Cigarette Smoke in Closed Spaces

by Ulrich R. Hoegg, M.D.*

For years it has been postulated that the cigarette smoker adversely affects the nonsmoker by contaminating the indoor atmosphere (*2,3*). Recently, the U.S. Surgeon General, J. L. Steinfeld, focused public attention on the question when he requested a ban on smoking in closed public spaces (*4*). The average person spends the great majority of his time, probably 80 to 90 percent, indoors (*5*); thus, there is widespread concern about the environmental conditions produced by indoor smoking.

Experiments on mouse skin have indicated that the condensate tar of the smoke from the glowing end of the cigarette (sidestream) has a higher tumor-producing activity than condensate leaving the mouthpiece of the cigarette (mainstream) (*6*). Other experiments showed that air pollution extract and cigarette smoke condensate combined have more than additive tumor-producing potential (*7,8*). Previous studies on cigarette smoke in closed spaces suggest that the nonsmoker is exposed to considerable amounts of cigarette smoke in the course of his normal activities (*9*). Thus, the pollution of closed spaces by cigarette smoke possibly contributes to such otherwise unexplained phenomena as lung cancer in nonsmokers, differences in lung cancer occurrence between rural and urban areas, allergies, and other diseases (*10, 13*). Although some studies have been made on smoked-filled rooms and vehicles (*9, 14*), on the health of smokers' children (*15*), and on some of the constitutents of the different smoke streams (see below), no exact method has been developed either to relate smoke concentrations in closed spaces to air quality standards objectively or to relate the extent of passive smoking to human health. The 1972 Surgeon General's report, "The Health Consequences of Smoking," recognizes the limitations of present knowledge about cigarette smoke in closed spaces and underscores the need for comprehensive study of the question (*16*).

The following steps are necessary to the development of an objective method: From the vast literature on active smoking, scattered data can be isolated on the subjects of passive smoking and smoke in closed spaces. Experimental research under controlled smoking conditions provides additional data on the composition of smoke and factors in its dissipation. The combined data can then be related to passive smoking and air quality standards.

Literature Review: Smoking Parameters

All parameters affecting the generation of cigarette smoke, the distribution of cigarette smoke in closed spaces, and the uptake of cigarette smoke from the ambient air, have to be analyzed for this study so that indoor atmospheric smoke can be compared quantitatively with actively inhaled smoke. Active smoking is the process of inhaling mainstream

*The author was a resident in occupational medicine at the Institute of Environmental Health, College of Medicine, University of Cincinnati, from 1969 to 1971, during which time this study was completed as part of his research for a Master of Science Degree (*1*). His advisors were H. G. Petering, Ph.D., Prof. Env. Health and L. B. Tepper, B.A., M.D., M.I.H., Sc.D., Associate Prof. Env. Health and Medicine. Reprint requests c/o H. G. Petering, 3223 Eden Avenue, Cincinnati, Ohio 45219

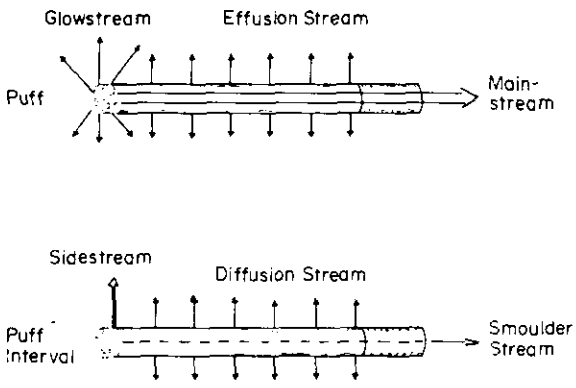

FIGURE 1. Smoke streams of the cigarette. translated after Lipp, (*17*).

smoke during the puff. Passive smoking can be defined as the uptake of cigarette smoke from the ambient air into the respiratory tract.

The smoke produced from a burning cigarette is distributed into different smoke streams (Figure 1) (*17*). The smoke which has heretofore received most experimental and public attention is the mainstream, which enters the mouth of the smoker during the puff. All other smoke streams are directly emitted into the ambient air. Of these, the sidestream, which leaves the burning end of the cigarette during the puff interval, contributes about 95%. The smoulder stream contributes approximately 4%. The remainder is emitted through the glowstream, effusion stream (emitted during the puff), and diffusion stream (emitted in the puff interval). This study focuses on mainstream and sidestream, which are quantitatively the most important smoke streams.

Correlation of the available experimental data on mainstream smoke to sidestream smoke requires a means of quantitative comparison. Therefore the ratio of sidestream to mainstream smoke (S/M) has been set up and the values of various compounds are calculated in Table 1. (All of the data were obtained under standard smoking conditions and with 70 or 85 mm nonfilter cigarettes unless otherwise specified.) Several conclusions can be drawn from this table:

- Sidestream smoke differs quantitatively from mainstream smoke, as shown by a S/M ratio ranging from 1.2 to 46.
- The vapor phase (range 1.3 to 46) varies more than the particulate phase (range 1.8 to 6.2).
- Filter cigarettes yield less mainstream than nonfilter cigarettes, while the sidestream is affected relatively little by the cigarette filter. This results in an increased S/M ratio in filter cigarettes.

There is no general agreement on the most efficient means of sidestream smoke collection. In the past, numerous methods had been used including exhaust hoods, open tubes, bell jars, closed cartridges (cooled or uncooled), small chambers, or smoke-filled meeting rooms (*18-25*). Despite this variety of methods, no comparison of different methods has ever been made.

Particle size governs the retention of smoke in the respiratory tract and affects the dissipation of smoke particulates in the atmosphere. The particulates of fresh mainstream smoke measure an average of 0.21 micron in diameter as compared to 0.15 micron for sidestream smoke (*26*). Aging cigarette smoke supposedly doubles its peak diameter rapidly, but it has not been studied and measured for longer than four minutes (*26*). Exhaled mainstream particles are slightly larger than the mainstream particles drawn in during inhalation (*29*).

Differences occur in the temperature of mainstream and sidestream smoke. The center of the cigarette cone measures about 884° C during the puff and about 835° C in the puff interval (*30*). Yet, the highest temperature is not in the center of the cone, but in the outer ring of the cigarette, where temperatures up to 1200° C have been recorded (*31*). The temperature of mainstream smoke as it leaves the cigarette does not exceed 30° C, if a 23 mm butt is left (*32*). Sidestream smoke is much hotter, reaching up to 400° C; 6 cm above the burning cigarette it measures 100° C (*33*).

Reproducible experiments involving the collection of cigarette smoke require standard smoking conditions. The most frequently used smoking conditions are(*34*): puff volume 35 ml, puff duration 2 sec., puff frequency one puff per minute and butt length 23 or 30

Table 1. Comparison of Mainstream and Sidestream Smoke

Compound	M (mg/cig)	S (mg/cig)	S/M	Comment
A. *General Characteristics*				
Duration of Smoke Production	20 sec.	550 sec.	27	*(24)*
Tobacco Burnt	347	411	1.2	*(25)*
Particulates, No. per cig.	1.05×10^{12}	3.5×10^{12}	3.3	*(26)*
B. *Particulate Phase*				
*Tar (chloroform Extract)	20.8 10.2	44.1 34.5	2.1 3.4	*(22)* Filter cig.
Nicotine	0.92 0.46	1.69 1.27	1.8 2.8	*(22)* Filter cig.
Benzo(a)pyrene	3.5×10^{-5}	13.5×10^{-5}	3.7	*(18)*
Pyrene	13×10^{-5}	39×10^{-5}	3.0	*(18)*
Total Phenols	0.228	0.603	2.6	*(21)*
Cadmium	12.5×10^{-5}	45×10^{-5}	3.6	Total 140×10^{-5} mg/cig. *(27)*
C. *Gases and Vapors***				
Water	7.5	298	39.7	3.5 mg. of M and 5.5 mg. of S in part. phase, rest in vapor phase. *(28)*
Ammonia	0.16	7.4	46	*(22)*
Carbon dioxide	63.5	79.5	1.3	*(22)*
Nitrous oxides	0.014	0.051	3.6	*(22)*

M = Mainstream Smoke
S = Sidestream Smoke
* see also TPM in research below
** for carbon monoxide see research below

mm. Tobacco moisture is usually 10%. The data of Table 1 were all produced under these conditions.

Without inhalation, 20-50% of smoke particles are retained in the mouth(*35*). Inhalation causes 70% of smoke particles of mainstream smoke to be retained in the lungs, and the remaining 30% to be emitted to the ambient air. The retention of the vapor phase of cigarette smoke varies with the properties of the gases and vapors: after deep inhalation, only 55% of carbon monoxide (CO) is retained, but 99% of nitrogen dioxide is retained even with slight inhalation (*36,37*).

Passive smoking is quantitatively related to the amount of air respired by the subject. The respiratory volume of a man at rest is 0.3 m^3/hr., and at light work it is 0.9 m^3/hr (*38*). Women, and especially children, have lower respiratory volumes.

In 1970, 534 billion cigarettes were sold in the United States (*39*). Cigarettes are smoked by 46% of all adult males and 30% of all adult females (*40*). Calculation of averages, including smokers and nonsmokers, reveals that persons 18 and over smoked 3,969 cigarettes per person in 1970. That is 10.9 cigarettes per day or 0.7 cigarettes per hour, if averaged over 16 waking hours. The maximum hourly smoking rate can be much higher: it takes 12 minutes to smoke one cigarette, thus a "chain smoker" can smoke up to 5 cigarettes per hour.

This study requires, as one of its parameters, determination of the size of commonly found spaces into which cigarette smoke is emitted. Because no actual measurements were available for this study, the recommendations of three widely used building codes are useful. These codes recommend the following space per person (*41*):

Residential:	640 ft^3 or 18 m^3
Assembly Areas:	135 ft^3 or 3.8 m^3
Offices:	800 ft^3 or 23 m^3
Automobiles (*42*):	140 ft^3 or 4.0 m^3

Room ventilation contributes to the elimination of cigarette smoke from the ambient atmosphere. The air exchange rate, a common measure of ventilation, can be calculated as the time required to supply a volume of outside air equal to the volume of the ventilated space. This rate is between 0.3 and 2.0 air changes per hour in rooms without ventilation (*43*). Ventilated spaces have much higher rates: offices average 8, automobiles in motion average 12, and meeting rooms average 16 air changes per hour (*44,45*). Usually only a part of the ventilated air is fresh air, the rest having been filtered and recirculated.

Calculation of the ventilation data is based on the following formula (*46*):

Formula I

$$C = C_i e^{-\frac{Qt}{V}} + \frac{C_i Q + G}{Q}\left[1 - e^{-\frac{Qt}{V}}\right]$$

Notation: V = volume of room (m^3)
t = time (hours)
C = concentration of contaminant in room at any time
C_i = initial concentration of contaminant
Q = volume rate of ventilation (m^3/hr.)
G = quantity rate of generation of room contaminant within the room (e.g. from cig.)
e = Naperian logarithmic base

In this formula, the expression to the left of the plus sign describes the elimination of a pre-existing concentration of contaminant from a ventilated room. The part to the right of the plus sign describes the build-up of a contaminant which is generated, as in cigarette smoking, inside a ventilated room.

Formula I assumes ideal ventilation. For most practical purposes, the calculation must be corrected for a mixing factor to account for incomplete mixing of room air with ventilation air (*47*). This factor ranges from 1/3 to 1/10; the derivation of this factor is not well documented. The dissipation of cigarette sidestream smoke attributable to factors other than ventilation is discussed among the experimental research findings.

Experimental Method

The parameters of cigarette smoke production and distribution in closed spaces obtained from the survey of the existing literature were not sufficient to permit an objective evaluation of human exposure to cigarette smoke in the ambient air. Experimental research was undertaken to provide data on the characteristics of aging cigarette smoke in the ambient air, its dissipation from the atmosphere, and smoke particle size as a function of time.

In addition, direct collection of the total particulate matter (TPM) of sidestream smoke on a filter permitted the comparison of this method with TPM collection in organic solvents. The experiments were designed to provide evidence on the possible differences between mainstream and sidestream smoke. Evaluation of the experimental data produced formulas for the calculation of the effects of passive smoking and the development of room smoke concentration information.

A special type of test chamber was required which would resemble commonly found closed spaces. All experiments were conducted in a sealed 25 m^3 chamber, where the experimenter and all test equipment remained during the experiments. Portable fans were used continuously to circulate the air in the room. The airtightness of the chamber was checked with carbon monoxide: a test concentration of 65 parts per million (p.p.m.) was generated from a source of concentrated CO and monitored over 5 hours. Less than 1% CO escaped from the chamber each hour, after correction for uptake by the experimenter had been made. Temperature and relative humidity were brought to practical, well-defined ranges (25-27° C and 26-30% respectively) before the start of each experiment.

A smoking machine, which holds up to 24 cigarettes simultaneously (type Mark III), smoked University of Kentucky research cigarettes (code IRI) to a 23 mm butt. These cigarettes resemble commercial cigarettes commonly smoked in the United States during 1966 (*48*). All mainstream smoke was discharged outside the test chamber where it could not affect the chamber air.

During all smoking experiments the carbon monoxide concentration in the test chamber was monitored. This was done by collecting a total of 3 samples in 100-liter gas sampling bags, at the beginning, the middle, and the end of the 3-hour experiments. The analysis of these bags was later performed by a Beckman infrared analyzer with a 40-inch detector cell.

Carbon monoxide concentration in the sidestream smoke was determined from the initial concentration of carbon monoxide in the air of the test chamber. The first sample, taken 15 minutes after the start of the experiment, was used to calculate the carbon monoxide concentration present in the sidestream smoke of each cigarette. This was done by relating the concentration in the chamber to the volume of the chamber and the number of cigarettes smoked.

Cambridge glass fibre filters measuring 44 mm in diameter were used to collect TPM (*49*). Up to 8 Cambridge filters monitored the TPM concentration in the ambient air of the test chamber over a period of three hours with an amount between 200 and 1,000 liters of chamber air passing through each filter. A pump with a capacity of 50 liters per minute produced the air flow, which was measured with a calibrated rotometer. Separate experiments involving 4, 8, 16 and 24 cigarettes were performed.

Cambridge filters in combination with 47 mm 0.45 micron Millipore filters collected the TPM in fresh sidestream smoke directly from the burning ends of the cigarettes. This was accomplished by holding an open filter holder which was connected to the high volume pump 0.5 to 5.0 cm over the burning end of the cigarette so that no visible smoke would escape. The direct collection of the smoulder stream was performed in a similar manner.

The calculation of a ratio relating mainstream and sidestream smoke required collection of the TPM produced by mainstream smoke by a standard method, also on Cambridge filters (*49*).

A microscale, which allowed readings to 0.05 mg accuracy was used to weigh the loaded filters, which were conditioned at 58% relative humidity before weighing (*50*). Double weighing of all fresh filters used in the experiments showed a difference of less than 0.1 mg on the average.

The size of the smoke particles was determined with a Casella Cascade impactor, which measures particles from 0.3 micron up to 6.0 microns on four stages and a filter.

Before evaluation of the sample data for total particulate matter, corrections were made for the cumulative sampling volume and

the uptake by the experimenter, which was assumed to be 70% of the respiratory volume. The respiratory volume of the experimenter had been determined in the course of the experiments. Statistical evaluation of the TPM data involved the use of linear regression analysis, and 95% confidence limits were calculated for a two-tailed distribution. The regression formula $y = a + bx$ was used to derive a general formula describing the decrease of TPM over a period of time.

As shown below, the dissipation of TPM from the ambient atmosphere is a log-linear function of time. Determination of the *average* dissipation is complicated, if the regression formula is used. Therefore a simple approximation was achieved by estimating the area under the parabolic curve described by the log-linear function. Ventilation affects the dissipation factor. Solving the first part of Formula I for time shows that 75% of the original TPM disappears from the average meeting room or car in 20 minutes, but 75% dissipation from the average residential or office space requires 3 hours.

Results

The highest concentration of CO in the test chamber was 69.8 parts per million (p.p.m.), generated by the sidestream of 24 cigarettes. The CO concentration was directly proportional to the number of cigarettes smoked in the chamber (Fig. 2). An average of 75.5 ml. of CO is present in the sidestream of a single cigarette, whereas the mainstream of the same type of cigarette contains only 16.0 ml. of CO (Fig. 3) (*51*). The sidestream-mainstream (S/M) ratio for CO is therefore 4.7. The CO from cigarette smoke dispersed into a closed space is stable over several hours; the experiments indicated no measurable loss of CO from the test chamber 3 hours after the cigarettes were smoked.

Mainstream smoke contained 36.2 mg TPM per cigarette, whereas total sidestream smoke contained only 25.8 mg TPM per cigarette (Fig. 3); the S/M ratio for TPM is thus 0.7. The 25.8 mg includes 1.3 mg of smoulder stream smoke (Fig. 1). Nearly 10% of *fresh* sidestream passed through the Cambridge filter and was collected on the Millipore filter.

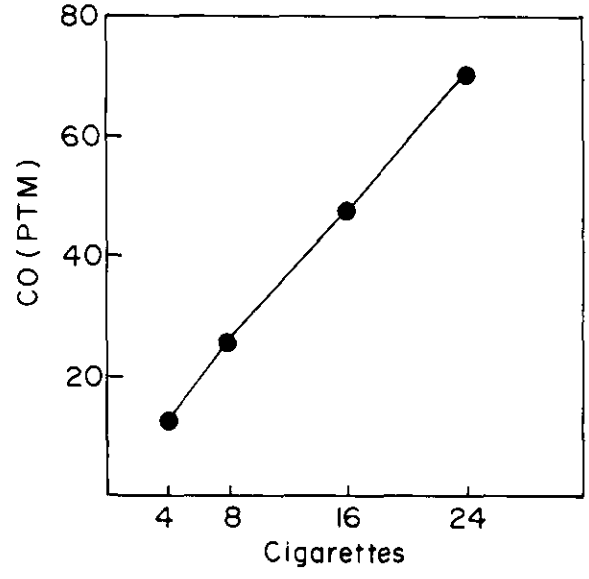

FIGURE 2. Sidestream smoke CO concentration in 25 m^3 test chamber generated by 4 to 24 cigarettes.

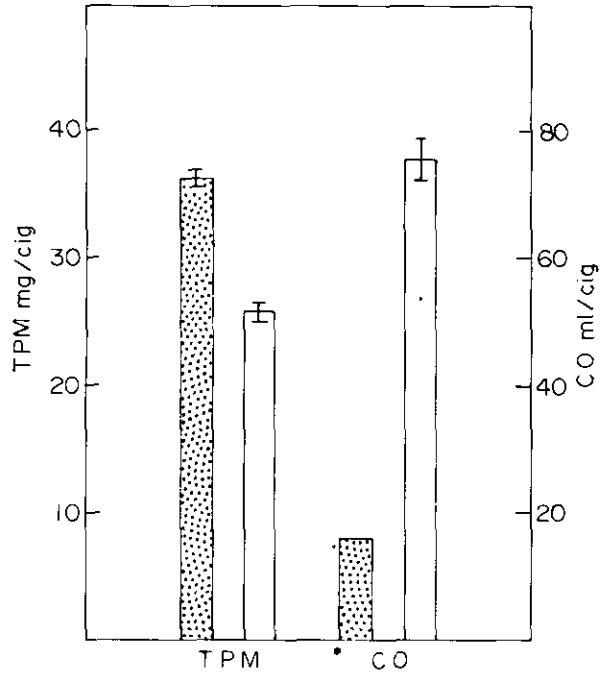

FIGURE 3. Comparison of TPM and CO in mainstream (shaded columns) and sidestream smoke (white columns). I indicates standard deviation. *Value from Ref. 51.

Evaluation of the data from the Cascade impactor showed that the majority of particles of sidestream smoke measured less than 0.7 micron in diameter. No particles larger than 2.0 micron were found during the 3-hour observation period.

The dissipation of TPM from the air of the test chamber is shown in Fig. 4. The highest measured concentration of TPM was 16.65 mg/m^3, 18 minutes after smoking 24 cigarettes; the lowest concentration was 1.21 mg/m^3, 150 minutes after smoking 4 cigarettes. The relationship between decrease of TPM and the $\log_{10}$ of the time is highly significant. The correlation coefficients for the regression lines in Fig. 4 are between 0.975 and 0.992. The rate of dissipation of cigarette smoke from the atmosphere is equal to the slope of the regression lines in Fig. 4. This slope is directly proportional to the number of cigarettes smoked, as is the amount of TPM present at any given time. Therefore, a general formula can predict the concentration of TPM in a sealed room merely as a function of the number of cigarettes smoked and time:

Formula II

$$\text{TPM } (mg/m^3) = \frac{Cg}{V}(-7.125 \log_{10} t + 25.5)$$

Notation: TPM = total particulate matter from sidestream smoke (mg/m^3)
Cg = number of cigarettes smoked
V = volume of chamber (m^3)
t = time after lighting of the cigarette (min.)

The two constants in this formula, −7.125 and 25.5 were calculated by averaging all data presented in Fig. 4. The value of 25.5 (mg TPM per cigarette) was derived from the intercept of the regression lines at one minute ($\log_{10}$ of one = zero). This value is close to the 25.8 mg TPM per cigarette actually recovered from the fresh sidestream smoke. The validity of Formula II was determined for the data of Fig. 4. With one exception, the observations were within the 95% confidence limits of the regression lines. The simplified method for estimation of the dissipation rate as described earlier yields an average dissipation factor (p) of 0.77, if 75% of the original smoke leaves the room in 20 minutes due to ventilation; if the time is 3 hours, (p) becomes 0.53.

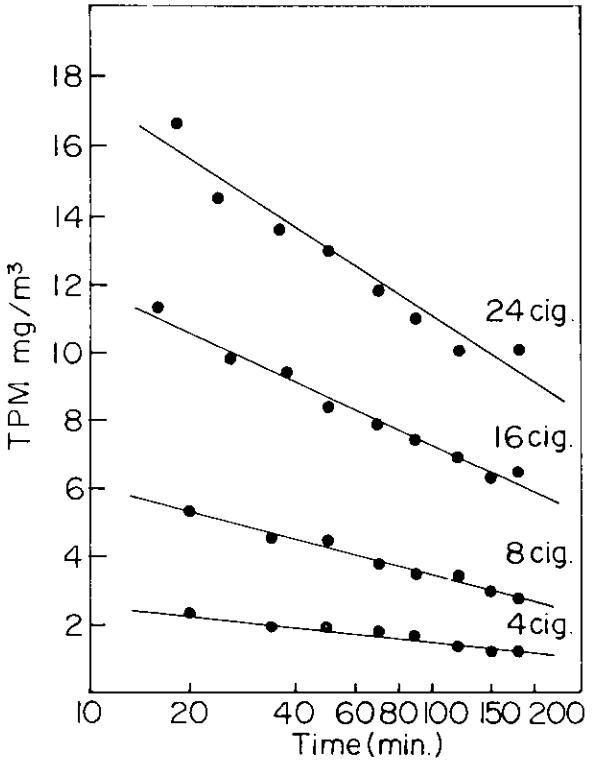

FIGURE 4. Concentration of TPM in 25 m^3 chamber from sidestream smoke. Linear regression of TPM vs. time after lighting of cigarettes.

The experimental data derived above permit an objective description of passive smoking using the concept of the Cigarette Equivalent (C.E.). The amount of sidestream cigarette smoke or its constituents which equals the amount present in the mainstream of one cigarette can be termed one C.E. Formula III allows for the calculation of C.E.:

Formula III

$$\text{C.E. per hour} = \frac{Cg \times S/M \times R \times p}{Qm} \times \left[1 - e^{\frac{-Qmt}{V}}\right]$$

Notation: Cg = number of cigarettes smoked (per hour)
S/M = Sidestream: Mainstream ratio
R = respiratory volume (m^3/hr)
Q = volume rate of room ventilation (m^3/hr)
m = mixing factor
e = Naperian logarithmic base
t = time (hours)
V = volume of room (m^3)
p = dissipation factor

This formula is derived from Formula I; it describes the buildup of cigarette smoke in a room when no initial smoke concentration is present. The formula has been corrected for the "mixing factor" different than previously described (*52,53*). In our opinion, previous corrections were not sufficient. In Formula III the term in parentheses indicates that the smoke concentration increases with time; as time becomes infinite and the term approaches one, it can be disregarded. The following examples show application of Formula III for two commonly occurring situations. The parameters used are based on per-person averages.

Example (1)

C.E. for average *residential space:*
(Cg = 0.7; S/M = 0.7 for TPM, 4.7 for CO; R = 0.6: Q = 18; m = 1/3; t = 3; V = 17; p = 0.53 for TPM, 1.0 for CO)
C.E. per hour = 0.016 for TPM
= 0.210 for CO

Example (2)

C.E. for average *meeting room* or automobile:
(Q = 51; t = 0.5; V = 4.0; p = 0.77 for TPM, other parameters as in Example (1))
C.E. per hour = 0.014 for TPM
= 0.130 for CO

In extreme situations (e.g. Cg = 5.0; m = 1/10, R = 2.0) the values for C. E. may be much higher or lower.

The contamination of room air by sidestream cigarette smoke can also be calculated from the experimental data. A slight change of Formula III (omit M from S/M and omit R) provides the necessary formula:

Formula IV

$$R.C. = \frac{Cg \times S \times p}{Qm} \times \left[1 - e^{-\frac{Qmt}{V}}\right]$$

Notation: R.C. = Room concentration per m^3
S = concentration in sidestream smoke per cig.
Other notations as in Formula III.

Applications of this formula can be shown for the same conditions as in Examples 1 and 2:

Example (3)

R.C. for average residential space:
(Cg = 0.7; S = 25.5 mg for TPM, 75.5 ml for CO; Q = 18; m = 1/3; t = 3; V = 17; p = 0.53 for TPM, 1.0 for CO)
R.C. = 1.0 mg/m^3 for TPM
= 5.7 p.p.m. for CO

Example (4)

R.C. for average meeting room or automobile:
(Q = 51; t = 0.5; V = 4.0; p = 0.77 for TPM, other parameters as in Example (3))
R.C. = 0.7 mg/m^3 for TPM
= 2.8 p.p.m. for CO

Extreme situations again may produce values differing by a factor of 10 or more.

Discussion

The test chamber experiments showed that the exposure of a person to sidestream cigarette smoke can be measured exactly in terms of the number of cigarettes passively smoked (C.E.) or in terms of pollutant concentration levels, if the number of cigarettes smoked in a closed space and all other variables are known. However, the study indicated that the problem is complicated by the number of variables and the present vagueness of description about commonly occurring closed spaces. These uncertainties preclude an exact statement of the significance of the resulting exposure until additional experimental and physiological evidence is gathered. This study can serve as a base for such further studies.

Per-person averages (including respiratory rate, room size, ventilation and smoking habits) provide a practical method from which to measure the extent of the health problem. Standard smoking conditions and other well-defined experimental conditions were chosen to facilitate reproduction of our data. An example of a necessary simplification of the problem was the elimination of exhaled mainstream smoke from consideration as a factor in test chamber smoke concentration.

For the smoking experiments, a sealed test chamber is preferable to an unsealed normal room where uncontrolled ventilation can be considerable (*14,9,23*). On the other hand, a ventilated test chamber might have contributed uncertainties about ventilation and air mixing.

Carbon monixide is present in sidestream smoke in very high concentrations. It remains stable in diluted smoke and therefore serves as a reliable indicator of the amount of fresh sidestream emission.

Previous research had posited that sidestream smoke is similar to mainstream smoke (*54*). We showed earlier that this is not true quantitatively in view of the wide range of the S/M ratio. It is also not true qualitatively. The distribution into particulate and vapor phase must be different for the two smoke streams, because "tar" in mainstream smoke, whether collected in an organic solvent or on a filter, provides similar yield, yet in sidestream smoke with organic solvents three times the amount of "tar" is collected than with the filter method used in this experiment (Table 1). The difference is probably due to the differing compositions of sidestream and mainstream smoke caused by the higher temperature of sidestream. Some of the constituents of the particulate phase of mainstream smoke probably appear in the vapor phase of sidestream smoke.

The dissipation of cigarette smoke from the ambient atmosphere of a closed space has not been considered before. It is of sufficient magnitude to require consideration in future studies on sidestream smoke. The extent and rate of dissipation from the atmosphere is probably a factor affecting not only the particulate phase but also the unstable constituents of the vapor phase (*55*).

Particles with a median diameter less than 2 to 5 microns are considered "respirable" (*56*): they can penetrate the periphery of the human lungs. Sidestream smoke does not exceed 2.0 microns at any time and can therefore be considered respirable. From data derived from the study of diluted mainstream smoke, the continuous, rapid growth of smoke particles was predicted (*26*). Had it been longer in duration, Keith and Derrick's study, which was conducted for only 4 minutes, would probably have shown that mainstream smoke also does not contain particles larger than 2 microns.

Theoretically the Cigarette Equivalent (C.E.) can be an exact measure of human exposure to sidestream cigarette smoke but, in the examples above, it is merely a potentiation of various estimates. Major uncertainties are introduced with the mixing factor, the ventilation rate and the room size.

Another problem in comparing human exposure to mainstream and sidestream is caused by the differences in their composition, partially reflected in the wide range of the S/M ratio (Table 1). Sidestream may be more or less harmful to humans than mainstream smoke.

The formula for the calculation of a room

concentration allows a comparison of air quality standards to smoky indoor atmospheres. It, thus, provides an objective method to evaluate the undesirability or harmfulness of cigarette smoke in the indoor environment. Comparison with federal community air quality standards provides an adequate basis to rate the indoor air inhaled by the general public in offices, residences, assembly halls, and moving automobiles (*57*). From our data it appears that at least the standard for TPM (0.260 mg/m^3 as a maximum 24 hr. average) will frequently be exceeded. Our data are not sufficient to permit further conclusions at present. In this context, the question of indoor air pollution in general needs more attention. After all, people in the United States spend most of their time in closed spaces.

Summary

This study describes a basic approach for the evaluation of cigarette smoke in closed spaces. Factors involved in a person's exposure to sidestream smoke were defined, and commonly found averages of such factors were used to determine common exposures. Information not available from the existing literature was developed through experimental research. Finally, all important factors were combined to calculate the extent of passive smoking and pollutant concentration levels in smoky atmospheres.

The following major conclusions were drawn from this research:

- The concentration in sidestream smoke compared to the concentration in mainstream (S/M ratio) differs for different smoke constituents. It ranges from 0.7 to 6.2 for the particulate phase and from 1.3 to 46 for the vapor phase of cigarette smoke. It is higher for filter than for nonfilter cigarettes.
- A *new method*, consisting of smoking research cigarettes at standard conditions in a large sealed chamber, is suitable for the study of cigarette smoke in closed spaces.
- Sidestream smoke of one cigarette contains 75.5 ml. of CO, a quantity 4.7 times greater than that present in mainstream smoke of one cigarette.
- The particles of aged cigarette smoke do not exceed a size of two microns and are therefore fully respirable.
- Direct collection of total particulate matter (TPM) in sidestream smoke using a filter technique yielded only 25.8 mg per cigarette in contrast to other techniques. This indicated that many compounds which occur in the particulate phase of mainstream smoke must belong to the vapor phase of sidestream smoke.
- Particulate matter of sidestream smoke dissipates from the ambient air at a rapid rate, which is a linear function of TPM and log-time; 50% of original TPM disappears within one hour.
- Passive smoking can be measured using the concept of the "Cigarette Equivalent" (C.E.). An estimated 0.01 to 0.20 C.E. per hour is inhaled in the average closed space.
- Room concentrations of cigarette smoke constituents can be calculated from basic parameters, permitting comparison with established air quality standards. The experimental data indicated that under average indoor conditions at least, TPM may exceed the federal community air quality standard.

Acknowledgements

I am thankful to the Institute of Environmental Health (Dr. R. R. Suskind, Director) for the privilege of their sponsoring my two-year residency program. I am obliged to my master thesis advisors, Dr. H. G. Petering and Dr. L. B. Tepper for their encouragement and advice for this research project. I am also obliged to many of the scientific staff members and senior students of the Institute for their suggestions and for providing me with the necessary equipment for this research. I thank J. A. Laurie for her assistance in editing this paper.

References

1. Hoegg, U. R. 1972. The Significance of Cigarette Smoke in Confined Spaces. Master Thesis, University of Cincinnati, (June).
2. Hoffstaedt. E. G. W. 1956. Atmospheric Pollution. The Lancet Jan. 21: 163.
3. Abelson, P. H. 1967. A Damaging Source of Air Pollution. Science 158:1527.
4. Newsweek: A Ban on Public Smoking: p. 90-91. January 25, 1971.
5. Bach, W. 1968. Suggestions for Pollution Monitoring In and Around Buildings in Cincinnati. Unpublished. University of Cincinnati.
6. Wynder, E. L. and Hoffman, D. 1967. Tobacco and Tobacco Smoke. Academic Press. New York. pp. 183 and 291.
7. Clemo, G. R. and Miller, E. W. 1960. Tumour Promotion by the Neutral Fraction of Cigarette Smoke. Brit. J. Cancer 14:651-656.
8. Roe, F. J. C., et al. 1964,: Synergic Effect of Tobacco Smoke Condensate and an Acetone-Soluble Fraction of Particulate Matter from London Air. Annual Report Brit. Empire Cancer Campaign 42:26.
9. Harmsen, H., and Effenberger, E. 1957. Tabakrauch in Verkehrsmitteln, Wohn-Und Arbeitstraumen. Arch. Hyg. 141:383-400.
10. Cooper, D. A., Crane, A. R. and Boucot, K. R. 1968. Primary Carcinoma of the Lung in Nonsmokers. Arch. Environ. Health, 16:398-400.
11. Buell, P. and Dunn, J. E. 1967. Relative Impact of Smoking and Air Pollution on Lung Cancer. Arch. Environ. Health 15:291-297.
12. Speer, F. 1968. Tobacco and the Nonsmoker. Arch. Environ. Health 16:443-446.
13. Lemon, F. R. and Walden, R. T. 1966. Death from Respiratory System Disease Among Seventh-Day Adventist Men. J. Amer. Med. Assoc. 198:137-146.
14. Srch, M. 1967. On the Significance of Carbon Monoxide in Cigarette Smoking in an Automobile. Deutsch. Z. Ges. Gerichtl. Med. 60:80-89.
15. Cameron, P., et al. 1969. The Health of Smokers' and Nonsmokers' Children. J. of Allergy 43:336-341.
16. The Health Consequences of Smoking. A Report of the Surgeon General. 1972, U. S. Dept. of Health, Education, and Welfare, U. S. Public Health Service, p. 179-206.
17. Lipp, G. 1965. Zur Definition Der Selektivitat Und Der Verschidenen Rauchstrome Der Cigarette. Beitrage Tabakforsch 3:220-222.
18. Kotin, P. and Falk, H. L. 1960. The Role and Action of Environmental Agents in the Pathogenesis of Lung Cancer. II. Cigarette Smoke. Cancer 13:250-262.
19. Bentley, H. R. and Burgan, J. G. 1960. Polynuclear Hydrocarbons in Tobacco Smoke: Part II. The Origin of 3:4 Benzo-Pyrene Found in Tobacco and Tobacco Smoke. Analyst 85:723-727.
20. Morrell, F. A. 1966. A Total Combustion Product Cigarette Smoking Machine—Analyses of Radioactive Cigarette Paper. Tobacco Science 10:45-50.
21. Neurath, G. and Ehmke, H. 1964. Apparatur Zur Untersuchung Des Nebenstromrauches. Beitrage Tabakforsch 2:117-121.
22. Scassellati Sforzolini, G. and Sabino, A. 1968. Evaluation of a Rapid Index of Ambient Contamination by Cigarette Smoke, in Relation to the Composition of the Gas Phases of the Smoke. Rivista Italiana d'Igiene 28:43-55.
23. Harke, H. P. 1970. The Problem of "Passive Smoking". Munch. Med. Wochenschr 112:2328-2334.
24. Neurath, G. and Horstman, H. 1963. Einfluss Des Feuchtigkeitsgehaltes Von Cigaretten Auf Die Zusammensetzung Des Rauches Und Die Glutzonentemperatur. Beitrage Tabakforsch 2:93-100.
25. Neurath, G., Ehmke, H. and Horstmann, H. 1964: Einfluss Des Feuchtigkeitsgehaltes Von Cigaretten Auf Die Zusammensetzung Des Rauches. III. Beitrage Tabakforsch 2:361-369.
26. Keith, C. H. and Derrick, J. C. 1960. Measurement of the Particle Size Distribution and Concentration of Cigarette Smoke by the "Conifuge". J. of Colloid Science 15:340-356.
27. Petering, H. G. 1971. University of Cincinnati. (to be published).
28. Seehofer, F., et al. 1966. Balance of Water in the Smoking of a Cigarette. Part 2. Beitrage Tabakforsch. 3:491-503.
29. Polydorova, M. 1961. An Attempt to Determine the Retention of Tobacco Smoke by Means of Membrane Filters. pp. 142-144 In: Davies, C. N. (Ed.) Inhaled Particles and Vapours. Pergamon Press, New York.
30. Touey, G. P. and Mumpower, R. C. 1957. Measurement of the Combustion Zone Temperature of Cigarettes. Tob. Science 1:33-37.
31. Egerton, A., Gugan, K. and Weinberg, F. J. 1963. The Mechanism of Smouldering in Cigarettes. Combustion Flame 7:63-68.
32. Wynder, E. L. and Hoffmann, D. 1967. Tobacco and Tobacco Smoke. Academic Press, New York, p. 132.
33. Neurath, G., Ehmke, H. and Schneemann, H. 1966. Uber Den Wassergehalt Von Haupt-Und Nebenstromrauch. Beitrage Tabakforsch 3:351-357.
34. Wynder, E. L. and Hoffmann, D. 1967. Tobacco and Tobacco Smoke. Academic Press, New York. p. 119.

35. Mitchell, R. I. 1962. Controlled Measurement of Smoke-Particle Retention in the Respiratory Tract. Am. Rev. Respirat. Diseases 85:526-533.

36. Dalhamn, T., Edfors, M. and Rylander, R. 1968. Retention of Cigarette Smoke Components in Human Lungs. Arch. Environ. Health 17:746-748.

37. Boxhaven, C. and Niessen, H. J. 1962. Amounts of Oxides of Nitrogen and Carbon Monoxide in Cigarette Smoke, With and Without Inhalation. Nature (London) 192:458.

38. Ganong, W. F. 1967. Review of Medical Physiology. Lange Medical Publications, Los Angeles. p. 542.

39. Federal Trade Commission 1970. Statistical Supplement to Federal Trade Commission Report to Congress. Pursuant to the Public Health Cigarette Smoking Act. Federal Trade Commission, Washington, D. C., December 31.

☆U.S. GOVERNMENT PRINTING OFFICE: 1972–735–500/1