TECHNICAL NOTE

Environmental Tobacco Smoke (ETS) in Airliners—A Health Hazard Evaluation

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Some passengers and **airline attendants have expressed concern about exposure** to **environmental** tobacco **smoke** (ETS) in **commercial airlines. Irritation** of tho **eyes** ond **respiratory** tract, odor, and **personal sensitivities** a n **often** tho **bases** of complaints. **Previous** studies **demonstrate** low **concentrations** of **materials,** including **ETS. Attendants fly some 800** h **per year, passengers much less. Based** on **previous** studios and duration of **exposures. The absorbed dose** of **ETS** is **less** than a **cigarette equivalent per year. Nicotine** absorption of 0.2 to 0.3 **mg** in **8–10** h **flights** has **been reported** as **unlikely** to **have physiologic effects.** Tho **retained 'dose'** in **relation** to tho **hypotheses** of **risks** to **health** bawd on tho conflicting **results** of studios on **'passive smoking' are discussed. There** are additional confounding foe- in aircraft. **We consider segregation** into smoking and nonsmoking **zones** to bo **reasonably effective** In mooting tho **preferences of passengers.**

THE LAST 50 YEARS have seen a vast increase in the development of airlines in numbers and qualities, an even greater increase in the number of passengers on a worldwide basis, and an increased number of passengers per aircraft. Relatively recently, jet aircraft have largely superseded piston-engined aircraft. The evolution of long range wide-bodied airliners is another recent development. These developments have taxed the engineering skills of aircraft manufacturers to provide an adequate cabin environment for both passengers and flight attendants. McFarland (12) in *1946* provided the first insight into cabin environmental conditions.

Passenger conditions may reasonably be related to the few standards produced by the U.S. Environmental Protection Agency (EPA) and the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). Flight attendants may be reasonably subject to the U.S. Occupational Safety and Health Administration standards where such are relevant. Clearly, if acceptable conditions are produced for passengers, then the flight attendants will be exposed to similar conditions and will differ from passengers in only a few respects:

a. They are exposed for more hours per year.
b. They are a selected group of workers (unlike passengers) who are healthy when first employed. They must pass physical examinations on first employment. After subsequent episodes of substantial illness or suspected incapacity, a fitness for duty evaluation may be required.

Earlier reviews of cabin air quality include those by Crawford (1) and Holcomb *(5).* The trend of separating airliners into smoking and nonsmoking zones has been reasonably effective in meeting the preferences of passengers. However, some passengers have strongly complained of ETS in the areas adjacent to the smoking sections and some cabin staff working in the smoking section have expressed annoyance and concern for their health and the maintenance of their healthy status. Prohibition of smoking is in effect in the continental USA. Canada and Australia and some intra-European flights. The justification for such actions has not been based on scientific air quality monitoring, but on the interpretations of the results of certain epidemiologic studies; e.g., International Agency For Research on Cancer 1987 (6), National Research Council (17).

This paper describes the results of recent international studies and discusses the hypothetical threats to the health of passengers and flight attendants. We will note that the scientific data on which decisions have been made is, at best, meager, and medical and epidemiologic data on passengers and flight crew appear to be nonexistent.

Health Factors Impacted by Air Quality?

Passengers and flight attendants have complained about eye irritation, headaches, nose and throat irrita-

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tion and breathing discomfort. Crawford (1) and Holcomb *(5)* have reviewed the literature and reported a variety of factors that may alone or in combination cause these complaints. These factors are low humidity, ozone, ETS, contact lenses, reduced oxygen pressure and chemicals such **as** NO_2, aldehydes and polycyclic aromatic hydrocarbons. Events such **as** fires initiated by smoking passengers are rare, but do occur, and the use of fire resistant or firesafe materials is standard practice in modem airliners (2).

Weber (22) reported on the irritative effects **on** eyes of those exposed to relatively high concentrations of ETS. Using CO as a surrogate, they postulated a tentative threshold limit value of ETS-generated CO of 1.7–**2.3** mg CO/m^3. As discussed in greater detail later, recent studies by Malmfors (10) and Geomet Technologies, Inc. **(4)** show monitored levels in a range of 0.8–1.1 ppm.

Lategola *et al.* (7) reported eye discomfort as the most frequent ozone symptom in conditions simulating flight conditions. In descending order they reported headache, nasal irritation and throat irritation.

At values less than 40% relative humidity, symptoms include dry mucous membranes and irritated eyes. All fight reports summarized by Crawford (1) and Holcomb (5), as well as the newer reports reviewed, give relative humidity values ranging from 8.5–25%.

Airliner Air Quality Data

Several studies of airliner air quality performed since McFarland's have previously been reviewed by Crawford **(1)** and Holcomb *(5)*. They found that, with few exceptions, **low** humidity and ozone were the most likely causes of the most commonly reported symptoms. The levels of tobacco constituents that were measured were too low to have caused the reported symptoms.

However, few parameters were measured in these studies. Because of this, exposure to many of the constituents of **ETS** as well as other chemicals that may have been present could not be evaluated.

Epidemiological Studies: Environmental Tobacco Smoke

During the same period that airline air quality data began to appear, reports released by the U.S. Surgeon General (19) and the **U.S.** National Research Council (NRC) **(17)** suggested that exposure to ETS may result **in** an increased risk of lung cancer. As a result of this, exposure to ETS **oii** airliners was no longer a question **of** irritation, but now represented a possible risk of contracting a serious, chronic disease.

The conclusion of these reports was based on reviews **of** the **13** epidemiologic studies that had compared lung cancer rates between nonsmoking women mamed to nonsmokers with the lung cancer rates of nonsmoking women married to smokers. The difference in rates of contracting lung cancer is calculated **as** a relative risk. **The** relative risk calculated from these studies is not a precise value. As a result, it is often more accurately portrayed **as** a ***95%*** confidence interval, or the range of values within which the true value has **a** 95% chance of being included. For a relative risk **to be** considered statistically significant, the 95% confidence interval must lie entirely above 1.0. It is generally accepted that the relative risk must be above 2.0 to be considered important. Fig. 1 illustrates significant and nonsignificant ranges of relative risk. Of the **13** studies reviewed **by** the NRC. only 2 demonstrated statistically significant increases in relative risk (Fig. 2). These studies have **also** been severely criticized by Uberla (20) and Layard (8), among others, for problems with confounding, misclassification, and bias.

As a result of the widespread criticism and lack of consistent results between the studies, the NKC **(17)** performed a meta-analysis of the studies. A similar analysis also has been performed by Wald (21). These meta-analyses have produced combined relative risks of **1.35** for all of the studies and 1.**13** for the U.S. studies. Letzel (9) has evaluated these meta-analyses, the assumptions behind them and their conclusions, and found that the criteria necessary to perform a proper meta-analysis have not been met in these studies. **He** has further found that of the 1,023 possible meta-analyses, only **24** would produce an overall significant increase in relative risk and that these were dominated by the poorer quality studies. Thus, even the attempts to combine the available studies to help correct for their weaknesses does nor produce a credible estimate of risk due to ETS exposure.

Studies on Nicotine and Cotinine

Crawford (1) and Holcomb *(5)* have reported on earlier studies regarding measurement of nicotine in airliner ambient air. Malmfors **(10)** and Geomet **(4)** monitored nicotine and reported mean levels between 0.04

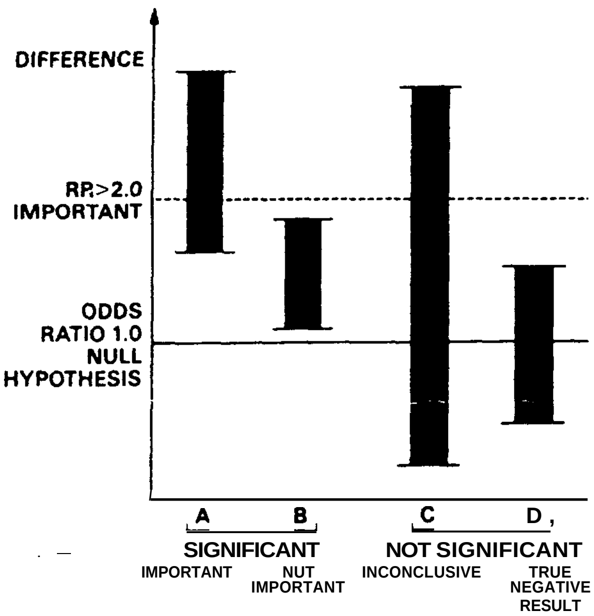


Fig. 1. **Illustration** of **statistical significance.** Studios *A* ***and* B** show **statistically significant** *95%* **Confidence Intervals.** Study **B however,** has an **increased RR** that Is small **enough** to bo **considered** unimportant. Studies **C** and **D, because** tho *95%* Confidonco **Interval does** not **exclude** tho **Null Hypothesis (RR = 1.0),** ***are not considered statistically*** significant ***even*** though study C **does** show a modest **increase** In risk.

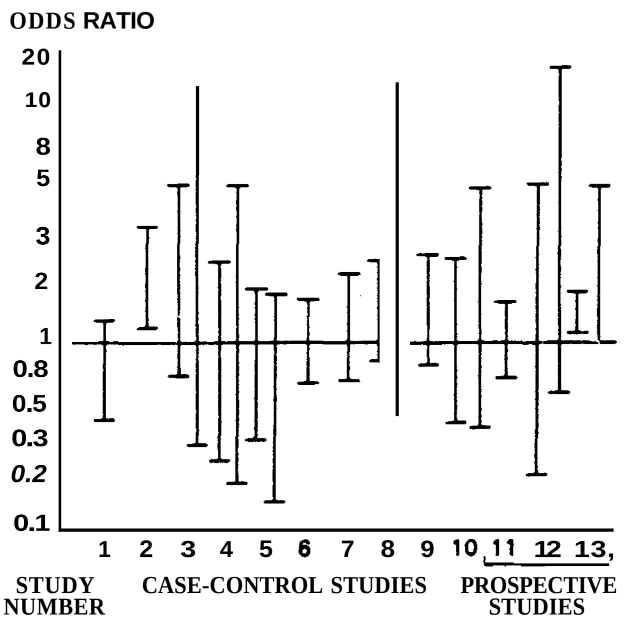


Fig. 2. ETS exposure by nonsmokers and lung cancer. Tho 95% Confidence Intervals from the 13 epidemiologic studies reviewed by the U.S. NRC Study (17): 1. Chan and fung, 1982; 2. Trichopoulos, 1983; 3. Correa, 1983; 4. Kabat and Wynder, 1984; 5. Buffler, 1984; 6. Oarfinkel, 1985; 7. Pershagen, 1987; 8. Akiba, 1986; 9. Koo, 1984; 10. Lee, 1986; 11. Oarfinkel, 1981; 12. Oillis, 1984; 13. Hirayama, 1984.

μg/m³ in the middle of a nonsmoking section to 32 μg/m³ in business class smoking sections.

Foliart (3) monitored flight attendant blood nicotine on transoceanic flights. Blood nicotine increased from a mean of 1.6 ng/ml to 3.2 ng/ml in five of six women. The authors concluded that physiologic effects were unlikely.

Mattson (11) demonstrated that nicotine in airliner air can be detected as urinary cotinine in the most highly exposed nonsmoking passengers and flight attendants. This confirms the previous data from Foliart (3).

Recent Airliner Studies: Is There a Health Risk?

In spite of the widespread criticism of the methodologies used to produce long term health claims resulting from ETS exposure, anti-smoking groups and the popular press have continued to fuel the controversy. In part because of this continued controversy, two recent studies by Malmfors (10) and Geomet (4) of airline air quality have increased the information on ETS exposure on airliners. They also monitored a wider array of chemicals and other environmental conditions to which one may be exposed during flight. The key findings of these studies are summarized in Tables I and II.

In addition to collecting basic data, Geomet attempted to calculate a lung cancer risk resulting from ETS exposure for various classifications of airline attendants and passengers. This risk estimation, based on measured respirable suspended particulate (RSP) levels inflight and assumed exposure durations, assumed a causal relationship between ETS exposure and lung cancer and a relative risk of 1.3 for this relationship. As has been shown earlier, both the assumption of a causal relationship and a magnitude of 1.3 for that relationship

TABLE I. AIR QUALITY STUDIES ON 48 SAS FLIGHTS (8) (WEIGHTED MEAN VALUES)

	Seating Category			
Parameter	BNS	BS	TNS	TS
Nicotine ($\mu g/m^3$)	5	41	21	32
RSP ($\mu g/m^3$)	60	250	160	220
Carbon Monoxide (ppm)	0.6	1.1	0.8	I
Carbon Dioxide (ppm)	1310	1310	1270	1430
Relative Humidity (%)	25	25	25	25
Temperature (°C)	23.9	23.8	23.6	23.

BNS = Business Nonsmoking; BS = Business Smoking; TNS = Tourist Nonsmoking; TS = Tourist Smoking.

TABLE II. AIR QUALITY STUDIES ON FLIGHTS BY GEOMET (3).

	69 Smoking Flights		23 Non-Smoking Flights
Parameter	Smoking Section	Non-Smoking Section	Middle Row
Nicotine ($\mu g/m^3$)	13.4	0.04	0.00
RSP ($\mu g/m^3$)	176	31	40
Carbon Monoxide (ppm)	1.4	0.7	0.5
Carbon Dioxide (ppm)	1562	1568	1756*
Relative Humidity (%)	15.5*		21.5*
Temperature (°C)	24.3*		24.1*
Ozone (ppm)	0.01	0.01	0.02
Bacteria (CFU/m³)**	163	131	131
Fungi (CFU/m³)**	5.9	5.0	9.0

* Represents value for entire aircraft.
** These were taken at the end of the flights and may not be repre sentative assays.

are based upon inappropriate evaluation of the studie involved and are not widely accepted within the scien tific community. In their calculation, Geomet also ne glected to consider retained dose and used instead ex posed dose. They also used incorrect values whe calculating respiration rates and employed a phenome nological risk assessment model not generally accepte in the scientific community. Geomet calculated est mated lifetime risks of lung cancer per 100,000 nor smoking attendants for domestic flights at between 12 17 persons.

Geomet calculated 48.9 μg/h per person of RSP. U ing a respiratory rate of 0.62 for women, this is correctl 14.58 μg/h of RSPs. Assuming 11% retention results i a dose of 1.6 μg/h. This recalculation reduces the po tulated risk by 31 times, giving between 0.40–0.57 canc cases. This would not be discernible within a populatio

In an *erratum*, Geomet also estimated the lifetime ris of deaths due to lung cancer that can be attributed radiation exposure on domestic flights at between 9(1,026 per 100,000 persons exposed.

In summary, flight attendant lifetime risk of lung ca cer deaths per 100,000 exposed on domestic flights wa

• ETS risk calculated by Geomet	12–17
• Corrected ETS risk values	0.40–0.57
• Radiation risk corrected in erratum	90–1026

One can use the correct values for respiration rates and exposure and, as is toxicologically correct, calculate retained dose of the constituent of concern. This will provide a much more accurate estimate of the magnitude of the exposure one may receive under the conditions measured in the Geomet study. The results of these calculations are in Table III.

TABLE III. CALCULATION OF ABSORBED DOSE OF RSPs FROM ETS.

Calculation of absorbed dose utilizing the data on RSPs (23.2 $\mu g/m^3$ on average) from the Geomet study based on the percentage of time that flight attendants were exposed to different concentrations of exposure in different aircraft sections.

TO CALCULATE ABSORBED DOSE

RSP × Respiratory Rate × Absorb. (%) × Hours Per Year = Absorbed Dose

WOMAN: $23.2\ \mu g/m^3 \times 0.62\ m^3 \times 0.11 \times 960 = 1519\ \mu g = 1.52\ mg$

MAN: $23.2\ \mu g/m^3 \times 1.08\ m^3 \times 0.11 \times 960 = 2646\ \mu g = 2.65\ mg$

TO CALCULATE CIGARETTE EQUIVALENT:

Tar Delivery/Cigarette to Smoker = 10.6 mg (Woman)
13.2 mg (Man)

$$\frac{\text{Absorbed Dose Nonsmoker}}{\text{Absorbed Dose Smoker}} = \text{Cigarette Equivalent}$$

WOMAN $\frac{1.52}{10.6} = 0.14/\text{Year}$

MAN $\frac{2.65}{13.2} = 0.20/\text{Year}$

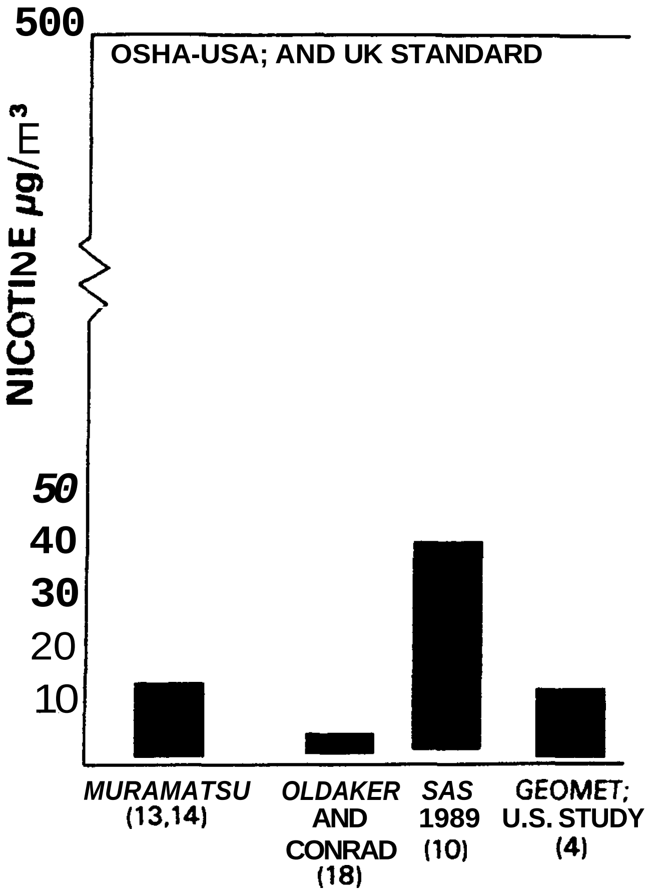


Fig. 3. Nicotine measurements compared to standards.

Air Quality Standards: Ventilation

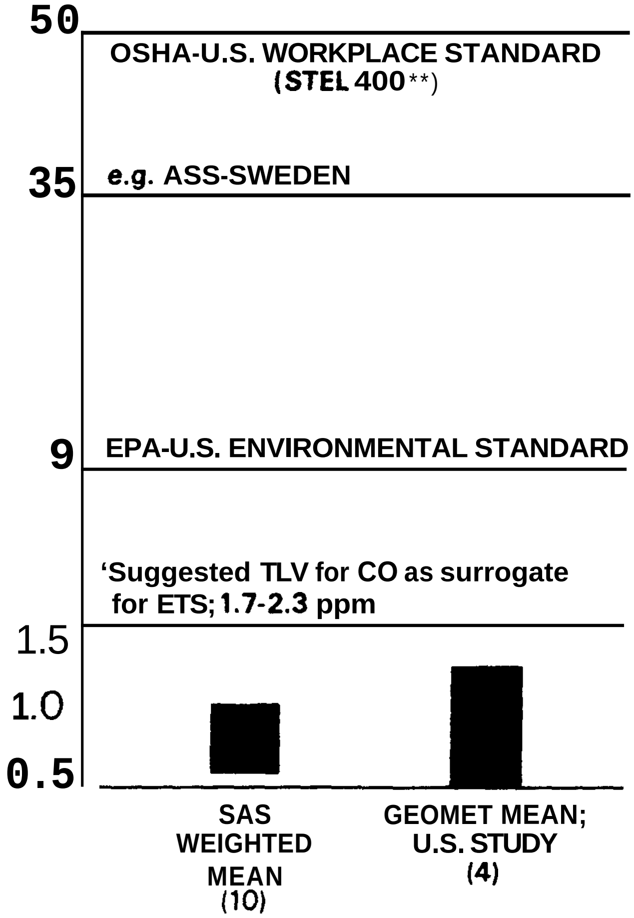
Several health-related organizations both American and international. have developed exposure standards to protect the health of those exposed. The most common parameters measured in the airline air quality studies that have been performed are nicotine, carbon monoxide, ozone, and carbon dioxide. The two parameters that may be related to ETS are nicotine and carbon monoxide. Fig. 3 and 4 show that the data derived for these parameters represent but a small fraction of the exposure standards. Of the two remaining parameters, ozone concentrations have exceeded the exposure standards in the earlier studies (FAA, in NAS (16); Nastrom (15)) but not the Geomet (4) study (Fig. 5).

Carbon dioxide has been snown to exceed both the ASHRAE and the Japanese exposure standards in all three studies where it was measured (NRC, (16); Malmfors (10); Geomet (4); Fig. 6). This standard has been developed, not as a health-based standard due to the toxicity of carbon dioxide, but as a surrogate for proper ventilation. ASHRAE recommends 20 cfm/person of fresh air for buildings. It is obvious from Fig. 7 that as fresh air ventilation decreases on airliners, CO_2 increases. Airlines are beginning to reduce fresh air quantities (NRC p. 141) (16) and recirculation of filtered cabin air is available in modem airliners. Overall air quality inevitably suffers as a result (this may be due to the density of passengers in airliners being greater than that of workers in offices).

Geomet investigators (4) attempted to use a tracer gas technique for estimating ventilation rates, but had technical problems since the technique, while adequate for aircraft with recirculation systems, was inadequate for other aircraft. If one calculates fresh air based on the CO_2 concentration inside and outside the aircraft and the CO_2 generation rate, the results demonstrate that fresh air was provided at less than 50% of the U.S. ASHRAE standards; i.e., less than 10 cfm/person. Proper ventilation is the primary factor in controlling exposure to other constituents in an indoor environment. Theoretically, the potential for increased air exchange rates is 2–4 times that in an office. This should provide good air quality, but in practice this was not found. Carbon dioxide levels rose to some 1,300 ppm, indicating that fresh air was not provided at sufficient rates to provide recommended air quality.

Discussion

Additional studies of cabin air quality clearly need to be conducted. There are variations between aircraft types and variation within types caused by differential operation of the ventilation systems. Therefore, much more data need to be acquired to understand overall cabin air quality. With such information air quality standards for airliners could and should be established. In addition to augmenting the type of data so far acquired, there is an absolute need to obtain data on other chem-



'EXPRESSED AS EXCESS CO
"Short Term Exposure Limit

Fig. 4. CO **measures compared to** standards.

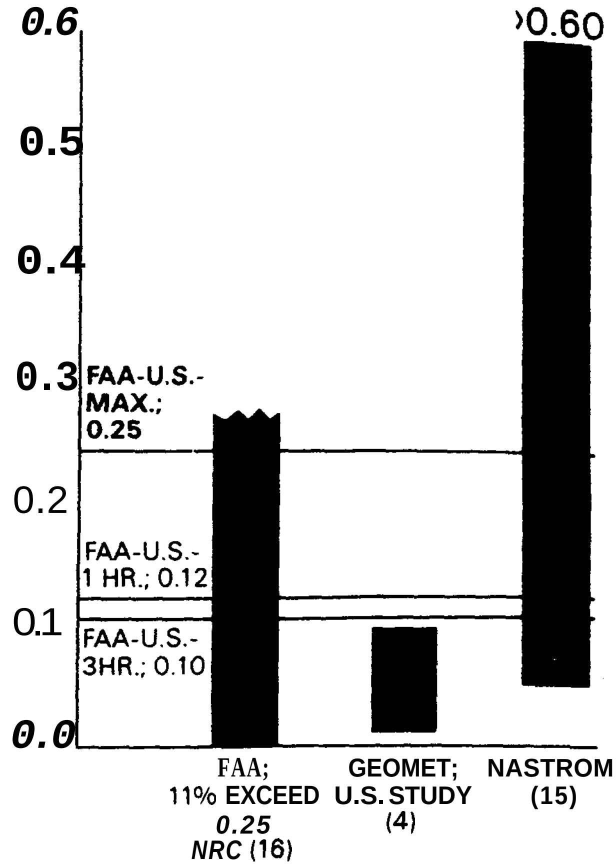


Fig. 5. Ozone measurements compared to standards.

icals of perhaps a more potentially hazardous nature. The potential hazard to health is related to the type and concentration present, the durations of exposure, and the retained dose.

A disturbing absence of epidemiologic information on flight attendants and passengers also exists. These data should be supplemented by objective eye irritation studies such as those of Weber et *al.* (22) in nonsmoking and smoking sections and also in nonsmoking flights.

Flight attendants are mainly concerned about the studies on the lung cancer status of nonsmoking spouses of smokers. The results of these studies are highly contentious, contradictory and largely not statistically significant. All 23 studies so far reported have been confounded, as were those selected for study by the NRC (17). Significantly, the extrapolations from these confounded epidemiological studies are being used to estimate the hazard to airline staff. Equally significantly, erroneous dose data are being used in such extrapolations and risk assessments. One questions whether the potentially low risks found in spousal studies can be applied to estimate a lower potential risk to flight attendants and the lowest potential risk for passengers.

Crawford (I) reviews the conditions and possible risk that flight attendants and passengers face in their nonflying hours at their homes and in overseas resting periods between flights.

In aerospace medical practice over the last 50 yea the progress of knowledge and application of th knowledge has been based on medical physiology ar the sciences. With regard to the health effects hypot esized for exposure to ETS, scientific data are quan tatively and qualitatively inadequate to estimate haza and, equally importantly, to justify prohibition of smo ing in airliners.

In our view the classical 'Type 1' error (i.e., false concluding that a health hazard is present when in fa it is not present) is being committed through the pr mulgation of regulations based on unscientific juc ments.

Conclusions

Airline cabin air quality is determined by a combir tion of chemical and physical factors, not the least which is proper ventilation. Low humidity, ozone, E1 and reduction in partial pressure of oxygen levels ha all been implicated in the effects that are felt in upper respiratory tract and eyes. Except for carbon oxide and, sometimes, ozone, airline cabins meet . standards for most occupational settings. However. air quality of airline cabins could be improved by creased ventilation and filtration.

The very low levels of ETS in airliners do not app to pose a measurable risk to health of passengers flight attendants.

If one looks at all the studies pertaining to ETS posure on airlines, the following conclusions can drawn regarding health:

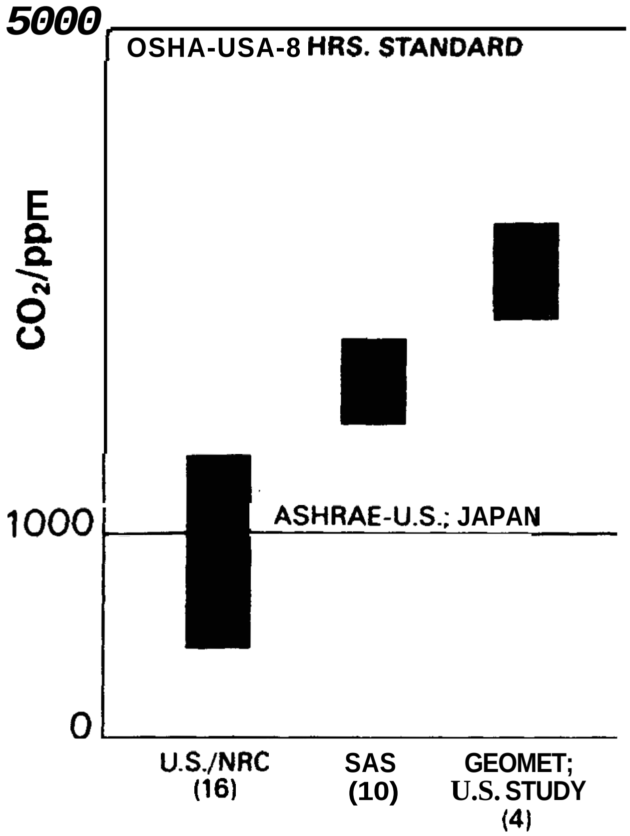


Fig. 6. CO_2 measurements compared to standards.

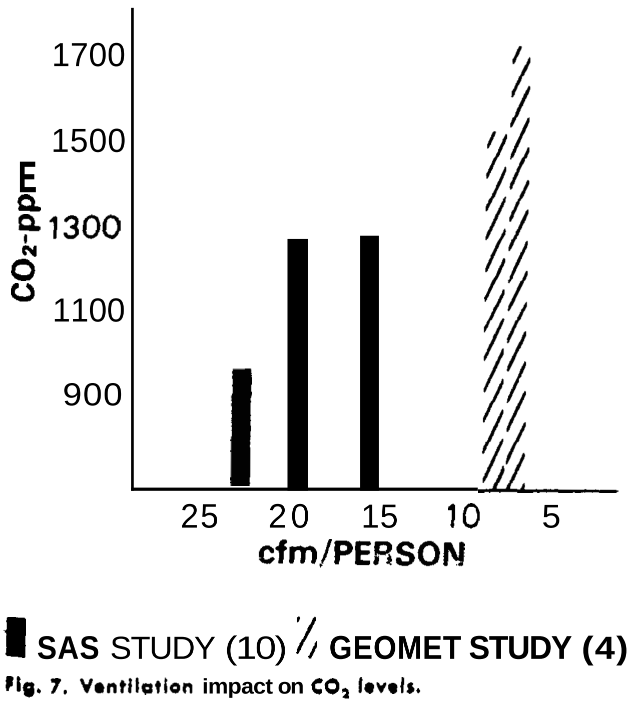


Fig. 7. Ventilation impact on CO_2 levels.

1. As has been shown previously by Crawford (1) and Holcomb (5). the levels of ETS constituents are not high enough to result in the symptoms most commonly reported by airline attendants or passengers. These symptoms are much more likely to result from elevated levels of ozone or abnormally low relative humidity, neither of which is uncommon on long flights.
2. The scientific data do not support a causal relationship between ETS exposure and the development of chronic health effects. The operational value of 1.3 for an overall relative risk is likewise the result of misapplication of the available data.
3. The ETS health risks calculated by Geomet (4) are based upon faulty assumptions and inaccurate data. Thus, the ETS health related conclusions reached by that study must be considered highly suspect.
4. The lack of data does not allow evaluation of exposures to a wider variety of environmental agents, and prevents any evaluation of potential health risks due to exposures resulting from air travel. We suggest, at a minimum, that the following parameters be evaluated: benzo(a)pyrene, kerosine, fuel vapors, aldehydes, other polynuclear aromatics, bacteria, fungi, viruses.
5. None of the epidemiologic studies conducted on ETS exposure evaluated exposure scenarios that are relevant to the airline environment. We suggest that epidemiologic studies of airline flight attendants be carried out as a more direct measurement of the health risks incurred by this professional group.

ADDENDUM

In *Aviarion, Space, and Environmental Medicine* June 1990; 61:531–42, Drake and Johnson report on six flights in 1987. Their data on nicotine and respirable particulates preceded the results reported herein but were not available before this paper was written. The title of their report is "Measurements of Certain Environmental Tobacco Smoke Components on Long-Range Flights." Their data do not conflict with conclusions of our paper.

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