the Ecolyzer is claimed to have a better continuous sampling instrument with an accuracy and reproducibility of 2%, First and Hinds[44] point out that the CO concentration becomes greatly exaggerated when used in the presence of ethanol. Note that Cuddeback, *et al.*,[35] Sebben, *et al.*,[31] and Chappell and Parker[37] use the Ecolyzer while measuring CO levels in licensed restaurants, nightclubs, and taverns.

The more accurate monitoring methodology includes the use of infared spectrophotometry[30,38,45–47] and coulometric titration.[48]

Nonsmoking control conditions are usually given in terms of outdoor CO levels, though Coburn, *et al.*,[47] Fischer, *et al.*,[32] Godin, *et al.*,[30] Sebben, *et al.*,[31] and White and Froeb[49] did measure separate nonsmoker areas. The differences between the areas were not noteworthy. For instance, measurements ranged from a 0.7 ppm average difference between smoking and nonsmoking cafeteria rooms (Fischer, *et al.*[32]) to about 3–5 ppm (White and Froeb[49] and Godin, *et al.*[30]). Indoor/outdoor CO value differences were even less and ranged from no difference (Chappell and Parker[37]) to the extreme of 9.5 ppm (Cuddeback, *et al.*[35]). Slavin and Hertz[50] found a 6 to 9 ppm difference in CO levels during separate nonsmoking measures of conference rooms.

The average measure in nine nightclubs by Sebben, *et al.*[31] of indoor CO levels appears to be an overestimate because repeated measurements of the most heavily crowded club are included. As the CO level averages for this club were 35.2 ± 5.1 and 28.8 ± 2.2 ppm, their inclusion biased the averages of the total number of nightclubs measured with the indoor CO levels of 13.4 ppm.

Nicotine

The descriptions by Harmsen and Effenberger[42] and Hinds and First[51] of the places measured were sparse. Values in various transportation vehicles and lounges ranged from 0.7 to 10.3 μg/m^3. Weber and Fischer,[48] using a Cambridge filter, found an average of only 0.9 ± 1.9 μg/m^3 in 44 offices. To arrive at this figure, the values from the controls were subtracted from the measured smoke condition values. Unfortunately, these control values are not given. On the other hand, Hinds and First[51] mention that their nicotine concentrations are, "Solely the result of tobacco smoke and do not include the background contribution from usual particulate air pollutants" (p. 845).

Employing similar experimental methods, Yoshida[52] measured very low levels of nicotine—0.01–0.03 mg/m^3. Badre, *et al.*,[53] using gas chromatography, found considerably higher levels, up to 215 μg/m^3 in a very smoky atmosphere, than have been obtained in measurements using filters. These researchers found that airflow through the filters tended to revolatilize the nicotine trapped there, thus giving unrealistically low results. Yet, even these significantly higher levels are less than one half the threshold limit value of 500 μg/m^3, and correlate to a "cigarette equivalent" of 0.04/hr.

Nitrogen Oxides

Fischer, *et al.*[32] found levels of the nitrogen oxides to vary widely according to whether the premises measured had adequate ventilation and according to how close they were to heavy traffic. Values for nitrogen oxide ranged from an average of 9 ppb in the cafeteria which was ventilated with eleven air changes per hour to 195 ppb in a crowded bar which had weak window ventilation.

In contrast, NO_2 values ranged from 21 ppb in the bar to 76 ppb in another restaurant situated on a busy street. Unlike NO, outdoor NO_2 values were comparable to indoor values, ranging from 34 ppb (vs. 58 ppb inside) to 63 ppb (inside levels being 76 ppb).

Nitrosamines

Brunneman and Hoffman[54] and Brunneman, *et al.*[55] were the only researchers to measure nitrosamine levels in environments where smoking was permitted. The levels of N-nitrosodimethylamine ranged from 0.1 ng/L in a bank to 0.24 ng/L in a bar. The only controls were measurements done in two nonsmokers' homes. The levels of N-nitrosodimethylamine were less than 0.005 ng/L.

Table II. Aromatic hydrocarbons measured under realistic conditions.

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels Mean	Levels Range	Nonsmoking controls Mean	Nonsmoking controls Range
					Benzene (mg/m^3)			
Badre, *et al.*, 1978 (53)	6 Cafes	Varied	Not given	100 mL samples		0.05–0.15		
	Room	18 smokers	Not given	100 mL samples	0.109			
	2 Train compartments	2 to 3 smokers	Not given	100 mL samples		0.02–0.10		
	Car	3 smokers	Natural, open	100 mL samples	0.04			
		2 smokers	Natural, closed	100 mL samples	0.15			
					Toluene (mg/m^3)			
	4 Cafes	Varied	Not given	100 mL samples		0.04–1.04		
	Room	18 smokers	Not given	100 mL samples	0.215			
	Train compartment	2 to 3 smokers	Not given	100 mL samples	1.87			
	Car	2 smokers	Natural, closed	100 mL samples	0.50			
					*Benzo(a)*pyrene (ng/m^3)			
Elliott and Rowe, 1975 (40)	Arena	8,647–10,786 people	Mechanical	Not given	7.1			
		12,000–12,844 people	Mechanical	Not given	9.9			
		13,000–14,277 people	Mechanical	Not given	21.7			
				Separate non-activity days			0.69	
Galuskinova, 1964 (60)	Restaurant	Not given	Not given	20 days in summer	6.2			
				18 days in the fall		28.2–144		
Just, *et al.*, 1972 (41)	4 Coffee houses	Not given	Not given	6 hr continuous	0.25–10.1		4.0–9.3 (outdoors)	
					Benzo(e)pyrene (ng/m^3)			
					3.3–23.4		3.0–5.1 (outdoors)	
					Benzo(ghi)perylene (ng/m^3)			
					5.9–10.5		6.9–13.8 (outdoors)	
					Perylene (ng/m^3)			
					0.7–1.3		0.1–1.7 (outdoors)	
					Pyrene (ng/m^3)			
					4.1–9.4		2.8–7.0 (outdoors)	
					Anthanthrene (ng/m^3)			
					0.5–1.9		0.5–1.8 (outdoors)	
					Coronene (ng/m^3)			
					0.5–1.2		1.0–2.8	
					Phenols (μg/m^3)			
					7.4–11.5			
					Benzo(a)pyrene (ng/m^3)			
Perry, 1973[a] (39)	14 Public places	Not given	Not given	Samples, 5 outdoor locations		<20–760		<20–43

[a] The correctness of the data is doubtful (See Grimmer, *et al.*,[23]).

Table III. Carbon monoxide measured under realistic conditions.

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm) Mean	Levels (ppm) Range	Nonsmoking controls (ppm) Mean	Nonsmoking controls (ppm) Range
Badre, *et al.*, 1978 (53)	6 Cafes	Varied	Not given	20 min samples		2–23	(outdoors)	0–15
	Room	18 Smokers	Not given	20 min samples	50		0 (outdoors)	
	Hospital lobby	12 to 30 Smokers	Not given	20 min samples	5			
	2 Train compartments	2 to 3 Smokers	Not given	20 min samples		4–5		
	Car	3 Smokers	Natural, open	20 min samples	14		0 (outdoors)	
		2 Smokers	Natural, closed	20 min samples	20		0 (outdoors)	
Chappell and Parker, 1977 (37)	10 Offices	Not given	Values not given	17 × 2–3 min samples	2.5 ± 1.0	1.5–4.5	2.5 ± 1.0 (outdoors)	1.5–4.5
	15 Restaurants	Not given	Values not given	17 × 2–3 min samples	4.0 ± 2.5	1.0–9.5	2.5 ± 1.5 (outdoors)	1.0–5.0
	14 Nightclubs and taverns	Not given	Values not given	19 × 2–3 min samples	13.0 ± 7.0	3.0–29.0	3.0 ± 2.0 (outdoors)	1.0–5.0
	Tavern	Not given	Artificial	16 × 2–3 min samples	8.5			
			None	2 × 2–3 min samples		35 (peak)		
	Office[a]	1440 cu ft	Natural, open	2–3 min samples		10.0 (peak)		
				30 min after smoking	1.0			
Coburn, *et al.*, 1965 (47)	Rooms	Not given	Not given	Not given		4.3–9.0		
				Nonsmokers rooms			2.2 ± 0.98	0.4–4.5
Cuddeback, *et al.*, 1976 (35)	Tavern 1	10–294 people	6 changes/hr	8 hr continuous	11.5	10–12	2 (outdoors)	
				2 hr after smoking	~1			
	Tavern 2	Not given	1–2 changes/hr	8 hr continuous	17	~3–22	Values not given	
				2 hr after smoking	~12		Values not given	
U.S. Dept. of Transport, 1971[b] (43)	18 Military planes	165–219 people	Mechanical	6–7 hr continuous		<2–5		
	8 Domestic planes	27–113 people	Mechanical	1¼–2½ hr continuous	≤2			
Elliott and Rowe, 1975[c] (40)	Arena 1	11,806 people	Mechanical	Not given	9.0		3.0 (Non activity day)	
	Arena 2	2,000 people	Natural	Not given	25.0		3.0 (Non activity day)	
				Nonsmoking arena			9.0	
Fischer, *et al.*, 1978 (32) also	Restaurant	50–80/470 m^3	Mechanical	27 × 30 min samples	5.1	2.1–9.9	4.8 (outdoors)	
	Restaurant	60–100/440 m^3	Natural	29 × 30 min samples	2.6	1.4–3.4	1.5 (outdoors)	
Weber, *et al.*, 1979b (62)	Bar	30–40/50 m^3	Natural, open	28 × 30 min samples	4.8	2.4–9.6	1.7 (outdoors)	
	Cafeteria	80–150/574 m^3	11 changes/hr	24 × 30 min. samples	1.2	0.7–1.7	0.4 (outdoors)	
				Nonsmoking room			0.5	0.3–0.8
Godin, *et al.*, 1972 (30)	Ferryboat	Not given	Not given	11 grab samples	18.4 ± 8.7		3.0 ± 2.4 (nonsmoking room)	
	Theatre foyer	Not given	Not given	Grab samples	3.4 ± 0.8		1.4 ± 0.8 (Auditorium)	
Harke, 1974a (16)	Office[d]	~72 m^3	236 m^3/hr	30 min samples		<2.5–4.6		
	Office[e]	~78 m^3	Natural	30 min samples		<2.5–9.0		
Harke and Peters, 1974c[f] (46)	Car	2 smokers	Natural	Samples		42 (peak)	(Nonsmoking runs) 13.5 (peak)	
			Mechanical	Samples		32 (peak)	(Nonsmoking runs) 15.0 (peak)	
Harmsen and Effenberger, 1957[b] (42)	Train	1–18 smokers	Natural	Not given		0–40		

Table III. (continued)

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm) Mean	Levels (ppm) Range	Nonsmoking controls (ppm) Mean	Nonsmoking controls (ppm) Range
Perry, 1973[b] (39)	14 Public places	Not given	Not given	One grab sample	<10			
Portheine, 1971[g] (8)	Rooms	Not given	Not given	Not given		5–25		
Sebben, *et al.*, 1977 (31)	9 Nightclubs	Not given	Varied	77 × 1 min samples	13.4	6.5–41.9		
				Outdoors			9.2	3.0–35.0
	14 Restaurants	Not given	Not given	Spot checks	9.9 ± 5.5		Values not given	
	45 Restaurants	Not given	Not given	Spot checks	8.2 ± 2.2		7.1 ± 1.7 (outdoors)	
	33 Stores	Not given	Not given	Spot checks	10.0 ± 4.2		11.5 ± 6.9 (outdoors)	
	3 Hospital lobbies	Not given	Not given	Spot checks		4–8	Values not given	
Slavin & Hertz, 1975 (50)	2 Conference rooms	Not given	8 changes/hr	Continuous, morning		8 (peak)	1–2 (separate nonsmoking day)	
			6 changes/hr	Continuous, morning		10 (peak)	1–2 (separate nonsmoking day)	
Szadkowski, *et al.*, 1976 (38)	25 Offices	Not given	Not given	Continuous	2.78 ± 1.42		2.59 ± 2.23 (Separate nonsmoking offices)	

[a] 3 cigarettes and 1 cigar smoked in 20 minutes.
[b] The Drager tube used is only accurate within ±25%.
[c] The MSA Monitaire Sampler used is only accurate within ±25%.
[d] About 40 cigarettes/day were smoked.
[e] About 70 cigarettes/day were smoked.
[f] 4 filter cigarettes were smoked.
[g] No experimental description given.

Particulates

While most of the researchers used filters of some sort to trap particulate matter, Weber and Fischer[48] and Repace and Lowrey[33] used a piezoelectric particle mass monitor. According to the latter authors, the piezobalance, "Underestimated the mass concentration of tobacco aerosol by about 15% compared to measurements made with low-volume filter sampling techniques" (p. 465). Repace and Lowrey[33] noted that the instrument readings are affected by a change in relative humidity, having a maximal error of 10%. (Recent personal communications from three separate investigators raise concern that currently available electrostatic precipitators, for instance the often used TSI model Piezobalance, may give spurious readings depending on when and how they are cleaned and how long they are operated. There seems to be an effect on subsequent measurements from cleaning the instrument. Also spurious high readings may result after lengthy operations. There are reports of variation in precision. There appears to be agreement that accuracy is faulty. Insufficient test results of reliability and validity of measures obtained by presently available instruments counsel caution in their use.*)

The particulate levels measured by the various researchers ranged in value from a low average of 0.021 ± 0.0136 mg/m^3 in a hospital unit[6] to a peak average of 1.15 mg/m^3 in a poorly ventilated tavern.[41] The outdoor particulate levels were even higher than the indoor levels in the hospital units, measured by Neal, *et al.*[6] These units had particle filters in the ventilation systems, thus while outdoor particulate levels were approximately 0.07 mg/m^3, indoor values averaged 0.02 to 0.04 mg/m^3.

Residuals

Just, *et al.*[41] were the only researchers to measure levels of phenols and aldehydes under realistic conditions. Only Fischer, *et al.*[32] monitored indoor SO_2 levels in various establishments where smoking was taking place. The mean values of SO_2 ranged from 15 to 30 ppb in four eating places; this differed only slightly from the 6 to 12 ppb levels found outdoors. The authors attribute the higher indoor SO_2 values to the striking of matches in order to light the cigarettes. According to Dockery and Spengler,[12] who measured sulfate levels in residences, "Cigarettes serve as a surrogate for matches" (p. 342).

Comparatively few of the three hundred different components found in tobacco smoke have been monitored in ambient air. Certainty there is an urgent need to conduct more research under controlled experimental as well as realistic conditions which address this important area of indoor air constituents. Nevertheless the data presently available are useful for gaining a reasonable perspective of the amount of combustion products contributed by cigarette smoking under different conditions, even though serious methodological problems persist. The data are most valuable when control measures from nonsmoking areas or outdoors are simultaneously available.

Description of Summary Tables

Next are a group of tables comparing available studies and their results. These studies were conducted under what we have called "realistic" conditions, that is, observations were obtained in offices, residences, or elsewhere under usual circumstances of smoking and ventilation with the experimenter passively recording relevant information that could affect measures taken of combustion byproducts. Compared are studies listed in the references by numbers (6, 12, 16, 18, 30–33, 35, 37–43, 46–48, 50, 51, 53–55, 60–62).

* For further information the reader is referred to Drs. T. Stocks (School of Public Health, University of Texas at Houston), G. Traynor (Lawrence Berkeley Laboratory) and R. D. Treitman (Environmental Health Center, Harvard University).

To facilitate a quick comparison of conditions between the studies, the following column descriptors are used in the tables:

Type of premises and occupancy: Includes the number of persons or the number of smokers present and the volume of the premises.

Ventilation: Air changes per hour, or just mechanical if no values are given: "natural" indicates no mechanical ventilation, while "closed" and "open" signify whether the windows and doors were closed or open; with "none," the space is sealed and airtight.

Monitoring conditions: The number of samples taken and time interval over which these were taken.

Smoking conditions: The mean and range of the Levels of the contaminants found in the ambient air during the smoking period are given in the units indicated, as well as those of the Nonsmoking conditions. Where no information is given, "Not given" is used. If mention of measurement is given but no values supplied, the table entry is "Values not given."

An identical summary of studies is available where indoor measurements were conducted under what we have called "experimental" conditions. These are studies in which experimenters exerted control primarily over smoking rates and ventilation. Many of these studies come from special chambers, were done without ventilation, used smoking machines or simulated multiple and constant smoking. These are studies listed in the references by numbers (2–5, 7, 9–11, 13–15, 17–23, 25, 27–29, 34, 42, 47, 52, 54, 56–59, 62, 63, 65, 66). These Tables are not shown here because of space considerations. They are available on request from the senior author (604-291-4685).

References

1. N. Orlien, "Passive smoking: which compounds contribute to the potential health hazards of passive smoking?" *T. Norske Laegeforen* **93:** 2300 (1973).
2. S. J. Penkala, G. De Oliveira, "The simultaneous analysis of carbon monoxide and suspended particulate matter produced by cigarette smoking," *Environ. Res.* **9:** 99 (1975).
3. M. A. H. Russell, P. V. Cole, E. Brown, "Absorption by non-smokers of carbon monoxide from room air polluted by tobacco smoke," *Lancet* 576 (March 1973).
4. H. P. Harke, A. Baars, B. Frahm, H. Peters, C. Schultz, "Passive smoking: concentration of smoke constituents in the air of large and small rooms as a function of number of cigarettes smoked and time," *Int. Arch. Arbeitsmed.* **29:** 323 (1972).
5. C. R. Johansson, "Tobacco smoke in room air—an experimental investigation of odour perception and irritating effects," *Build. Serv. Eng.* **43:** 254 (1976).
6. A. D. Neal, R. A. Wadden, S. Rosenberg, "Evaluation of indoor particulate concentrations for an urban hospital," *Am. Ind. Hyg. Assoc. J.* **39:** 578 (1978).
7. P. J. Lawther, B. T. Commins, "Cigarette smoking and exposure to carbon monoxide," *Ann. N.Y. Acad. Sci.* **174:** 135 (1970).
8. F. Portheine, "To the problem of passive smoking," *Muench. Med. Wschr.* **18:** 707 (1971).
9. P. E. McNall, "Practical methods of reducing airborne contaminants in interior spaces," *Arch. Environ. Health* **30:** 552 (1975).
10. R. J. Shephard, R. Collins, F. Silverman, "Responses of exercising subjects to acute passive cigarette smoke exposure," *Ann. Clin. Res.* **9:** 261 (1979).
11. R. J. Shephard, R. Collins, F. Silverman, "Passive exposure of asthmatic subjects to cigarette smoke," *Environ. Res.* **20:** 392 (1979b).
12. D. W. Dockery, J. D. Spengler, "Indoor-outdoor relationships of respirable sulfates and particles," *Atmos. Environ.* **15:** 335 (1981).
13. W. Dublin, "Unwilling smoker," *Calif. Med.* **117:** 76 (1972).
14. H. P. Harke, W. Liedl, D. Denker, "The problem of passive smoking: II. Investigations of CO levels in the automobile after cigarette smoking," *Int. Arch. Arbeitsmed.* **33:** 207 (1974b).
15. C. Jermini, A. Weber, E. Grandjean, "Quantitative determination of various gas-phase components of the sidestream smoke of cigarettes in room air as a contribution to the problem of passive smoking," *Int. Arch. Occup. Environ. Hlth.* **36:** 169 (1976).
16. H. P. Harke, "The problem of passive smoking. I. The influence of smoking on the CO concentration of office rooms," *Int. Arch. Arbeitsmed.* **33:** 199 (1974a).
17. G. Anderson, T. Dalhamn, "Health risks from passive smoking," *Lakastidningen* **70**(33): 2833 (1973).
18. G. Grimmer, H. Bohnke, H. P. Harke, "Problem of passive

Table IV. Nicotine measured under realistic conditions.

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels ($\mu g/m^3$) Mean	Levels ($\mu g/m^3$) Range	Nonsmoking controls Mean	Nonsmoking controls Range
Badre, *et al.*, 1978 (53)	6 Cafes	Varied	Not given	50 min sample		25–52		
	Room	18 Smokers	Not given	50 min sample	500			
	Hospital lobby	12 to 30 Smokers	Not given	50 min sample	37			
	2 Train compartments	2 to 3 Smokers	Not given	50 min sample		36–50		
	Car	3 Smokers	Natural, open	50 min sample	65			
			Natural, closed	50 min sample	1010			
Harmsen and Effenberger, 1957 (42)	Train	Not given	Natural, closed	30–45 min samples		0.7–3.1		
Hinds and First, 1975[a] (51)	Train	Not given	Not given	2½ hr samples	4.9		Values not given	
	Bus	Not given	Not given	2½ hr samples	6.3		Values not given	
	Bus waiting room	Not given	Not given	2½ hr samples	1.0		Values not given	
	Airline waiting room	Not given	Not given	2½ hr samples	3.1		Values not given	
	Restaurant	Not given	Not given	2½ hr samples	5.2		Values not given	
	Cocktail lounge	Not given	Not given	2½ hr samples	10.3		Values not given	
	Student lounge	Not given	Not given	2½ hr samples	2.8		Values not given	
Weber and Fischer, 1980[b] (48)	44 Offices	Varied	Varied	140 × 3 hr samples	0.9 ± 1.9	13.8 (peak)	Values not given	

[a] Background levels have been subtracted.
[b] Control values (unoccupied rooms) have been subtracted.

Table V. Nitrogen oxides measured under realistic conditions.

Study	Type of Premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppb) Mean	Levels (ppb) Range	Nonsmoking controls (ppb) Mean	Nonsmoking controls (ppb) Range
Fischer, *et al.*, 1978 (32) also	Restaurant	50–80/470 m^3	Mechanical	27 × 30 min samples	NO_2: 76	59–105	63 (outdoors)	
					NO: 120	36–218	115 (outdoors)	
Weber, *et al.*, 1979b (62)	Restaurant	60–100/440 m^3	Natural	29 × 30 min samples	NO_2: 63	24–99	50 (outdoors)	
					NO: 80	14–21	11 (outdoors)	
	Bar	30–40/50 m^3	Natural, open	28 × 30 min samples	NO_2: 21	1–61	48 (outdoors)	
					NO: 195	66–414	44 (outdoors)	
	Cafeteria	80–150/574 m^3	11 changes/hr	24 × 30 min samples	NO_2: 58	35–103	34 (outdoors)	
					NO: 9	2–38	4 (outdoors)	
				Other—non-smokers room			NO_2: 27	15–44
							NO: 5	2–9
Weber and Fischer,[a] 1980 (48)	44 Offices	Varied	Varied	348–354 samples	NO_2: 24 ± 22	115 (peak)	Values not given	
					NO: 32 ± 60	280 (peak)	Values not given	

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

smoking: measurements of polycyclic aromatic hydrocarbons in rooms after machine smoking of cigarettes," *Int. Arch. Occup. Environ. Hlth.* **40:** 83 (1977a).
19. C. Hugod, L. H. Hawkins, P. Astrup, "Exposure of passive smokers to tobacco smoke constituents," *Int. Arch. Occup. Environ. Hlth.* **42:** 21 (1978).
20. A. Seppanen, "Smoking in enclosed space and its effect on carboxyhaemoglobin saturation of smoking and nonsmoking subjects," *Ann. Clin. Res.* **9:** 281 (1977).
21. H. P. Harke, "The problem of passive smoking," *Muench. Med. Wschr.* **51:** 2328 (1970).
22. U. R. Hoegg, "Cigarette smoke in closed spaces," *Environ. Health Persp.* **1:** 117 (1972).
23. G. Grimmer, H. Bohnke, H. P. Harke, "Problem of passive smoking: intake of polycyclic aromatic hydrocarbons by breathing air containing cigarette smoke," *Int. Arch. Occup. Environ. Hlth.* **40:** 93 (1977b).
24. T. Dalhamn, M. Edfors, R. Rylander, "Retention of cigarette smoke components in human lungs," *Arch. Envir. Health* **17:** 746 (1968).
25. G. Holzer, J. Oro, W. Bertsch, "Gas chromatographic-mass spectrometric evaluation of exhaled tobacco smoke," *J. Chromatography* **126:** 771 (1976).
26. "The Health Consequences of Smoking, Report of the Surgeon General: 1972," U.S. Department of Health, Education and Welfare, Public Health Services, Health Services and Mental Health Documentation, DHEW Publication No. (HSM) 72-7516, 1972.
27. A. Weber, C. Jermini, E. Grandjean, "Irritating effects on man of air pollution due to cigarette smoke," *Am. J. Pub. Health* **66:** 672 (1976a).
28. A. Weber-Tschopp, C. Jermini, E. Grandjean, "Air pollution and annoyance from cigarette smoke," *Sozial und Praventwmedizin* **21:** 101 (1976b).
29. P. Pimm, F. Silverman, R. J. Shephard, "Physiological effects of acute passive exposure to cigarette smoke," *Arch. Environ. Health* **33:** 201 (1978).
30. G. Godin, G. Wright, R. J. Shephard, "Urban exposure to carbon monoxide," *Arch. Environ. Health* **25:** 305 (1972).
31. J. Sebben, P. Pimm, R. J. Shephard, "Cigarette smoke in enclosed public facilities," *Arch. Environ. Health* **32:** 53 (1977).
32. T. Fischer, A. Weber, E. Grandjean, "Air pollution by tobacco smoke in restaurants and bars," *Int. Arch. Occup. Environ. Hlth.* **41:** 267 (1978).
33. J. L. Repace, A. H. Lowrey, "Indoor air pollution, tobacco smoke and public health," *Science* **208:** 464 (1980).
34. A. Weber, T. Fischer, E. Grandjean, "Passive smoking: Irritating effects of the total smoke and the gas phase," *Int. Arch. Occup. Environ. Hlth* **43:** 183 (1979a).
35. J. E. Cuddeback, J. R. Donovan, W. E. Burg, "Occupational aspects of passive smoking," *Am. Ind. Hyg. Assoc. J.* **37:** 263 (1976).
36. R. M. Jones, R. Fagan, "Application of mathematical model for the buildup of carbon monoxide from cigarette smoking in rooms and houses," *ASHRAE* 49, (Aug. 1974).
37. S. B. Chappell, R. J. Parker, "Smoking and carbon monoxide levels in enclosed public places in New Brunswick," *Can. J. Public Health* **68:** 159 (1977).
38. D. Szadkowski, H. P. Harke, J. Angerer, "Burden of carbon monoxide from passive smoking in offices," *Int. Med.* **3:** 310 (1976).
39. J. Perry, "Fasten your seat belts: no smoking," *B.C. Med. J.* **15:** 304 (1973).
40. I. P. Elliott, D. R. Rowe, "Air quality during public gatherings," *JAPCA* **25:** 635 (1975).
41. J. Just, M. Borkowska, S. Maziarka, "Air pollution by tobacco smoke in Warsaw coffee houses," *Rocz. Pantstw. Zakl Hig.* **23**(2): 129 (1972).

Table VI. Nitrosamines measured under realistic conditions.

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ng/L) Mean	Levels (ng/L) Range
					N-Nitrosodimethylamine	
Brunneman and Hoffman, 1978 (54) also	Train bar car	Not given	Mechanical	90 min continuous	0.13	
	Train bar car	Not given	Natural	90 min continuous	0.11	
Brunneman, *et al.*, 1977 (55)	Bar	Not given	Not given	3 hr continuous	0.24	
	Sports hall	Not given	Not given	3 hr continuous	0.09	
	Betting parlour	Not given	Not given	90 min. continuous	0.05	
	Discotheque	Not given	Not given	2¾ hr continuous	0.09	
	Bank	Not given	Not given	5 hr continuous	0.01	
	House	Not given	Not given	4 hr continuous	<0.005	
	House	Not given	Not given	4 hr continuous	<0.003	

Table VII. Particulates measured under realistic conditions.

Study	Type premises	Occupancy	Ventilation	Monitoring conditions	Levels (mg/m^3) Mean	Levels (mg/m^3) Range	Nonsmoking controls (mg/m^3) Mean	Nonsmoking controls (mg/m^3) Range
Cuddeback, *et al.*, 1976 (35)	Tavern	Not given	6 changes/hr	4 × 8 hr continuous		0.233–0.346		
	Tavern	Not given	1–2 changes/hr	8 hr continuous	0.986			
U.S. Dept. of Transportation 1971 (43)	18 Military planes	165–219 people	Mechanical	72 × 6–7 hr samples		<0.01–0.12		
	8 Domestic planes	27–113 people	Mechanical	24 × 1¼–2½ hr samples	Not given			
Dockery and Spengler 1981, (12)	Residences	Not given	Varied	24-hr samples	0.0324			
Elliott and Rowe, 1975 (40)	Arena 1	11,806 people	Mechanical	Not given	0.323		0.042 (nonactivity day)	
	Arena 2	2,000 people	Natural	Not given	0.620		0.092 (nonactivity day)	0.148
				Nonsmoking arena				
Harmsen and Effenberger, 1957 (42)	Trains	15–120 people	Natural	Not given		46–440 particles/cc		
				Nonsmokers cars				20–75 particles/cc
Just, *et al.*, 1972 (41)	4 Coffee houses	Not given	Not given	Not given	1.15		0.57 (outdoors)	
Neal, *et al.*, 1978 (6)	Hospital unit	Not given	Mechanical	48 hr samples	0.021 ± 0.0136	0.0027–0.0576	0.0727 ± 0.0248 (outdoors)	
	Hospital unit	Not given	Mechanical	48 hr samples	0.0395 ± 0.0217	0.0134–0.0794	0.0717 ± 0.0250 (outdoors)	
Repace and Lowrey, 1980 (33)	Church bingo game	20 smokers/4224 m^3 = 0.47/100 m^3	Not given	8 min sample at church service	0.279 ± 0.018		0.030	
	Restaurant	2.25 smokers/781 m^3 = 0.29/100 m^3	Not given	20 min sample	0.110 ± 0.036		0.040 (outdoors)	
				Nonsmoking section			0.055 ± 0.005	
	Restaurant	1.5 smokers/360 m^3 = 0.42/100 m^3	Not given	40 min sample	0.109 ± 0.038		0.030 (separate run)	
	Restaurant	1 smoker/781 m^3 = 0.13/100 m^3	Not given	8 min sample	0.086 ± 0.007		0.051 (nonsm. section)	
	Restaurant	1 smoker/90 m^3 = 1.11/100 m^3	Not given	90 min sample	0.107		0.030 (separate run)	
	14 Public places	Varied	Not given	Varied	0.093–0.697		0.22–0.63 (outdoors)	
Spengler, *et al.*, 1981 (61)	Residences	>2 smokers	Not given	24-hr samples	0.0704 ± 0.429		0.0211 ± 0.0119 (outdoors)	
		1 smoker	Not given	24-hr samples	0.0365 ± 0.0145		0.0211 ± 0.0119 (outdoors)	
Weber and Fischer, 1980[a] (48)	44 Offices	Varied	Varied	429 × 2 min samples	0.133 ± 0.130	0.962 (peak)		

[a] Control values (unoccupied room) have been subtracted.

Table VIII. Residuals measured under realistic conditions.

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels Mean	Levels Range	Nonsmoking controls Mean	Nonsmoking controls Range
					Acetone (mg/m³)			
Badre, et al., 1978[a] (53)	6 Cafes	Varied	Not given	100 mL samples		0.91–5.88		
	Room	18 Smokers	Not given	100 mL samples	0.51			
	Hospital lobby	12 to 30 Smokers	Not given	100 mL samples	1.16			
	2 Train compartments	2 to 3 Smokers	Not given	100 mL samples		0.36–0.75		
	Car	3 Smokers	Natural, open	100 mL samples	0.32			
	Car	2 Smokers	Natural, closed	100 mL samples	1.20			
					Sulfates (μg/m³)			
Dockery and Spengler, 1981 (12)	Residences	Not given	Varied	24 hr samples	4.81			
					SO_2 (ppb)			
Fischer, et al., 1978 (32)	Restaurant	50–80/470 m³	Mechanical	27 × 30 min samples	20	9–32	12 ppb	
	Restaurant	60–100/440 m³	Natural	29 × 30 min samples	13	5–18	6	
	Bar	30–40/50 m³	Natural, open	28 × 30 min samples	30	13–75	8	
	Cafeteria	80–150/574 m³	11 ch./hr	24 × 30 min samples	15	1–27	12	
				Other nonsmokers room			7	3–13
					Aldehydes (μg/m³)			
Just, et al., 1972 (41)	4 Coffee houses	Not given	Not given	6 hr continuous	12.0–15.3			

[a] See original paper for 9 other residuals.

42. H. Harmsen, E. Effenberger, "Tobacco smoke in public transportation, dwellings, and work rooms," *Arch. Hyg.* **141:** 383 (1957).
43. "Health Aspects of Smoking in Transport Aircraft", U.S. Department of Transportation, U.S. National Technical Information Service, December, 1971.
44. M. W. First, W. C. Hinds, "Ambient tobacco smoke measurement," *Ind. Hyg. Assoc. J.* **37:** 655 (1976).
45. A. Seppanen, A. J. Uusitalo, "Carboxyhaemoglobin saturation in relation to smoking and various occupational conditions," *Environ. Res.* **19:** 279 (1977).
46. H. P. Harke, H. Peters, "The problem of passive smoking. III. The influence of smoking on the CO concentration in driving automobiles," *Int. Arch. Arbeitsmed.* **33:** 221 (1974c).
47. R. F. Coburn, R. E. Forster, P. B. Kane, "Considerations of the physiological variables that determine the blood carboxyhemoglobin concentration in man," *J. Clinical Investigation* 44: 1899 (1965).
48. A. Weber, T. Fischer, "Passive smoking at work," *Int. Arch. Occup. Environ. Health* **47:** 209 (1980).
49. J. R. White, H. F. Froeb, "Small-airways dysfunction in nonsmokers chronically exposed to tobacco smoke," *New Eng. J. Med.* **302:** 720 (1980).
50. R. G. Slavin, M. Hertz, "Indoor Air Pollution: A study of the 30th Annual Meeting of the American Academy of Allergy," *Proc. 30th Annual American Academy of Allergy Conference*, 1975.
51. W. C. Hinds, M. W. First, "Concentrations of nicotine and tobacco smoke in public places," *New Eng. J. Med.* **292:** 814 (1975).
52. D. Yoshida, "Measurement of nicotine in sidestreams of tobacco smoke," *Sci. Papers of the Cent. Res. Inst. Japan Tobacco and Salt Publ. Corp.* No. 118: 203 (1976).
53. R. Badre, R. Guillerm, N. Abran, M. Bourdin, C. Dumas, "Pollution atmosphérique par la fumée de tabac," *Annales pharmaceutiques francaises* **36:** 443 (1978).
54. K. D. Brunnemann, D. Hoffman, "Chemical Studies on Tobacco Smoke. LIX. Analysis of Volatile Nitrosamines in Tobacco Smoke and Polluted Indoor Environments," In *Environmental Aspects of N-Nitroso Compounds*, Walker, Griciute, Castegnaro and Lyle, eds. International Agency for Research on Cancer, Lyon, 1978. pp. 343–355.
55. K. D. Brunnemann, J. D. Adams, D. P. S. Ho, D. Hoffmann, "The Influence of Tobacco Smoke on Indoor Atmospheres II. Volatile and Tobacco Specific Nitrosamines in Main- and Sidestream Smoke and Their Contribution to Indoor Pollution." In: American Chemical Society 4th Joint Conference on Sensing of Environmental Pollutants. 1977.
56. D. P. Bridge, M. Corn, "Contribution to the assessment of nonsmokers to air pollution from cigarette and cigar smoke in occupied spaces," *Environ. Res.* 5: 192 (1972).
57. J. P. Cano, J. Catalin, R. Badre, C. Dumas, A. Viala, R. Guillerme, "Determination de la nicotine par chromatographie en phase gazeuse II. Applications," *Annales pharmaceutiques francaises* **28:** 633 (1970).
58. "CO as an Indicator of Cigarette Caused Pollution in Intercity Buses," U.S. Department of Transportation, Technical Report, 1973.
59. A. DeRouane, G. Verduyn, "Study of some factors affecting air pollution inside buildings," *Trib. Cebedeau* **27:** 482 (1974).
60. V. Galuskinova, "3–4 benzo(a)pyrene determination in the smokey atmosphere of social meeting rooms and restaurants," *Neoplasm* **98:** 1041 (1964).
61. J. D. Spengler, D. W. Dockery, W. A. Turner, J. M. Wolfson, B. G. Ferris, "Long term measurements of respirable sulphates and particles inside and outside homes," *Atmos. Environ.* **15:** 23 (1981).
62. A. Weber, T. Fischer, E. Grandjean, "Passive smoking in experimental and field conditions," *Environ. Res.* **20:** 205 (1979b).
63. N. Lefcoe, I. Inculet, "Particulates in domestic premises," *Arch. Environ. Health* **22:** 230 (1971).
64. M. A. H. Russell, C. Feyerabend, "Blood and urinary nicotine in non-smokers," *The Lancet* 179 (January 25, 1975).
65. M. Srch, "The significance of carbon monoxide during cigarette smoking inside of automobiles," *Deut. Z. Gesamte. Gericht. Med.* **60**(3): 80 (1967).
66. H. P. Harke, "The Problem of Passive Smoking. Particulate Matter from Tobacco Smoke in Closed Spaces," presented at 28th Tobacco Chemists' Research Conference, Raleigh, NC 1974.

Dr. Sterling is University Research Professor, Faculty of Interdisciplinary Studies, and Ms. Dimich is in the Department of Kinesiology, Simon Fraser University, Burnaby, British Columbia, Canada, V5A 1S6. Ms. Kobayashi is in the Department of Epidemiology, Columbia University, New York, NY.

This paper is based on a review of the literature on sources and health effects of indoor combustion byproducts, done for the NAS/NRC Committee on Indoor Pollutants under Contract No. ALS 53-79-307(21). The original manuscript was submitted for review on October 6, 1981. A revised manuscript was received on December 28, 1981.