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ENVIRONMENTAL TOBACCO SMOKE IN COMMERCIAL AIRCRAFT

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Environmental tobacco smoke and other pollutants present in both smoking and nonsmoking cabin sections during commercial passenger flights on DC-10 aircraft were determined on four, 4 to 5 hour smoking flights. The concentrations of nicotine, 3-ethenylpyridine, CO, NO_x, RSP and UV-PM (environmental tobacco smoke particles) and other pollutants were determined with a briefcase sampling system. The data from the four flights allow the development of a model to predict the penetration of environmental tobacco smoke from the smoking to the nonsmoking section of the passenger cabin under a variety of flight conditions.

INTRODUCTION

In recent years there has been an increased emphasis in determining the concentrations of environmental tobacco smoke (ETS) in various indoor environments because of the suspected health hazards associated with exposure. Several studies have determined the concentration of ETS components present in commercial aircraft cabins. Data have been reported on the concentrations of nicotine present in the cabin environment in a number of commercial aircraft flights (1-5). Oldaker et al. (4) have reported the determination of the concentrations of nicotine, RSP and UV-PM on several long commercial flights using a portable air sampling system. A similar sampling system was used to determine the concentrations of nicotine, CO and RSP at four locations in the passenger cabin of flights on MD-80 aircraft (5). The latter two studies are the only studies reported to date which have attempted to correlate the concentrations of nicotine in the passenger cabin of commercial aircraft with the concentrations of other constituents of environmental tobacco smoke.

A study has been conducted to measure a variety of compounds associated with ETS as well as several non-unique species (such as RSP and CO) in both smoking and nonsmoking sections of aircraft cabins. The spectrum of species and aircraft sampled is intended to provide a data base for the development of models for the prediction of ETS concentrations in aircraft cabins under a variety of conditions. This paper presents the results obtained from a series of DC-10 flights.

METHODS

Sampling Equipment and Analysis Methods

Data on the aircraft were collected by four volunteers using Briefcase Automated Sampling Systems (BASS) (6). The inlet to the BASS was a Teflon tube

located at about breathing height and fastened to the seat in front of the subject. The tube led to the BASS located under the seat in front of the subject. A complete description of the sampling systems used in the BASS has been given (6). A brief description of each system used to determine the concentrations of the species reported in this paper follows:

System 1. A 3 micron Teflon membrane filter (Teflo, Gelman Sciences) was used to collect <2.5μm particles for the gravimetric determination of particle concentrations. Air was drawn through the system at a rate of 8 sLpm.

System 2. Two mini-annular denuder sections coated with benzenesulfonic acid (BSA) for collection of gas phase nicotine and 3-ethenylpyridine were followed by a 1 micron Teflon filter (Zefluor, Gelman Sciences) for collection and determination of nicotine and UV-PM. Following the Teflon filter was a BSA saturated filter for the collection of any nicotine lost from particles during sampling. Air was drawn through the system at a rate of 2 sLpm.

All species collected in system 2 were extracted with water and analyzed by ion chromatography for nicotine and 3-ethenylpyridine (7) with the exception of the Teflon filter. The Teflon filter was extracted with methanol, with half of the extract analyzed for UV absorbance using a spectrophotometer to determine UV-PM (4,8), and the other half analyzed for nicotine by ion chromatography (7).

System 3. A series of sorbent tubes (Drager) sampled various gas phase compounds found in ETS and associated with human respiration. Concentrations are given for CO and NO_x. Air was drawn through each tube at 200 mL/min. Concentrations were read directly from each tube following each flight.

Sampling Protocol

Four volunteer non-smokers participated in four DC-10 flights. Each subject was seated in the rear passenger cabin which contained the economy class smoking section at the back of the aircraft as given in Table I. All flights were about 4 1/2 hours in length. Flights 1 and 3 and flights 2 and 4 were the same origination and destination, however, a different aircraft was flown for each flight. Smoking activity during each flight was observed and recorded by the subject(s) in the smoking section and cigarette ends were counted after each flight.

RESULTS AND DISCUSSION

The concentrations of the various species reported in this paper for samples collected in the smoking section during the four DC-10 flights are given in Table II. The variation of the concentrations of the species measured with seat location in flights with a high and moderate concentration of environmental tobacco smoke is given in Figure 1. Complete data for the four flights are available (9).

The flight-integrated concentrations of environmental tobacco smoke species in the smoking section were directly dependent on the number of cigarettes smoked per seat in the smoking section, Table II. The concentrations of nicotine and mass for the flight with 2.7 cigarettes smoked/seat appear to be outliers. From regression analysis of the data in Table II, ratios of UV-PM mass and nicotine to CO present in the environmental tobacco smoke in the smoking sections are calculated to be 4.0±0.1 g mass/mol CO and 5.6±0.7 mmol nicotine/mol CO. These ratios are comparable to and smaller than the expected ratios of 4.2±0.8 g mass/mol CO and 12.8±4.0 mmol nicotine/mol CO (10,11), respectively. The expected absolute concentrations of these species may be estimated from the known number of cigarettes smoked, expected sidestream emission per cigarette smoked (11), volume of the smoking

section and air exchange rate in the cabin. For example, for Flight 3, the flight with the highest smoking frequency and the observed highest concentrations of environmental tobacco smoke constituents, the expected flight-integrated concentrations of nicotine, mass, and CO in the smoking section are calculated to be 840±200 nmol nicotine/m^3, 300±75 μg mass/m^3 and 1.6±0.4 ppm CO, respectively. The measured concentrations of mass and CO, Table II, are in reasonable agreement with the calculated concentrations. However, the measured concentration of nicotine is about half the predicted concentration. All of these data are consistent with the expected rapid removal of nicotine in an indoor environment (10,11). For example, in studies in the chamber at the U.S. Environmental Protection Agency (12) the ratio of RSP to nicotine in environmental tobacco smoke in the empty chamber was 3.0 g RSP/g nicotine, a ratio consistent with the value obtained for sidestream smoke and in inert chambers (11). When the chamber had people in it with a small air exchange rate, the measured ratio was 13 g RSP/g nicotine. The ratio measured in the smoking section of the aircraft cabin with a high air exchange rate, 4.9±0.8 g RSP/g nicotine, is between these two values.

Ventilation in a DC-10 (13) is controlled by three air cycle machines which introduce fresh air equally along the length of the cabin. The air is then exhausted at the same longitudinal distance that it was introduced with no air recirculation. Penetration of environmental tobacco smoke constituents from the smoking into the nonsmoking section of the aircraft will be controlled by the rate of mixing of air along the length of the aircraft perpendicular to the exhaust gradient. This process should be first order and a plot of the log of the concentration of a species versus distance from the smoking section should be linear. If there are other sources of any of the measured environmental tobacco smoke constituents other than in the smoking section, the plot will show a positive deviation from the expected linearity with distance, e.g. a more positive slope. First order penetration plots for the various species measured in Flights 3 and 4 are shown in Figure 1. Similar results were obtained for the other flights. The data follow the expected linear decrease in the log of the concentration (normalized to the concentration measured in the smoking section). The data fall into three groups:

1. The nicotine concentration decreases most rapidly with distance. Nicotine in the cabin environment is predominantly, >98%, in the gas phase. The rapid decrease in gas phase nicotine with distance from the smoking section parallels the concentration of nicotine in the smoking section being less than expected compared to other constituents of environmental tobacco smoke and can be attributed to the more rapid removal of gas phase nicotine by surfaces in the cabin (11,14). This effect is more pronounced for Flight 4. The flight with the lower concentration of environmental tobacco smoke due to less smoking during the flight, Figure 1.

2. The compounds with an intermediate rate of concentration decrease with distance into the smoking section are UV-PM, 3-ethenylpyridine and, for Flight 3 with high concentrations of environmental tobacco smoke, CO.

3. The data for RSP and NO_x in both flights and for CO in Flight 4 with lower concentrations of environmental tobacco smoke give more positive slopes, Figure 1. This suggests that RSP, NO_x and CO can be produced by other sources in the aircraft, e.g. the inlet air. The data from all the flights suggest an average background, non-ETS RSP concentration of about 20-30 $\mu g/m^3$ in the cabin environment. The flights with the highest concentrations of non-ETS CO and NO_x were Flights 2 and 4, the flights with measurable concentrations of ozone in the nonsmoking sections of the aircraft.

The slopes of the various $\log(C/C_o)$ versus distance from the smoking section plots, Figure 1, are a measure of the degree of penetration of ETS

constituents into the nonsmoking section. The slope of this line based on the UV-PM, 3-ethenylpyridine and CO (corrected for background) data is 0.17±0.05, 0.18±0.05, 0.18±0.03 and 0.09±0.02 /row for Flights 1 - 4, respectively. The variation in the ETS concentration for each flight is shown in Figure 2. For all flights where data were available, the rate of penetration of UV-PM, 3-ethenylpyridine and/or CO were the same. The rate of penetration of ETS into the nonsmoking section is comparable for Flights 1, 2, and 3 and about a factor of two faster for Flight 4, e.g. see Figure 2. Relative humidity data collected during the flight show that the ventilation rate on this flight was less than expected. Presumably, the more rapid penetration of environmental tobacco smoke into the nonsmoking section during Flight 4 was due to the lower ventilation rate during that flight. The rate of decrease in $\log(C/C_o)$ for nicotine was greater than the rate of decrease for UV-PM, 3-ethenylpyridine, and/or CO for all flights by a factor of from 1.3 to 2.3. The selective removal of nicotine by the surfaces in the cabin appears to increase with decreasing total smoking and increasing passenger load in the nonsmoking section.

SUMMARY

The concentration of most environmental tobacco smoke constituents in the smoking section of an aircraft cabin can be calculated from the frequency of smoking during a flight, the size of the smoking section and ventilation rate. The rate of penetration of environmental tobacco smoke constituents from the smoking section into the nonsmoking section follows a first order mechanism. The rate of penetration appears to be constant at constant ventilation rates for the various DC-10 aircraft flown in this study. The expected rate of decrease in the concentration of various constituents with distance into the nonsmoking section can be altered by selective removal of compounds by cabin surfaces (e.g. nicotine) or by the presence of non-ETS sources of some species in the nonsmoking section (e.g. CO, RSP or NO_x). Additional data are needed to determine what variables control the magnitude of the first order penetration of environmental tobacco smoke constituents from the smoking to the nonsmoking sections of a variety of aircraft.

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Table I. Location of the Various Persons Responsible for Collection of Samples on Each Flight.

Flight No.	Smoking Section	# of Cigarettes Smoked During Flight	Subject	Seat
1	Rows 33-37	115	I	35 D
			II	17 D
			III	34 G
			IV	32 J
2	Rows 34-37	32	I	33 A
			II	24 C
			III	33 C
			IV	34 C
3	Rows 32-37	218	I	30 D
			II	31 F
			III	26 F
			IV	32 F
4	Rows 34-37	76	I	35 D
			II	29 C
			III	33 D
			IV	24 F

Table II. Concentrations of Environmental Tobacco Smoke Constituents in the Smoking Section of DC-10 Cabins During a 4-5 Hour Flight.

Flight	Cigarettes smoked/ seat	UV-PM $\mu g/m^3$	RSP $\mu g/m^3$	Nicotine $nmol/m^3$	3-Ethenyl pyridine $nmol/m^3$	CO, ppm	NO_x, ppb
1	3.19	NA[a]	203	285	22	0.89	28
2	0.89	NA	75	84	1.3	0.21	7
3	4.84	360	NA	475	21	2.2	40
4	2.71	62	75	71	3.3	1.1	27

[a]NA-not analyzed

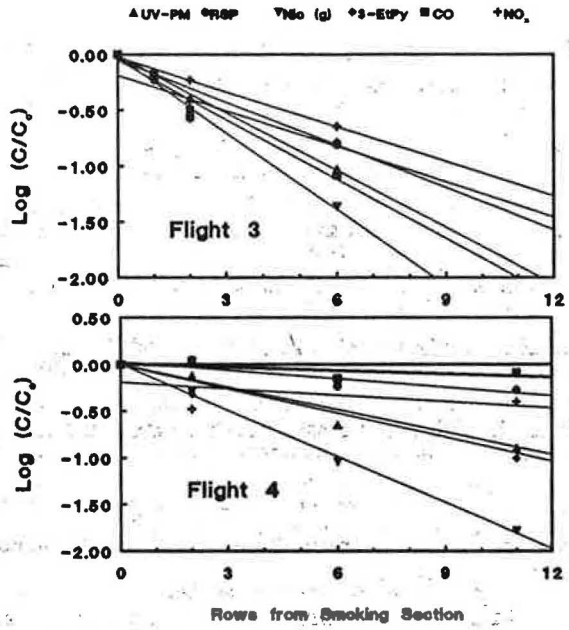

Figure 1 The log(C/Co), where Co is the concentration in the smoking section, versus number of rows from the nonsmoking section into the smoking section for Flights 3 and 4.

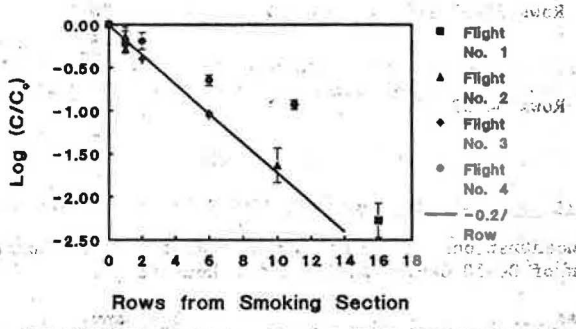

Figure 2 The log(C/Co), where Co is the concentration of ETS in the smoking section, versus number of rows from the nonsmoking section into the smoking section for ETS for all flights