UC Irvine
UC Irvine Previously Published Works

Title
Physical characterization of incense aerosols

Permalink

Journal

ISSN

Authors
Mannix, Richard C
Nguyen, Khanh P
Tan, Eric W
et al.

Publication Date

DOI

Copyright Information

Peer reviewed

Physical characterization of incense aerosols

Richard C. Mannix, Khanh P. Nguyen, Eric W. Tan, Esther E. Ho,
Robert F. Phalen*

*Air Pollution Health Effects Laboratory, Department of Community and Environmental Medicine,
Center for Occupational and Environmental Health, University of California, Irvine, CA 92697-1825, USA*

Abstract

Experiments were performed to study the physical characteristics of smoke aerosols generated by burning three types of stick incense in a 4 m^3 clean room. Sidestream cigarette smoke was also examined under the same conditions to provide a comparison. Among the parameters measured were (a) masses of aerosol, carbon monoxide and nitrogen oxides generated by burning the incense or cigarettes, (b) rates of decay of the particles from the air, and (c) estimates of count median particle size during a 7 h period post-burning. There was variability among the types of incense studied with respect to many of the parameters. Also, as a general trend, the greater the initial particulate mass concentration, the more rapid the rate of decay of the smoke. In relation to the quantity of particulate generated, cigarette smoke was found to produce proportionally larger quantities of carbon monoxide and nitrogen oxides than did incense. Due to the fact that burning incense was found to generate large quantities of particulate (an average of greater than 45 mg/g burned, as opposed to about 10 mg/g burned for the cigarettes), it is likely, in cases in which incense is habitually burned in indoor settings, that such a practice would produce substantial airborne particulate concentrations. Copyright © 1996 Elsevier Science B.V.

Keywords: Aerosols; Carbon monoxide; Incense; Indoor air; Nitrogen oxides; Smoke

1. Introduction

Although incense has been burned for centuries, few studies have been performed to examine the physical characteristics of incense smoke.

In a study dealing with the exposure of humans to nitrogen dioxide (NO$_2$) gas, it was noted that incense burning represented a major source of NO$_2$ exposure for adults, but not for children [1]. In another study, it was determined that the emission of particulate produced by incensing was greater than that for tobacco smoking [2]. In a study of particles and carbon monoxide (CO)

---

* Corresponding author. Tel.: + 1 714 8245860; fax: + 1 714 8244763.

associated with burning incense and cigarettes, it was concluded that incense generated greater particulate mass, a larger count median particle diameter, a more persistent aerosol, and a greater ratio of particulate mass concentration to CO mass concentration, than did burning of research cigarettes [3]. Another study found that incense aerosol particles were spherical, had a count median diameter (CMD) of about 0.13 μm, and a density of 1.06 g/cm^3 [4]. It is known that incense emits various compounds, including aldehydes, both before and during burning [5]. A study using the bacterium *Salmonella typhimunium* concluded that incense has mutagenic activity, but it is weak when compared with that of other tested mutagens [6].

The goal of this study was to physically characterize the particulate-phase and some gas-phase compounds generated into the air of an enclosed 4 m^3 clean room by burning three types of incense. Among the parameters measured were (a) the peak particulate, CO and NO$_x$ (nitrogen oxides) mass concentrations, (b) the estimated aerosol particle size distribution, (c) the persistence in the air of the smoke, and (d) the particulate mass generated per gram of incense burned. The incense types studied were produced in three different countries: Thailand, the US, and Mexico. In addition, sidestream cigarette smoke (from research cigarettes) was tested in order to provide a comparison. The smokes were not chemically characterized, as the study was performed to examine physical characteristics of incense aerosols.

2. Materials and methods

2.1. Clean room

The materials were burned in a custom-manufactured (Hemco, Independence, MO) thermally-insulated, 4 m^3 clean room (Fig. 1) which had smooth washable walls and a sliding glass door. The room was fitted with inlet and outlet air filters (HEPA-type), and a small fan inside the room stirred the air.

2.2. General experimental plan

Twelve experiments were conducted (Table 1). In each experiment, the particulate mass concentration was monitored for 7 h; CO was monitored in five of the experiments in order to ascertain the average room air leakage rate, as well as to provide peak CO concentration data. The peak concentration of the oxides of nitrogen (NO$_x$), which is the sum of the nitric oxide (NO) and NO$_2$, was also measured. Particle size estimates using an optical particle counter were made about every 45 min. Each incense experiment was repeated.

Prior to burning the samples, several steps were performed (Fig. 2). A ring stand held the samples in the center of the room. Incense sticks (one to four) were placed upright on a metal stage. The cigarettes were compressed about 54 mm from their tips using two metal rods, and their tips were angled downward at 45 degrees. A human-hair hygrometer (AB 167B, Abbeon Cal., Santa Barbara, CA) and a small low-speed fan were attached to the ring stand. The fan was directed to blow towards a ceiling corner of the room (away from the incense or cigarettes) so that the air was
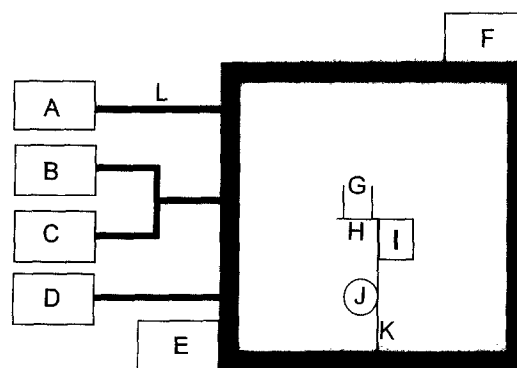

Fig. 1. Experimental setup for the incense study, depicting the experimental room enclosure with the (A) optical particle counter, (B) CO analyzer, (C) NO$_x$ analyzer, (D) real-time aerosol monitor, (E) inlet HEPA filter/blower unit, (F) outlet HEPA filter/blower unit, (G) stick incense or research cigarette samples, (H) sample support, (I) stirring fan, (J) hygrometer, (K) ring stand support, and (L) sampling lines. The ring stand was placed in the center of the room, and the samples were positioned midway between the floor and the ceiling.

Table 1
Summary of experiments performed, including samples burned and measurements made

Experiment	Sample	No. burned	Particle mass	Carbon monoxide	Oxides of nitrogen	Particle size
1	Type 1	2	X	X	X	
2	Type 2	2	X	X	X	
3ª	Type 1	2	X	X	X	X
4	Type 3	2	X	X	X	
5ᵇ	Type 1	2	X	X	X	X
6	Type 2	2	X	X	X	X
7	1R3 cigarettes	2	X	X	X	X
8	Type 3	2	X	X	X	X
9	Type 1	1	X	X	X	X
10	Type 2	4	X		X	X
11	Type 1	1	X		X	X
12	Type 2	4	X		X	X

X, measurement taken.
The stirring fan was on low speed setting, except as indicated.
ª Particle size data was obtained at a later date.
ᵇ The stirring fan was on high setting in this experiment.

stirred without directly affecting the rising plume of smoke. The surfaces of the room were previously cleaned to remove any residue from the previous experiment. Prior to the experiments, the fan was turned on, and the inlet air blower/filter unit was operated in order to allow HEPA-filtered air to purge the experimental room. Once the air in the room was cleaned sufficiently, the inlet air blower/filter unit was turned off and the inlet side was tightly covered to minimize the leakage of air into the room through the filter unit. The exit filter unit was sealed throughout. The incense or cigarettes were then lighted with a propane lighter (the oxygen and temperature profiles of the burning tips were not characterized). Of necessity, the door to the room was opened briefly during lighting; however, mass monitor readings demonstrated that negligible particulate mass entered the room from the outside. Immediately after the substances were lighted, the door was closed, and the door tracks were sealed. Particulate mass and CO concentration measurements were typically taken at 15 min intervals for 7 h. The nitrogen oxides concentration was measured once at either 15 min or at 30 min post-burning. For all sampling, several readings were recorded at each time point, and the means of these readings used. Particle size estimates, using an optical counter,

were collected every 30 min during the first several hours, and every 60 min thereafter.

2.3. Samples studied

The stick incense used in the study included: type 1, from Thailand; type 2, from the US; and type 3, from Mexico. The incense sticks differed in appearance (color, width, mass, length), and in fragrance. However, the three types were similar with respect to structural appearance (grainy, pressed material), friability, and packing density.

Research cigarettes (1R3, University of Kentucky, Lexington, KY) were burned in a separate experiment. The 1R3 is a relatively low-tar and low-aerosol-mass output cigarette, in comparison with other research cigarettes.

2.4. Particulate mass measurements

Particulate mass data were acquired using a real-time aerosol monitor (RAM-1, MIE, Bedford, MA), which has been employed by others in similar studies [4]. RAM-1 sampling was performed using flexible conductive tubing (Bev-A-Line XX Tubing, Cole Parmer, Chicago, IL). The RAM-1 detects concentrations of particles in the air from 0.001 up to 200 mg/m³. The data were

corrected on the basis of a calibration of the RAM-1 for each aerosol by performing gravimetric analyses. The data were graphed on log-linear paper to display the rate of decay; the half-times ($T_{1/2}$) of the aerosols were calculated using these data. The $T_{1/2}$ is the time required for half of the particulate mass to be removed from the air due to mechanisms such as settling to the floor, evaporation, and diffusion to surfaces. Only data after 255 min post-burning were included in the $T_{1/2}$ analysis, since this was the earliest time-point at which all of the decay curves appeared to exhibit single exponential decay behavior. The $T_{1/2}$ values thus represented the half-times of the late phase of decay, and were independent of extremely high, unstable initial particle concentration phenomena which complicate the behavior of the aerosols soon after their generation. Data were entered into a linear regression program to obtain the

WASH HEMCO
ROOM & PURGE
WITH CLEAN AIR

PLACE SAMPLES
IN ROOM & COVER
INLET FILTER

LIGHT SAMPLES
& SEAL DOOR

TAKE DATA
AFTER SAMPLES
BURN OUT

Fig. 2. Sequence of events for a single experiment.

slope of decay, which was then converted into the half-time: ($T_{1/2}$ = ln 2/slope of decay).

2.5. CO measurements

A calibrated Dasibi CO Analyzer (Model 3003, Dasibi Environmental, Glendale, CA) measured the CO concentration. The data collected were analyzed by log-linear regression analysis to obtain the rate of air leakage from/into the room. In addition, the maximum CO concentration readings provided the quantities of this pollutant gas which were generated.

2.6. NO_x measurements

NO_x measurements were taken using a calibrated Beckman $NO/NO_2/NO_x$ Analyzer (Model 952A, Beckman Instruments, Fullerton, CA) sampling through fluorocarbon tubing. NO_x (NO and NO_2) concentrations were measured to quantify the total NO_x generated.

2.7. Particle size measurements

To estimate the particle size distribution, the smoke was diluted so that it would not overwhelm the optical particle counter (OPC) (Cl-7602-81233, Climet Instruments, Redlands, CA). This instrument has a size range of 0.1–5.0 μm in diameter (in 5 particle-size intervals), so particles below 0.1 μm were not detectable, which may lead to overestimates of the count median particle sizes. Before each measurement, a 2 l flask was purged with filtered air and a background particle count was acquired. During sampling, makeup air was pulled by the vacuum in the flask (created by the sampling) through a high-efficiency particle filter. Thus, near-atmospheric pressure was maintained in the flask without permitting particles from outside of the flask from entering. Then, either 10 or 20 cm^3 of smoke was extracted from the experimental room with a 60 cm^3 plastic syringe (large enough in diameter to permit less than 2% estimated losses of 0.2 μm diameter particles due to sedimentation and diffusion) and was quickly injected into the flask. The OPC then was permitted to go through at least four sam-
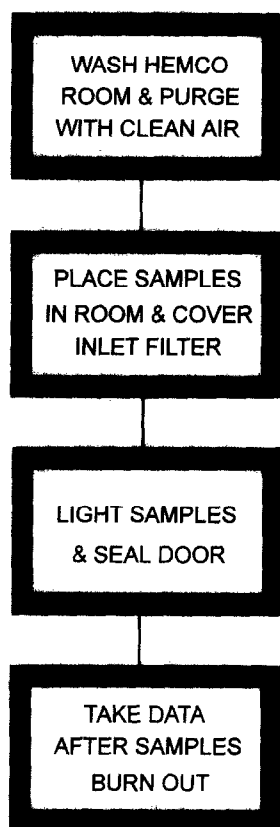
pling sequences and two sequences were selected for analysis. Selection criteria included absence of an overload indication, and sufficient counts. After particle size data from the OPC were reduced, the data were input into a log-probability computer program to estimate the CMD and geometric standard deviation (GSD).

The response of the OPC is a function of the index of refraction of the particulate media [7]. Thus, the true CMDs may differ somewhat from the values recorded here. However, the average CMD value obtained in this study for cigarette smoke is similar to those measured by others using alternative means [8].

2.8. Correction of RAM-1 data

It is known that the RAM-1 has limitations which could affect its accuracy. For example, the instrument was factory-calibrated using Arizona road dust, and the response of the instrument exhibits a particle size dependence, but the dependence is much less pronounced for polydisperse aerosols than it is for monodisperse aerosols [9]. In addition, since the incense smoke could change during the course of the studies due to the transfer of volatile components, particle coagulation, etc., there was concern that the RAM-1 would provide artifactual data as the smoke aged. Therefore, studies were performed in which the RAM-1 output was compared with results obtained using a gravimetric analysis in order to provide a means of correcting the RAM-1 data, and to make sure that the correction factor was relatively constant during a study. Others have reported a RAM-1 correction for incense smoke [4].

In separate experiments, two incense sticks of each type were burned as already described. Two 1R3 research cigarettes were burned in an experiment performed to calibrate the RAM-1 for sidestream cigarette smoke. Immediately after sampling, the filters were weighed using an electrobalance (Cahn Model 29; Cerritos, CA). Due to the brief (about 3 min) interval between the end of sampling and the weighing, and the similarity of the humidity in the laboratory and the clean room, no correction was needed for evaporative changes. After the gravimetric mass concentrations were determined, the RAM-1 correction factors were calculated ([gravimetric mass concentration]/[RAM-1 mass concentration]).

3. Results

3.1. Clean room air leakage rate

Analyses of the CO data indicated that the leakage turnover rate was relatively consistent for all studies (mean CO leakage half-time = 1061 min; S.E. = 42 min). The leakage half-time was generally large in comparison with the decay half-times of the incense and cigarette smoke aerosols. Therefore, it was disregarded in the smoke decay rate analyses.

The average temperature during an experiment was generally 26–28°C. The relative humidity was initially (at the time of the burning of the material) between 80 and 85%; during the course of each study, the humidity gradually decreased about 5% as the ambient temperature increased.

3.2. Particulate mass concentration and particle size results

The decay curves are shown in Fig. 3. In general (for type 2 incense, type 3 incense, and the cigarettes), the measured mass concentration rose following the end of the burning, and then declined in a manner fit well by a single exponential function. However, during all four experiments in which type 1 incense was burned, the mass concentration fell immediately post-burnout, and the decay curves exhibited a two-component nature. The data which made up the second component of these curves could be adequately fit to a single exponential function. The reason(s) for this reproducible, but anomalous, behavior is presently unknown, but possible explanations will be given in the Section 4.

A general observation which can be made is that, across incense types, the greater the particulate mass concentration was at 255 min post-burnout, the shorter the half-time (Table 2, Fig. 4).
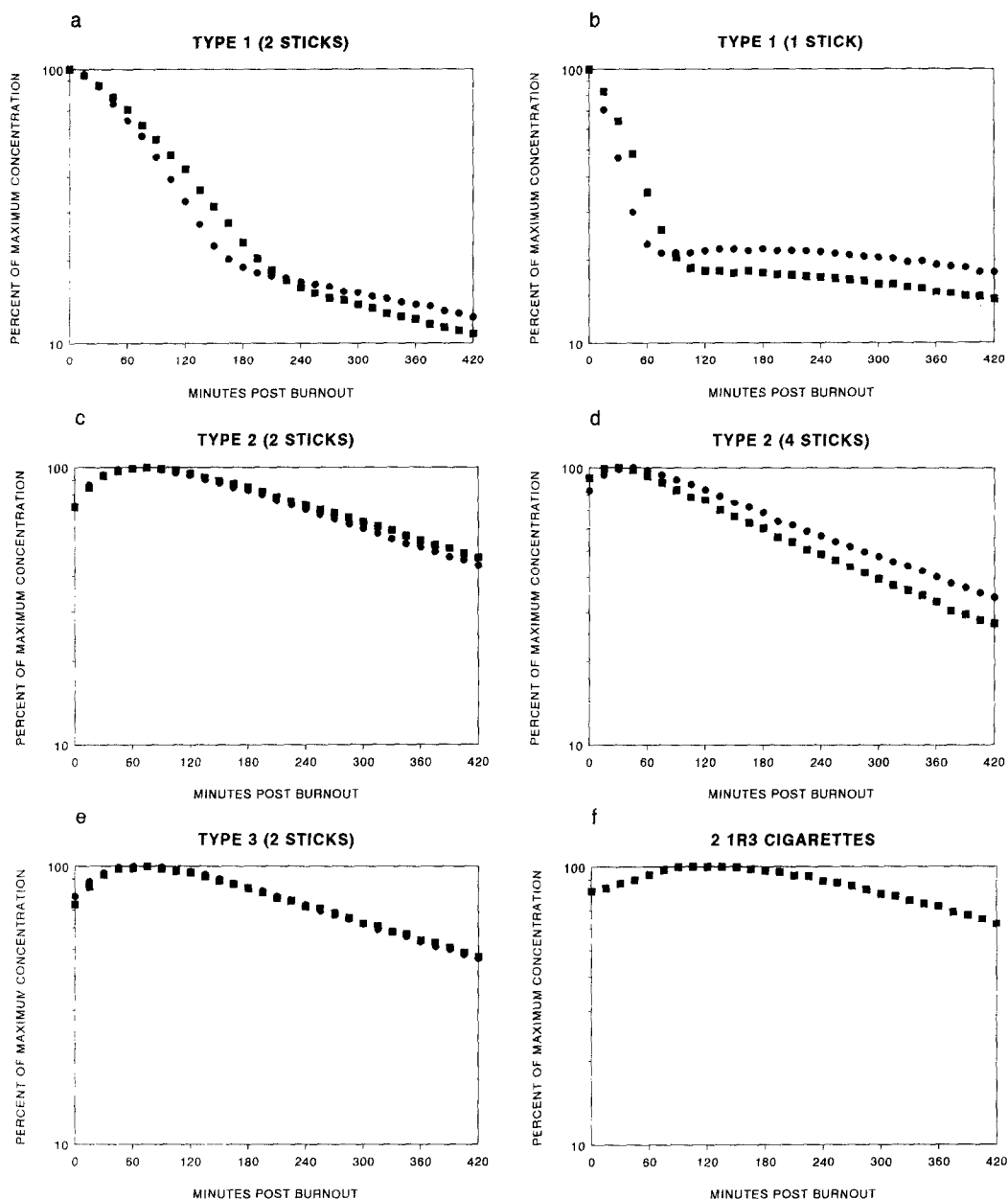
Fig. 3. Smoke decay curves representing the smoke mass concentration in the experimental room vs. the time post-burning. Depicted in the figure are the six experimental conditions studied; note that each incense study was repeated: (a) two sticks of type 1 incense; (b) one stick of type 1 incense; (c) two sticks of type 2 incense; (d) four sticks of type 2 incense; (e) two sticks of type 3 incense; (f) two 1R3 cigarettes.

The RAM-1 correction factors determined using the gravimetric analysis were: type 1, 0.25; type 2, 0.21; type 3, 0.22; cigarettes, 0.19. The values of these factors did not vary with time for each type of incense (S.E. < 0.02 in all cases), indicating that dynamic changes which could produce artifactual RAM-1 readings were negligible.

Table 2
Summary of average smoke decay half-times, average count median diameters, and average geometric standard deviations for each experimental condition

Sample	No. burned	Particle half-time (min)	Count median diameter (μm)	Average geometric S.D.
Type 1[a]	2	374 ± 59	0.25	1.4
Type 1[b]	2	354	0.32	2.0
Type 1	1	688 ± 68	0.30	1.7
Type 2	2	274 ± 8	0.37	1.9
Type 2	4	228 ± 20	0.42	1.9
Type 3	2	284 ± 0	0.42	1.8
1R3 cigarettes	2	340	0.34	1.8

Average of two experiments, when repeated; S.D. are given, when appropriate.
[a] Particle size data was redone at a later date.
[b] The stirring fan was on high setting in this experiment.

3.3. Peak particulate and gas concentrations

The correlation between the mass of material (incense or cigarettes) burned and the mass of particulate generated is shown in Fig. 5; the peak gas concentrations are displayed in Table 3. The data indicate that the greater the mass of material burned, the greater the particulate mass that is generated (for example, the grams burned/particulate mass regression analysis yielded a correlation coefficient of 0.996 for type 1). Per gram burned, incense generated substantially more aerosol particulate mass; using peak concentrations, the average incense particulate mass was 45.6 mg/g burned, as opposed to about 10 mg/g burned for the cigarettes. Similarly, the greater the mass of

material burned, the greater are the quantities of CO and NO_x produced. It is interesting to note that the ratios of the peak particulate concentration (in mg/m$_3$) to the peak CO and NO_x concentrations (also expressed in units of mg/m$_3$) are greater for all three types of incense than for the research cigarettes. For each of the three types of incense studied, approximately 2–3% of the NO_x was NO_2. In contrast, for cigarettes, about 9% of the NO_x was NO_2, with the remainder being NO.

4. Discussion and conclusions

It is apparent that there is variability among types of incense with regards to shape and slope
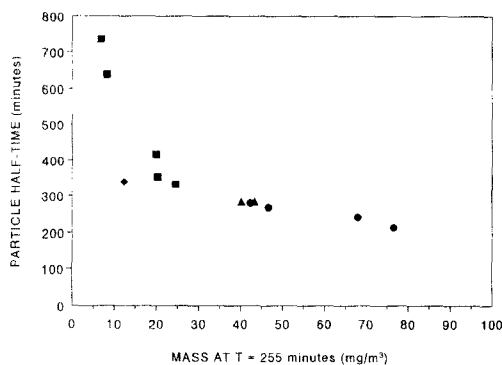

Fig. 4. The relationship between the smoke mass concentration at the beginning of the exponentially-declining phase of the decay curves and the calculated smoke decay half-times; type 1, ■; type 2, ●; type 3, ▲; 1R3 cigarettes, ◆.
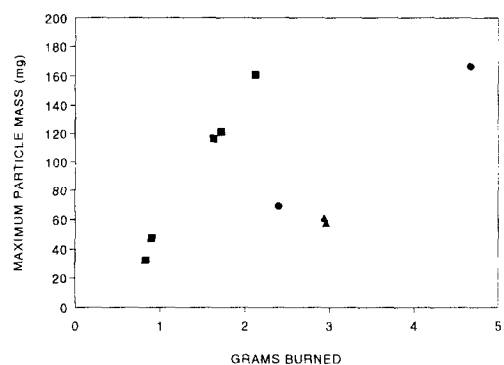

Fig. 5. Particulate mass generated into the air vs. the original mass of incense burned. The particulate mass values are the corrected (by gravimetric analysis) RAM-1 readings: type 1, ■; type 2, ●; type 3, ▲.

Table 3
Yields of particulates and selected gases generated by burning incense or cigarettes

Sample	Number burned	Peak particle concentration[b] (mg/m³)	Peak carbon monoxide (mg/m³)	Peak oxides of nitrogen (mg/m³)	Grams burned (g)	PTC/CO[c]	PTC/NO$_x$[d]
Type 1	2	35.2 ± 7.1	65.5 ± 11.3	1.9 ± 0.1	1.92 ± 0.28	0.54	18.5
Type 1[a]	2	29.1	55.5	2.0	1.63	0.52	14.9
Type 1	1	10.0 ± 2.7	26.0[e]	0.7 ± 0.0	0.87 ± 0.05	0.46[e]	13.8
Type 2	2	16.1 ± 1.6	71.5 ± 20.5	1.9 ± 0.1	2.40[e]	0.23	8.5
Type 2	4	36.6 ± 7.1	—	2.8 ± 0.7	4.67[e]	—	13.1
Type 3	2	14.9 ± 0.6	54.5 ± 7.5	1.2 ± 0.4	2.95 ± 0.01	0.27	12.4
1R3 cigarettes	2	3.5	33.8	2.2	1.35	0.10	1.6

When experiments were repeated, the data from the two experiments were averaged, and S.D. calculated, for this table.
—, no measurement taken.
[a] The stirring fan was on high setting in this experiment.
[b] Corrected (by gravimetric analysis) RAM-1 readings.
[c] Ratio of peak particulate mass concentration to peak carbon monoxide concentration.
[d] Ratio of peak particulate mass concentration to peak oxides of nitrogen concentration.
[e] Value from one of two experiments.

of the smoke decay curves, the quantity of particulate generated by burning, the quantities of the CO and NO_x generated, and the estimated median particle size of the smoke aerosols. Type 1 differs uniquely from types 2 and 3 in most of these respects. The two-component nature of the type 1 decay curves suggests two distinct particle removal phenomena, or the initial presence of two distinct populations of particles. It is interesting to note that the persistence half-time of the early component for the case in which one stick of type 1 was burned was about 50 min, while when two sticks were burned it was about 100 min. Type 1 was probably composed of ingredients which generated a two-phase aerosol with regards to some parameter which affected the persistence or the output of the RAM-1 (index of refraction, particle size, particle density, etc.).

An apparent increase in the aerosol mass concentration after cessation of burning was evident for types 2 and 3 and for the cigarettes. Explanations for this phenomenon include particle coagulation (which is proportional to the square of the number of particles/cm³), which could produce an artifactual early increase in the mass concentration, and the outgassing of volatile components. The selection of 255 min post-burning as the standardized initial point for the calculation of decay constants was made because type 1 smoke was anomalous. The mass concentration of the cigarette smoke also started its exponential descent at around 240 min. There appeared to be an inverse relationship between the mass concentration reading at 255 min and the calculated decay half-time $T_{1/2}$. Thus, the denser the smoke aerosol at 255 post-burning, the less persistent the smoke aerosol.

There are many factors which influence the decay of the smoke, including sedimentation to the floor, diffusion to room surfaces, impaction on the fan, particle agglomeration, loss of particle mass due to evolution of volatile components, and gain of particle mass due to condensation of volatile components. In addition, initially there may be regions of the room with sufficiently high particle densities such that pronounced hydrodynamic interactions and cloud (bulk) settling occurred [10–12]. Modeling a aerosol decay system

of this complexity is beyond the scope of this project, but all of the above mechanisms may have been contributory to the observed decay phenomena.

The decay curve for the cigarette smoke was similar in shape to those obtained for types 2 and 3 incense, but not type 1 incense. The estimated CMD measured during the cigarette smoke experiment was not greatly different from those measured during the incense smoke experiments. However, the burning of two cigarettes generated considerably less particulate into the air per gram of material burned, and proportionally greater quantities of CO and NO_x (in relation to the particulate generated), than did the burning of the incense. Therefore, burning of incense in indoor environments has greater potential for contaminating the air with particulate matter.

It is difficult to compare our results with those obtained by others, because the literature is scant. However, as mentioned earlier, a study is reported in which the particulate output per gram of material burned was determined for both an unspecified type of incense and an unspecified type of cigarette [2]. The values reported (2 mg/g for incense, 1.2 mg/g for cigarette smoke) are less than the values observed in this study (Fig. 5). A study in which Chinese joss sticks were burned inside of a 36.7 m³ furnished room determined that (a) the CMD of the generated incense aerosol was on the order of 0.13–0.14 μm, (b) that the decay of the incense smoke could be adequately fit by a single exponential function (if room leakage is disregarded), and (c) the correction factor for their RAM-1 collected data was 0.256 [4]. Another study in which joss stick smoke was characterized yielded a CMD measurement on the order of 0.07 μm [13]. These results, except for the CMD values, are similar to ours. Possible explanations for this discrepancy in CMD results are (a) different types of incense burned, (b) the use of a much larger room in the case of one study, with a decreased likelihood of particle agglomeration due to particle-particle interactions, and (c) differences in the ambient relative humidity (conditions for hygroscopic particle growth were favorable at the high relative humidities which existed during the present study). The general

shapes of our smoke decay curves (except for type 1) are similar to those found by others [3,4].

Since the average CMDs estimated for the various types of incense and sidestream cigarette smoke ranged from 0.24 to 0.40 μm, it is expected that deposition efficiencies of these aerosols in the human respiratory tract would be similar. The deposition efficiency of 0.37 μm particles (the average CMD for type 3 incense) at a tidal volume of 750 cm^3/breath (representative of a low rate of physical activity) was estimated using the proposed National Council on Radiation Protection (NCRP) deposition model [14]. A total of 18% of the 0.37 μm particles is predicted to deposit in the respiratory tract: 3.5% in the nasopharyngeal region, 3.5% in the tracheobronchial region, and 11% in the pulmonary region. Thus, since incense burning generates a large amount of particles, over an extended period of time (e.g. years of incense use) habitual incense use increases the exposure to respirable-size particles. However, the literature does not supply epidemiological links with respiratory disease and incense use.

While no chemical characterization of compounds present in the particulate phase was performed, it is clear that only after such a characterization is completed can the potential risks associated with inhalation of incense smoke be properly estimated. In addition, only three types of incense were studied, so other types could differ with respect to the parameters studied. The experimental room used was small with minimal ventilation, no furniture, and with no warm bodies present. In actual human exposure scenarios, the conditions would be different.

References

[1] Koo, L.C., J.H.-C. Ho, C.-Y. Ho, et al. Personal exposure to nitrogen dioxide and its association with respiratory illnesses in Hong Kong. Am. Rev. Respir. Dis., 141 (1990) 1119–1126.
[2] Yuan, C.S. and C.M. Chen. Characterization and dispersion of particulate matter emitted from tobacco smoking, incensing, and mosquito incensing in a control environment. J. Aerosol Sci., 26 (1995) 163 (abstract).
[3] Nguyen, K.P., R.F. Phalen and R.C. Mannix. Particle characteristics and carbon monoxide concentrations associated with burning incense and cigarettes. Air Pollution Health Effects Laboratory Report No. 95-02. Community and Environmental Medicine, University of California, Irvine, CA, 1995.
[4] Cheng, Y.S., W.E. Bechtold, C.C. Yu and I.F. Hung. Incense smoke: Characterization and dynamics in indoor environments. Aerosol Sci. Technol., 23 (1995) 271–281.
[5] Madany, I. and D. Crump. The burning of incense as an indoor source of volatile organic compounds. Indoor Environ., 3 (1994) 292–298.
[6] Rasmussen, R.E. Mutagenic activity of incense smoke in salmonella typhimurium. Bull. Environ. Contam. Toxicol., 38 (1987) 827–833.
[7] Ho, A.T. and K.A. Bell. Experimental studies of the response of an optical counter to dry and liquid particles of different shape and refractive index. J. Aerosol Sci., 12 (1981) 239–246.
[8] Davies, C.N. Cigarette smoke: generation and properties of the aerosol. J. Aerosol Sci., 19 (1988) 463–469.
[9] MIE, Inc. Particle size dependence of MIE dust/smoke monitors. Bedford, MA, Technical Note No. 2, March 1990.
[10] Phalen, R.F., M.J. Oldham, R.C. Mannix and G.M. Schum. Cigarette smoke deposition in the tracheobronchial tree: evidence for colligative effects. Aerosol Sci. Technol., 20 (1994) 215–226.
[11] Fuchs, N.A. The Mechanics of Aerosols. Pergamon, New York, 1964, p. 47–51.
[12] Hinds, W.C. Aerosol Technology: Properties, Behavior and Measurement of Airborne Particles. Wiley, New York, 1982, p. 347–353.
[13] Lin, W.H., C.S. Li and F.T. Jeng. Field characterization of particle emissions from indoor combustion sources. Eleventh Annual Meeting of the American Association for Aerosol Research, San Francisco, CA, Abstract No. 1P01, October 12–16, 1992.
[14] Yeh, H.C., R.G. Cuddihy, G.L. Fisher, et al. The proposed NCRP respiratory tract model. Proc. 1st Symp. on Pollution and Health Effects of Aerosols, Taipei, Taiwan, Republic of China, September 10–12, 1991.