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NIOSH HEALTH HAZARD EVALUATION REPORT

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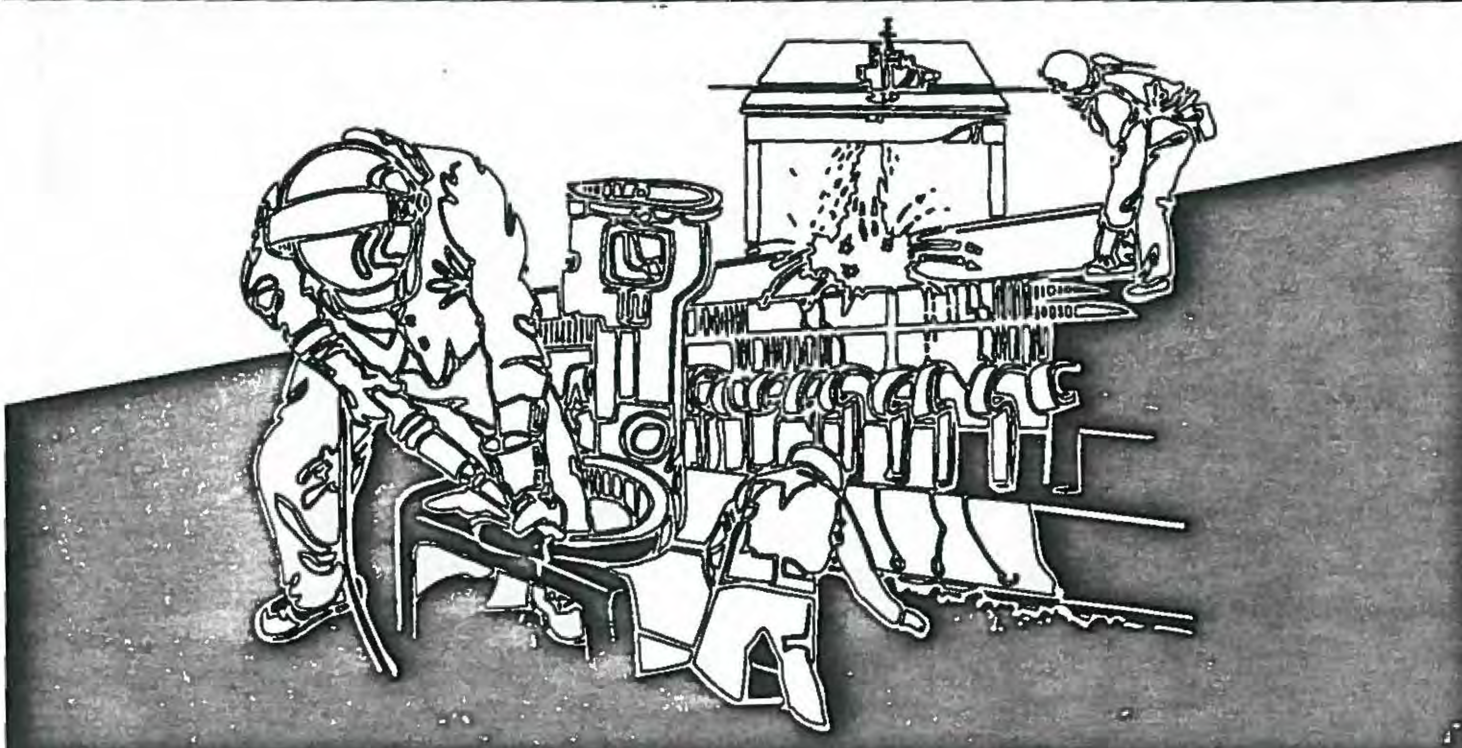
ALASKA AIRLINES
SEATTLE, WASHINGTON



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer and authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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SUMMARY

A request was received from the Association for Flight Attendants (AFA) in April 1990, for a NIOSH Health Hazard Evaluation (HHE) to evaluate potential employee exposures to toxic gases and/or a lack of oxygen aboard Alaska Airlines flights on McDonnell Douglas MD-80 airplanes (manufactured by Douglas Aircraft Company, Long Beach, California). The request resulted from a number of incidents during passenger flights on Alaska Airlines MD-80 airplanes, during which some of the flight attendants experienced illness symptoms (including headache, dizziness, blurred vision, mental confusion, and numbness) which were attributed to the cabin air quality.

Three NIOSH site visits were made in association with this HHE: (1) May 30-31, 1990, (2) July 10-11, 1990, and (3) November 18-20, 1990. The purpose of the first site visit was to collect information from Alaska Airlines and employee representatives, and conduct a walkthrough survey of the airplane which had been involved in the most illness incidents. During the second site visit NIOSH investigators conducted environmental monitoring aboard three test flights on two Alaska Airlines MD-80 700 series airplanes, under flight conditions thought to represent "worst case" and "normal" for cabin air quality. Representatives of Alaska Airlines and the AFA, in cooperation with NIOSH, jointly conducted follow up monitoring for carbon monoxide on 10 commercial flights from September 27 to October 10, 1990, using equipment provided by NIOSH. The third NIOSH site visit was to conduct additional follow up CO monitoring on three commercial flight segments.

Results of previous environmental monitoring by Alaska Airlines and McDonnell Douglas aboard the airline's MD-80s were reviewed; the results did not suggest a toxic exposure or lack of oxygen on either incident or non-incident flights, but were limited by a lack of continuous monitoring during the flights and contamination problems with an evacuated container sampling method.

Results of NIOSH environmental monitoring (continuous and grab measurements) aboard the "worst case" and "normal" MD-80 flights did not reveal a health hazard. In-flight average ranges for cabin air pressure (654-656 millimeters of mercury [mm Hg]), carbon dioxide (550-1191 parts per million [ppm]), nitrogen dioxide (not detected, <2.5 ppm), oxygen (20.75-20.84%), ozone (0.005-0.017 ppm), temperature (74-75°F), total particulates (0.003-0.026 milligrams per cubic meter [mg/m^3]), and relative humidity (20-21%) were consistent with previous studies of commercial aircraft cabin air quality. The results indicated that cabin conditions commonly may not meet the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) comfort criteria for temperature, relative humidity, and carbon dioxide concentrations, particularly during gate time. The highest instantaneous and in-flight

average carbon dioxide concentrations, 4882 and 1191 ppm, respectively, were measured on the "normal" flight, which unintentionally had the longest gate time. In-flight grab sample results for carbon monoxide on the test flights were low (2-6 ppm), all below the ambient level of 9 ppm measured at Seattle/Tacoma airport. Results of direct reading continuous monitoring for CO were inconclusive (due to instrument miscalibration in the field); however, the consistent finding of apparent short-term peaks (5-10 ppm above baseline) indicated a possible source of CO exposure and the need for follow up monitoring (see below).

Several methods were used to sample volatile organic compounds (VOCs) in cabin air on the test flights. Continuous in-flight monitoring with photoionization detectors found average total VOCs concentrations to be well below 10 ppm toluene equivalent (range: 1.8-3.2 ppm toluene equivalent). A brief, relatively high concentration peak in total VOCs was measured at one seat location (72-176 ppm toluene equivalent); no unusual events or odors were associated with the event. The major compound identified in sampling for VOCs was ethanol; other compounds found in trace (non-quantifiable) concentrations were cyclopentadiene, 1,1,1 trichloroethane, benzene, trichloroethylene, perchloroethylene, toluene, xylene isomers, siloxane compounds, limonene, and aliphatic compounds. No ethanol was detected in samples collected prior to take off (<0.5 ppm); in-flight average concentrations were low, but quantifiable (range: 0.9-4.6 ppm). It is likely that alcoholic beverages served during the flights were the source. No aldehydes were detected in air samples (<0.07 ppm). Neither grab air sampling method (1-liter gas bag and 50-mL evacuated container) tested for possible flight crew use during incidents was satisfactory for sampling for trace levels of VOCs.

Follow up monitoring for CO was conducted by Alaska Airlines and the AFA (with electrochemical dosimeters) on 10 non-incident commercial flights, which involved nine McDonnell Douglas (MD-80s) and Boeing (727 and 737) aircraft, five of which had been involved in a previous incident. The ranges for time-weighted average (TWA) personal and area CO concentrations were <1-5 ppm (5 samples) and <1-7 ppm (59 samples), respectively; all were well below the NIOSH Recommended Exposure Limit (REL)-TWA (adjusted for altitude) of 20 ppm. Corresponding instantaneous peak CO concentrations ranged from <1 to 25 ppm, all well below the NIOSH REL-Ceiling Limit of 200 ppm; however, the consistent finding of apparent CO peaks on commercial flights suggested either a common source or interference. During two additional non-incident commercial flights, NIOSH investigators conducted monitoring for CO using paired sealed and unsealed dosimeters, and a laboratory-based grab sampling method. The results indicated that a CO peak measured with a dosimeter (30-35 ppm) was due to an interfering gas or vapor.

A company-maintained log of illness incidents among flight attendants was reviewed, as were medical records available for 44 (23%) of 192 potentially affected flight attendants. Of the 83 illness incidents from 1989 to April 1991, 30 (36%) occurred during the period April-June 1990, at a rate of about 1 per 1000 flight segments. The occurrence of incidents was not related to higher latitude or percent of seats occupied. Alaska Airlines MD-80 700 aircraft had a higher incident per plane ratio than other aircraft, including the mechanically similar MD-80 900's. An identifiable exposure was reported in 21 (25%) of the incidents. Regardless of whether an exposure was identified, however, lightheadedness/dizziness, headache, and other neurologic symptoms were the most commonly reported, other generalized symptoms, nausea, and irritative symptoms were intermediate in frequency, and other gastrointestinal and respiratory symptoms were the least common. In 15 incidents, the pattern of symptoms was suggestive of hyperventilation.

Most of the medical records referred to a possible flight-related chemical exposure, based primarily on the patient's history and/or physician's knowledge of previous incidents. Most examination findings and medical tests yielded no abnormal results relevant to determining the cause of the illnesses. Four cases, all from the same incident, were initially diagnosed as carbon monoxide poisoning on the basis of elevated carboxyhemoglobin levels that were subsequently found to be due to analytical error. In six persons, magnetic resonance imaging of the head showed possible brain abnormalities, and in three of these cases (all of whom had persistent neurologic symptoms), psychometric testing indicated cognitive or motor abnormalities.

Environmental monitoring aboard Alaska Airlines MD-80s did not reveal a toxic exposure or lack of oxygen; the results were generally consistent with previous studies of cabin air quality. The environmental and medical data do not support the hypothesis that carbon monoxide exposure was a cause of any of the in-flight incidents. No plausible work-related etiologic exposure that would account for the persistent neurologic findings among some flight attendants was identified. The cause of most of the incidents remains undetermined, as does the reason for their increased rate of occurrence during the spring of 1990 (but not, apparently, 1991). Neither the incident reports nor the environmental investigations provide a satisfactory explanation for the seemingly higher rate of incidents in Alaska Airlines' MD-80 700 airplanes. A comprehensive evaluation that would address the possible roles of physiologic, ergonomic, work organizational, or non-occupational physiologic stresses as contributors to the illness episodes is beyond the scope of NIOSH's health hazard evaluation program. Recommendations for recordkeeping, continued investigation of illness incidents by a joint labor/management committee, increased cabin ventilation during gate time, and chemical purchase procedures are provided--see Recommendations section.

KEYWORDS: SIC 4512 (air transportation, scheduled), aircraft, cabin air quality, carbon monoxide, flight attendants, indoor environmental quality.

INTRODUCTION

A request was received from the Association for Flight Attendants (AFA) in April 1990, for a NIOSH Health Hazard Evaluation (HHE) to evaluate potential employee exposures to toxic gases and/or a lack of oxygen aboard Alaska Airlines flights on McDonnell Douglas MD-80 airplanes (manufactured by Douglas Aircraft Company, Long Beach, California). The request resulted from a number of reported incidents (13 at the time of the request) during passenger flights on Alaska Airlines MD-80 airplanes, during which some of the flight attendants experienced illness symptoms which were attributed to the cabin air quality. Symptoms initially reported included headache, dizziness, blurred vision, mental confusion, and numbness.

Three NIOSH site visits were made in association with this HHE: (1) May 30-31, 1990, (2) July 10-11, 1990, and (3) November 18-20, 1990. The purpose of the first site visit was to collect information from Alaska Airlines (including specifics of the MD-80 ventilation system and results of previous environmental monitoring aboard Alaska Airlines MD-80's) and employees, and conduct a walkthrough survey of airplane number 784, which had been involved in the most illness incidents. During this visit, Alaska Airlines representatives expressed concerns about adverse business repercussions if NIOSH conducted conspicuous environmental monitoring on their commercial flights. Since a comprehensive environmental monitoring protocol could not be conducted inconspicuously, NIOSH investigators agreed to initially monitor specially scheduled "test" flights.

During the second site visit NIOSH investigators conducted environmental monitoring aboard three test flights on two MD-80 700 series airplanes, under flight conditions thought to represent "worst case" and "normal" for cabin air quality. McDonnell Douglas representatives also conducted environmental measurements, including cabin temperatures and air flow rates, and monitoring for selected contaminants during the test flights. Representatives of Alaska Airlines and the AFA, in cooperation with NIOSH, jointly conducted monitoring for carbon monoxide on 10 commercial flights from September 27 to October 10, 1990, using equipment provided by NIOSH. The third NIOSH site visit was to conduct additional follow up CO monitoring on three commercial flight segments.

The focus of the NIOSH investigation, as requested by the AFA, was to assess potential employee exposures to toxic gases and/or a lack of oxygen during flights on Alaska Airlines McDonnell Douglas MD-80 aircraft. Various other potential causes of illness symptoms that were presented to NIOSH investigators by interested parties, including electromagnetic fields, the Faraday cage effect (working in a metal enclosure), monosodium glutamate in airline food, and negative ion concentrations in air, were not evaluated.

Interim reports of the environmental and medical aspects of the NIOSH investigation, dated April 25, 1991, and June 14, 1991, respectively, were provided to the AFA, Alaska Airlines, and other interested parties. This final report includes additional environmental and medical data, discussion, and recommendations.

BACKGROUND

General

In 1990 Alaska Airlines was the 13th largest U.S. airline (currently 10th), with headquarters in Seattle, Washington. The company employed at total of 1280 flight attendants, 180 based in Long Beach, California, and 1100 based in Seattle. Alaska Airlines began passenger service in 1932; at the time of the NIOSH survey it served Western continental states (California, Oregon, Washington, Arizona, and Idaho), Alaska, Russia, and Mexico. The company began using MD-80 series airplanes (MD-82 and MD-83 models) for passenger service in February 1985. Alaska Airlines classified its MD-80s into 700 and 900 series (which refer to aircraft tail numbers). All of the Alaska Airlines 700 series airplanes were MD-82s; the 900 series included both MD-83s and MD-82/83s (planes purchased as MD-82s and later upgraded to MD-83s). Alaska Airlines instituted a prohibition of cigarette smoking on all its domestic flights in April 1988. (Since February 1990, federal legislation [Public Law 101-164] has prohibited smoking on all scheduled domestic flights of less than six hours duration.)

The McDonnell Douglas MD-80, a twin jet airplane built as a successor to the DC-9 by Douglas Aircraft Company, Long Beach, California, was certified by the Federal Aviation Administration, and entered airline service, in 1980. McDonnell Douglas manufactures five MD-80 models (MD-81, MD-82, MD-83, MD-87, MD-88) which differ in takeoff weight, passenger capacity, and nonstop range. According to the company, as of July 1992, 1000 MD-80s had been delivered to at least 56 airlines around the world, with 4,500 daily flights and a total of 12.5 million commercial hours and 760 million passengers.

During the initial reported incident on July 29, 1989, four flight attendants experienced severe illness symptoms during an MD-80 flight; they were subsequently diagnosed with, and received treatment for, carbon monoxide poisoning (the diagnosis was later reported to be in error).

After a number of incidents had been reported (prior to the NIOSH HHE), Alaska Airlines (with an industrial hygiene consultant) and McDonnell Douglas conducted investigations, including environmental monitoring during non-incident flights aboard Alaska Airlines MD-80 airplanes. Alaska Airlines made a number of changes in materials, operating procedures and policies. According to the company, these changes (and their effective dates) were:

Materials

1. A review of chemical cleaners used by Alaska Airlines to clean aircraft cabins was conducted (no incidents had been attributed specifically to cleaning products). The use of 6 commercial cleaning products was discontinued; 2 of the products were replaced with a "less harsh" product (May/June 1990).

2. A chemical dispensing system was installed at the Seattle maintenance facility to ensure that cleaning chemicals used by cabin service employees were mixed properly (after May 1990).

Procedures and Policies

1. Managers were directed to verify, and enforce company policy that vendors and employees use only aircraft cleaning products approved by Alaska Airlines (June 1990). Chemicals must conform to Aerospace Materials Specifications or be approved by the aircraft manufacturer, McDonnell Douglas or Boeing (December 1991).

2. A Chemical Review Committee was formed to review and approve all chemicals under consideration for purchase and use by the company, and use of personal protective equipment. The committee, which included representatives of Finance, Maintenance, Engineering, Administration, and Station Operations departments, replaced review by the Engineering Department (November 1990).

3. Return air grills on all MD-80 700 series airplanes were cleaned. "C" check maintenance schedules (done every 13 months) were modified to include the cleaning of return air grills on all MD-80 airplanes (before May 1990).

4. Heat exchangers on all MD-80 700 series airplanes were replaced. "C" check maintenance schedules were modified to include replacement of heat exchangers on all MD-80 airplanes at 26-month intervals, every other "C" check (before May 1990).

5. The replacement schedule for coalescer bags (water separators or "socks") was increased to every 600 hours (before May 1990).

6. Prescribed maintenance activities were established which would follow any suspected air quality problem entered into the flight log. These procedures included replacement of coalescer bags, inspection of pneumatic ducts for contamination, and replacement of recirculation fan filter and functional testing of the fan. If any contaminants were discovered in air ducts, an additional purging with engine bleed air at temperatures up to 800°F was required (before May 1990).

7. A new system (Garrett Airlines Service Division) for computerized condition monitoring during maintenance of auxiliary power units (APUs) and environmental control systems was initiated to "ensure adequate cabin air flow" (before May 1990).

8. The APU operating temperature was reset on all MD-80 airplanes to increase the air flow to the cabin air conditioning units during gate time (before May 1990).

MD-80 Aircraft Ventilation

The basic design of the cabin ventilation system used for MD-80 aircraft is similar to many other airplanes in commercial service. According to McDonnell Douglas representatives there are no differences in the ventilation systems among the MD-80 aircraft used by Alaska Airlines (MD-82 and MD-83 models). Outside air is drawn into the jet engines and compressed to high temperature and pressure in multistage compressors. Air extracted from the 8th or 13th compressor stages, known as "bleed air," is used to provide ventilation to the cockpit and cabin. There is an inverse relationship between the amount of bleed air taken from the engines and the fuel efficiency of the aircraft. Because fuel costs are a substantial portion of total aircraft operating costs, modern airplanes increasingly recirculate cabin air. Airplanes in which a significant portion ($\geq$ 22%) of cabin air is recirculated include the Boeing 767, 757, and 737-300; and the McDonnell Douglas MD-80 and DC-10-40.[1]

When the aircraft is on the ground, outside air may be provided by an auxiliary power unit (APU) or by a pneumatic connection to a pressurized ground system. Outside air from the engines or auxiliary sources is ducted to two air conditioning units (ACUs). On the ground and at lower altitudes, excess humidity is removed from the outside air in two water separators located downstream of the ACUs. The conditioned outside air is mixed in a plenum, and provided to the cockpit and cabin through fixed outlets located in the ceiling and adjustable ("eyeball") vents above passenger seating. Recirculation air for the first class and main cabin areas is added to the conditioned air downstream of the mixing plenum and supplied through the fixed ceiling outlets. The distribution of cabin air is shown in Figure 1.

The volume of conditioned air supplied to various occupied areas of the aircraft is primarily determined by the respective cooling requirements. The majority (approximately 50-60%) of the cooling requirements for various areas results from heat loads other than occupants, namely, electronic equipment, lighting, solar input, and heat conduction through the aircraft.[2] Because of this, the MD-80 cockpit and first class areas have higher outside air ventilation rates per occupant than the main cabin. According to McDonnell Douglas representatives, the cockpit is supplied with 100% outside (conditioned) air, resulting in an outside air supply of approximately 140 cubic feet per minute (cfm) per occupant; while 30% of the air supplied to the cabin areas is recirculated, resulting an outside air supply of 13.5 cfm/occupant (with 155 passengers, at 30,000 ft cruise altitude).

Air flows from the cockpit to avionics cooling below, and then is exhausted overboard. In the first class and main cabin areas, air flows into return grills located along the floor, through cargo bay areas, and to a recirculation plenum or overboard exhaust (Figure 1). Overboard exhaust through outflow valves is automatically controlled to maintain the desired cabin pressure. Galleys are located in the first class and main cabin areas, with one and two lavatories located in first class and main cabin areas, respectively (Figure 2). Air is exhausted directly from the lavatories and galleys through outflow (venturi) valves. The exhaust in the galleys and lavatories is designed to keep them under negative pressure with respect to the rest of the cabin.

There are a several circumstances that could result in readily apparent noxious odors or fumes in the aircraft cabin. On rare occasions when seals in the jet engines leak or fail, oil vapor can be introduced into the airstream and subjected to high temperatures and pressures in the compressor stages; which could result in vapors or fumes in the bleed air which supplies the cabin. A fluid leak in or near the APU could cause similar results. Because recirculation air is passed through the cargo compartments, a leak or spill in the cargo can cause odors and vapors in the first class and main cabin areas. When the aircraft is on the ground, outside contaminants such as engine exhaust and fuel vapors can be drawn into the cabin by either the engines or the APU.

EVALUATION METHODS

Environmental

The environmental evaluation consisted of review of previous studies of aircraft cabin air quality, and a field investigation in four phases, presented below.

1. An initial site visit to Alaska Airlines facilities was conducted on May 30-31, 1991. During this visit a walkthrough survey of aircraft number 784 (which was involved in the most incidents) was conducted, including visual inspection of the ventilation

system. Reports of previous industrial hygiene sampling were reviewed, and flight attendants, maintenance and technical staff were interviewed to illicit descriptions and potential causes of odor and illness incidents.

2. During the second site visit on July 10-11, 1990, NIOSH investigators conducted environmental monitoring for air quality parameters and contaminants on two MD-80 700 series airplanes during three test flights which were scheduled by Alaska Airlines. NIOSH investigators planned to monitor test flights which represented "worst case" and "normal" conditions for cabin air quality, to the extent that these variables could be practically controlled. The flight conditions during the three test flights are presented in Table 1. Two flights (worst case and normal) aboard aircraft no. 784, which had been involved in 8 incidents at the time, and one flight (worst case) on aircraft no. 785, which had been involved in one incident at the time were monitored. Except as noted, sampling locations for each of the flights were seat 2C (first class), and seats 16D and 29D (main cabin)--see Figure 2. Since odors were associated with some of the incidents, bulk samples of oven residue and oven trays used to serve meals on MD-80 flights were collected for analysis of thermal decomposition products. Monitoring equipment and analytical methods are described in Table 2 and below.

3. Alaska Airlines and the AFA, in cooperation with NIOSH, jointly conducted follow up monitoring for carbon monoxide (CO) on 10 regularly-scheduled commercial flights (13 flight segments) from September 27 to October 10, 1990, using a sampling protocol and personal CO dosimeters provided by NIOSH. The monitoring equipment is described in Table 2. All of the dosimeters were laboratory calibrated by NIOSH before the survey. Since the electrochemical sensors are pressure-sensitive, CO concentrations measured were corrected for an assumed average cabin air pressure of 656 mm Hg (unless otherwise noted) according to the manufacturer's (National Draeger, Inc.) recommendation below.

Pressure correction--electrochemical CO dosimeters

$$CO_{P_2} = CO_{INSTR} \times \frac{760}{P_2}$$

P_2=ambient pressure, mm Hg
CO_{P_2}=CO conc. corrected for P_2
CO_{INSTR}=CO, instrument reading

Flights on Alaska Airlines' MD-80 700 and 900 series, Boeing 727, and Boeing 737 airplanes were monitored. Locations and personnel which were monitored included: cockpit (left and right), first class galley, first class seats, main cabin galley, main cabin seats, main cabin flight attendants, and main cabin aft entry door.

4. Additional follow up monitoring for carbon monoxide was conducted on two flights during a November 18-20, 1990 NIOSH site visit. The purpose of the visit was to determine if interferences were responsible for the short-term peaks that frequently appeared in the previous continuous CO monitoring results. Continuous monitoring was performed with CO dosimeters, and grab air samples were collected using Mine Safety and Health Administration (MSHA) 50-mL evacuated containers. Two CO dosimeters were used side-by-side at each sampling location; one dosimeter of each pair was sealed in a plastic bag to prevent entry of gases or vapors (a check for electrical interferences). MSHA samples were collected next to the dosimeter during any dosimeter readings above the audible alarm level, which was set at 15 ppm. The equipment and methods are described in Table 2 and below.

Sampling and analytical methods used in the evaluation of cabin air quality are summarized in Table 2; the NIOSH analytical methods referenced are described in the *NIOSH Manual of Analytical Methods, Third Edition*.[3] Each of the laboratory methods described has a limit of detection (LOD) and limit of quantitation (LOQ) specific to that method. The respective LOD and LOQ for each method were determined in the laboratory. A minimum detectable concentration (MDC) and minimum quantifiable concentration (MQC) for a given sample set can be determined by dividing the analytical LODs and LOQs by the respective air sample volumes; these are reported with the results where appropriate. In the case of direct-reading instruments, the manufacturer's LOD or MDC are reported.

For sampling methods utilizing sample media, air samples were collected with battery-operated personal sampling pumps, which were calibrated immediately before and after sampling (on the ground) with a Kurz Pocket Flow Calibrator® mass flowmeter, which in turn had been previously calibrated with a primary standard (bubble flowmeter). The mean of the pre- and post-sampling flow rate measurements was used to calculate air sample volumes.

To determine what substances might be released by the galley ovens during hot meal service, a plastic oven tray (used to serve meals) and a sample of oven residue were collected in resealable plastic food bags. Portions of the plastic oven tray (obtained by filing off material with a metal file) and oven residue were placed in ceramic boats which were heated to 180 - 200°C for thirty minutes. The effluents were sampled with charcoal tubes for volatile organic compounds (VOCs), and with an Orbo-23 tube for aldehyde screening (oven tray only) at a flow rate of 0.1 liters per minute (ℓ/min). The sampling media were then analyzed by gas chromatography/mass spectrometry (GC/MS).

Medical

The medical evaluation consisted of an analysis of existing data regarding incidents of illness among Alaska Airlines flight attendants. The following sources of information were used:

1. A company-maintained log of each incident; entries included dates, flight number and location, aircraft number, home base, names of flight attendants and indication of which were affected, and passenger load data. In addition, for each incident, there was an accompanying narrative report containing symptom and medical evaluation information, as well as any findings indicating a potential exposure to unusual environmental conditions.

2. Medical records available to the company as a result of workers' compensation claims.

3. Information received, in writing or by phone, from Alaska Airlines and from a local AFA representative regarding, among other things, number of flight attendants, composition and usage of the aircraft fleet, number of flight segments per month, average passenger load by month, and flight attendant workload and staffing practices.

4. Medical records received from physicians and affected flight attendants.

EVALUATION CRITERIA

NIOSH experience and general guidelines

The basic approach that NIOSH has developed from experience with indoor environmental quality investigations, with appropriate modifications, was used to investigate Alaska Airlines aircraft cabin air quality. NIOSH investigators have completed over 1100 investigations of the indoor environmental quality in a wide variety of non-industrial workplaces. The majority of these investigations have been conducted since 1979.

The symptoms and health complaints that have been attributed to the indoor environment, and reported to NIOSH investigators are diverse and usually not suggestive of any particular medical diagnosis or readily associated with a causative agent. A typical spectrum of symptoms has included headaches, unusual fatigue, varying degrees of itching or burning eyes, irritations of the skin, nasal congestion, dry or irritated throats and other respiratory irritations. Typically, the workplace environment has been implicated because workers report that their symptoms lessen or resolve when they leave the workplace.

A number of published studies have reported high prevalences of symptoms among occupants of office buildings.[4,5,6,7,8] Scientists investigating indoor environmental problems believe that there are multiple factors contributing to building-related occupant complaints.[9,10] Among these factors are imprecisely defined characteristics of heating, ventilating, and air-conditioning (HVAC) systems, cumulative effects of exposure to low concentrations of multiple chemical pollutants, odors, elevated concentrations of particulate matter, microbiological contamination, and physical factors such as thermal comfort, lighting, and noise. Indoor environmental pollutants can arise from either outdoor sources or indoor sources.

There are also reports describing results which show that occupant perceptions of the indoor environment are more closely related to the occurrence of symptoms than any measured indoor contaminant or condition.[11,12,13] Some studies have shown relationships between psychological, social, and organizational factors in the workplace and the occurrence of symptoms and comfort complaints.[14,15,16]

Less often, an illness may be found to be specifically related to something in the indoor environment. Some examples of illnesses potentially related to the indoor environment are allergic rhinitis, allergic asthma, hypersensitivity pneumonitis, Legionnaires' disease, and carbon monoxide poisoning. Problems NIOSH investigators have found in the non-industrial indoor environment have included poor air quality due to ventilation system deficiencies, overcrowding, volatile organic chemicals from furnishings, machines, structural components of the building and contents, tobacco smoke, microbiological contamination, and outside air pollutants; comfort problems due to improper temperature and relative humidity conditions, poor lighting, and unacceptable noise levels; adverse ergonomic conditions; and job-related psychosocial stressors. In most cases, however, these problems could not be directly linked to the reported health effects.

The primary sources of industrial occupational standards or recommended limits for occupational exposures are: NIOSH Criteria Documents and Recommended Exposure Limits (RELs),[17] the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs),[18] and OSHA Permissible Exposure Limits (PELs).[19] These values are usually expressed as time-weighted average (TWA) exposures, which refers to the average airborne concentration of a substance over an entire 8-hr (OSHA, ACGIH) or 10-hr (NIOSH) work shift. Concentrations are usually expressed in parts per million (ppm), milligrams per cubic meter (mg/m^3), or micrograms per cubic meter ($\mu g/m^3$). In addition, for some substances there are short-term exposure limits (STELs), for periods up to 15 minutes; or ceiling limits (not to be exceeded at any time). The STELs and ceiling limits are intended to supplement the TWA limits where there are recognized toxic effects from short-term exposures. Contaminant concentrations observed in non-industrial indoor environments generally fall well below these published occupational standards or recommended exposure limits.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has published recommended ventilation design, air quality, and thermal comfort guidelines to maintain acceptable indoor air quality in occupied indoor environments.[20,21] ASHRAE defines acceptable indoor air quality as "air in which there are no known contaminants at harmful concentrations...and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction." (The ASHRAE guidelines do not specifically address aircraft.)

The Federal Aviation Administration (FAA) has promulgated Federal Aviation Regulations which include standards for ventilation and cabin air quality on commercial aircraft. The standards include general requirements that "each passenger or crew compartment must be ventilated, and each crew compartment must have enough fresh air (but not less than 10 cu. ft. per minute per crewmember) to enable crewmembers to perform their duties without undue discomfort or fatigue;" and that "crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapors."[22] The FAA standard includes limits for cabin air pressure, and carbon dioxide, carbon monoxide, and ozone concentrations in commercial aircraft passenger and crew compartments; these are discussed under specific environmental parameters below.

Specific environmental parameters

A list of the substances evaluated in this survey is presented in Table 3, with applicable exposure limits and a brief description of the primary health effects the limits are designed to prevent. A more detailed discussion of air pressure, carbon dioxide, carbon monoxide, VOCs, and temperature and relative humidity is provided below.

AIR PRESSURE

At cruising altitudes, commercial airplanes cabins are typically pressurized to maintain air pressure in the range of 632 to 565 mm Hg, which is equivalent to altitudes of 5,000 to 8,000 ft above sea level. One of the most apparent effects of work at higher altitudes is the decreased availability of oxygen. The percentage of oxygen in the atmosphere is virtually constant at all altitudes; however, the partial pressure of oxygen decreases from 160 mm Hg at sea level to 121 mm Hg at 7500 ft. The reduced air pressure in airplane cabins at cruising altitudes results in some decrease in arterial oxygen saturation and work capacity; however these do not represent a health risk for most individuals.[23]

Atmospheric pressures in commercial airplane cabins are relatively constant except during ascent and descent. The middle ear, sinuses, lungs, and intestinal tract can be affected by changes in pressure, particularly if they are extremely rapid (for example, during unplanned depressurization of an aircraft cabin at cruising altitude). The primary effects which may be experienced by some individuals on normal flights are pain or discomfort in the middle ear and sinuses during ascent and descent, particularly if a person's nasal mucus membranes are swollen due to a cold or allergies.

FAA aircraft regulations require occupied compartments and cabins to provide a cabin pressure equivalent to an altitude no greater than 8,000 ft. Additionally, the aircraft must be able to maintain a cabin pressure altitude of not more than 15,000 ft in the event of any reasonably probable failure or malfunction in the pressurization system.[24]

CARBON DIOXIDE

Carbon dioxide (CO_2) is a normal constituent of exhaled breath. CO_2 concentrations in occupied indoor areas are normally higher than the generally constant ambient (outdoor) CO_2 concentration (range: 300-350 ppm). CO_2 levels are often monitored in occupied areas as a useful indicator of outside air ventilation rates. ASHRAE recommends that CO_2 concentrations in occupied areas be maintained below 1000 ppm, with minimum outdoor air supply rates of 20 cubic feet per minute per person (cfm/person) for office spaces and conference rooms, 15 cfm/person for reception areas, and 15 cfm/person in vehicles. The ASHRAE ventilation recommendations are designed to maintain comfort and dilute indoor particulates, odors, and other air contaminants which are normally present.[20] When indoor CO_2 concentrations exceed 1000 ppm in areas where the only known source is exhaled breath, inadequate ventilation is suspected.

The amount of fresh air supplied per occupant on commercial airplanes varies widely with the aircraft model and the passenger load. At 100% passenger loads, the outside air ventilation rates for typical domestic commercial airplanes range from about 9 to 18 cfm/occupant (MD-80: 14 cfm/occupant).[1] A 1989 U.S. Department of Transportation (DOT) study of randomly selected commercial aircraft flights found that the average cabin CO_2 level was greater than 1500 ppm and that about 90% of the flights had average CO_2 levels exceeding the ASHRAE recommendation of 1000 ppm.[1] A Canadian study of one aircraft type and airline found that 24 of 33 commercial flights did not satisfy the ASHRAE outside air ventilation criteria of 15 cfm/occupant, and 18 of 33 flights had less than 10 cfm/occupant.[25]

FAA regulations limit the concentration of CO_2 in passenger and crew compartment air to 30,000 ppm (3% by volume) at any time.[26] The OSHA PEL-TWA is 10,000 ppm, with a STEL of 30,000 ppm. The NIOSH REL-TWA and ACGIH TLV-TWA for CO_2 are

5,000 ppm, with STELs of 30,000 ppm. The occupational exposure criteria are intended to protect against the simple asphyxiant and central nervous system health effects of overexposure to CO_2.

CARBON MONOXIDE

Carbon monoxide (CO) is a colorless, odorless, tasteless gas that combines with hemoglobin (Hb) molecules in the red blood cells to form carboxyhemoglobin (COHb). This interferes with the blood's oxygen-carrying capacity. Symptoms of CO poisoning include headache, nausea, dizziness, weakness, and confusion.[27] Acute exposure to high concentrations may be fatal. Chronic exposure to CO causes central nervous system and cardiovascular effects.[28]

The most common sources of CO are combustion of hydrocarbon fuels (in vehicle engines and heating devices) and cigarette smoke. Previous studies have found that cabin CO concentrations on non-smoking flights are low. A 1989 DOT study of commercial aircraft cabin air quality found that peak CO concentrations on non-smoking flights ranged from 0.9-1.3 ppm.[1] An EPA study of airplane cabin air quality in 1970 (when smoking was permitted) found that CO concentrations were highest (approximately 10-15 ppm) when airplanes were at a gate loading passengers (at which time smoking was not permitted), and that during passenger loading the cabin CO concentrations reflected outdoor levels at the airport.[29]

The OSHA PEL-TWA carbon monoxide is 35 ppm, with a ceiling limit of 200 ppm. The ACGIH TLV-TWA is 25 ppm, with a Biological Exposure Index (BEI) for COHb of less than 8% at end of shift. (The BEI is the level above which a potential overexposure should be considered).[18]

The NIOSH REL-TWA is 35 ppm, with a ceiling limit of 200 ppm; this should keep a non-smoker's COHb below 5%. Additionally, NIOSH recommends the REL should be adjusted for work at altitude (e.g., 5,000 to 8,000 ft above sea level) to compensate for loss in the oxygen-carrying capacity of the blood.[28] For flight attendants working an 8-hour shift, with a light level of work activity, at an average cabin altitude of 8,000 feet, the adjusted NIOSH REL-TWA for CO is 20 ppm . The NIOSH REL is adjusted using an equation designed to predict the maximum exposure level that will result in acceptable ($\leq$5%) COHb levels at end of shift (see Appendix I for an explanation of the calculation).[28]

FAA regulations limit the cabin carbon monoxide concentration to 50 ppm (1 part in 20,000 parts air).[30]

TEMPERATURE AND RELATIVE HUMIDITY

The perception of comfort is related to one's metabolic heat production, the transfer of heat to the environment, physiological adjustments, and body temperatures. Heat transfer from the body to the environment is influenced by factors such as temperature, humidity, air movement, personal activities, and clothing. ANSI/ASHRAE Standard 55-1981 specifies conditions in which 80% or more of the occupants would be expected to find the environment thermally comfortable.[22] Because of seasonal changes in typical clothing worn by occupants, the thermal comfort range for sedentary or slightly active occupants in summer, 23-26°C (73-79 °F), is higher than for winter, 20-23.6°C (68-74.5°F).

Relative humidity refers to the percentage of water vapor present in air with respect to the amount the air can hold at a given temperature and pressure. Relative humidity in occupied spaces should be maintained between 30% and 60% wherever possible. The lower and upper limits are based on occupant comfort, and to minimize the growth of microorganisms, respectively.

On modern commercial airplanes, air supplied to the cabin is conditioned air. Humidity is removed from the outside air at low altitudes and on the ground in water separators. At cruising altitudes, the outside air is very cold and has little water vapor. A 1989 DOT study of randomly selected commercial airplane flights found that the average relative humidity level was 22%, and about 90% of the flights had average humidity levels below the ASHRAE comfort criterion.[1] Due to weight and cost considerations, commercial airplanes are generally not equipped with humidification systems. Some humidification of cabin air is produced by occupants, and by meal or beverage service.

VOLATILE ORGANIC CHEMICALS

VOCs are emitted in varying concentrations from numerous indoor sources (e.g., carpeting, fabrics, adhesives, solvents, paints, cleaning products, waxes, disinfectants, perfumes, foods, beverages, and cigarettes). New construction materials, products, and furnishings are known to emit a large number of organic chemicals into indoor air.[31] The length of time over which each material strongly emits VOCs can be highly variable. A material may have very high emissions over a short period, another may have low total emissions over a long period. A critical factor in the rate of decrease of material emissions is the ventilation rate. Concentrations of VOCs and aldehydes indoors (including residences) typically exceed corresponding outdoor levels.[32]

VOCs in airplane cabins originate from the same types of sources as in buildings. Additionally, on the ground, VOCs from vehicle exhaust, fuel, and other sources may be drawn into the cabin air supply.

Health symptoms experienced by occupants are often blamed on the presence of VOCs in indoor air, although the health consequences of exposures to the relatively low levels of VOCs emitted from construction materials are not well understood. Some organic species (for example, formaldehyde and benzene) emitted by construction materials are carcinogenic. NIOSH, OSHA, and the ACGIH have established compound-specific recommended exposure limits for many organic compounds, but these are rarely exceeded in non-industrial environments.

RESULTS AND DISCUSSION

Environmental

A. Review of Previous Monitoring

During the initial visit to Alaska Airlines, information was collected from representatives of the company, the AFA, FAA, and McDonnell Douglas. A walkthrough survey of the MD-80 which had been involved in the most incidents (airplane no. 784) was conducted. Inspection of the aircraft and its ventilation system did not reveal any apparent environmental health hazard.

Alaska Airlines had conducted environmental monitoring on two non-incident commercial flights on aircraft no. 785 on February 20-21, 1990. The flights reportedly had low passenger loads. Sampling was conducted for temperature, relative humidity, carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), and volatile organic compounds (VOCs). The ranges for in-flight grab samples were: 20.5-25.5°C (69-78 °F) temperatures, 9-36% relative humidity, CO not detected, 350-800 ppm CO_2, and 17-22% O_2 (although O_2 concentrations were apparently not corrected for cabin air pressure), and VOCs not detected (< 1 ppm), except for 30 mg/m^3 2-methyl propane, a component of natural gas.

Alaska Airlines also attempted to develop a method for conducting air monitoring on incident flights; however, this was problematic due to their relative infrequency, unpredictability, and the need to use environmental monitoring devices which flight crews could readily use. Alaska Airlines placed 250-mL evacuated sampling containers (Vacu-Sampler®, MDA Scientific, Inc.) on MD-80 airplanes. Flight crews were instructed to collect air samples if an illness incident occurred during a flight. The grab air samples were collected simply opening (for 10 seconds) and then resealing the metal containers, which were similar in appearance to aerosol shaving cream containers. The samples were submitted to a laboratory for GC/MS analysis for VOCs, nitrogen, O_2, CO_2, and CO.

Results of air samples collected with Vacu-Samplers® on two non-incident, and four incident flights between January 1990 and May 1990 were reviewed. All the results for O_2 (22%), and CO_2 (400-1100 ppm) were within the normal ranges. All samples had low concentrations of VOCs: less than 0.5 ppm acetone, 2-butanone, ethyl ether, Freon-TF®, hexane, methylene chloride, toluene, and xylene; and less than 5 ppm ethanol. However, the reported results (for acetone, 2-butanone, Freon-TF®, methylene chloride, toluene, and xylene) were not meaningful, because of high blank values. Additionally, relatively high levels of carbon disulfide (1-7 ppm), well above the odor threshold for this compound, were reported for all the evacuated container samples, including blank Vacu-Samplers® (no strong or unusual odor was reported).

Representatives of McDonnell Douglas conducted monitoring for CO, CO_2, nitrogen oxides, ozone, VOCs, and aldehyde compounds on airplane no. 784 during a specially scheduled flight on April 18, 1990. Concentrations of aldehydes (acrolein, acetaldehyde, butyraldehyde, and formaldehyde), nitrogen oxides, and ozone were below detection limits. VOCs were not detected, except that ethanol (ethyl alcohol) concentrations of 1.0-1.8 ppm were measured in personal breathing zone and area air samples. The presence of ethanol was attributed to the serving of alcoholic beverages to passengers during the flight. Grab sampling for CO indicated that concentrations ranged from non-detectable to 2 ppm. The CO_2 levels (in grab samples) ranged from 600 to 1100 ppm during flight, with a level of 1400 ppm measured during a 10-minute period between push back and take off.

B. Test Flights

Flight conditions during the three scheduled test flights are presented in Table 1. Results of NIOSH bulk sample analyses, air pressure measurements, and air monitoring for aldehydes, carbon dioxide, carbon monoxide, nitrogen dioxide, oxygen, other gases (hydrogen, nitrogen, argon, methane, acetylene, ethylene, and ethane), ozone, temperature and relative humidity, total particulates, and VOCs are presented below. The average concentrations for pertinent substances during the three flights are presented in Table 4.

McDonnell Douglas Measurements

McDonnell Douglas representatives installed instrumentation in the air conditioning supply systems of airplanes 784 and 785 (both MD-82s) to monitor the cabin air supply during the test flights. According to the company, the cabin air supply during each of the test flights was about 1700 cubic feet per minute (cfm) with the recirculation fan off during takeoff, 2550-2630 cfm at cruise altitude with the recirculation fan off, and 2520-2620 cfm during cruise and descent with the recirculation fan on (with 30% recirculation). The recirculation fan was apparently on (as is normal) during most of the flights. All of the reported air supply measurements during the test flights exceeded the cabin air supply design criterion of 1550 cfm, intended to provide a minimum of 10 cfm/occupant. Given these measurements, the amount of outside air supplied during most of the test flights would have been at minimum 1764 cfm (70% of 2520 cfm), which corresponds to ventilation rates of 20 and 15 cfm/passenger for flights 9300 and 9301-9302, respectively.

The company reported that temperature variation (between points 48 inches above the floor) was within design limits, less than 4°F on the test flights, indicating uniform air distribution to occupied areas. Cabin air pressure was measured by the company and was reported to be within design limits at cruising altitude ($\leq$ 8,000 ft $\pm$ 200 ft). CO_2 levels of 2600 to >3300 ppm (grab samples) were measured during boarding and pushback (at the gate) during each of the test flights. In-flight CO_2 measurements (grab samples) were reported to be 800-1300 ppm for flight 9300, and 800-900 ppm for flights 9301 and 9302. Concentrations of other substances measured (aldehydes, hydrocarbons, carbon dioxide, nitrogen dioxide) were reportedly low, and consistent with previous company sampling (see Section A above).

In a report following the test flights, McDonnell Douglas provided recommendations which included: a) leaving overhead galley vents open (one was found to be closed), particularly if "dry ice" was used for refrigeration; and b) evaluating methods to increase cabin air flow during boarding and push back to reduce excursion levels of CO_2.

Symptom Reports

Flight attendants who worked the test flights were interviewed privately as a group immediately after the flights (for consecutive flights 9300 and 9301, interview followed last flight).

Three of four flight attendants on flight 9300 reported symptoms; two reported headache, and one reported headache, lightheadedness, and dizziness. The onset was associated by all three with set up for the in-flight meal and meal service. One flight attendant reported that adjustment to air pressure change in the ears was harder than normal. One flight attendant reported feeling "short of air" during the taxi between gate and runway. All four reported that their performance was not adversely affected on flight 9300. None of the four reported symptoms during flight 9301; they said that it was a normal or better than average flight.

All four flight attendants who worked test flight 9302 stated that it was a normal flight; none reported symptoms.

Bulk Samples

The oven residue was relatively inert; the only compounds detected in emissions from the heated sample were very low levels of aliphatic hydrocarbons. The heated oven tray emitted more VOCs. Most of the compounds detected were branched aliphatic hydrocarbons in the C_{10}-C_{12} range (which cannot be specifically identified). Other compounds identified include acetaldehyde, benzaldehyde, formaldehyde, propanol, butanol, valeraldehyde, hexanal, heptanal, octanal, nonanal, decanal, undecanal, toluene, styrene. The actual workplace exposures to these substances can only be determined by air monitoring under normal working conditions (see VOCs air sampling results below).

Air Sampling

Aldehydes

Five area samples for aldehydes were collected on flights 9300 and 9302, and four samples on flight 9301. No aldehydes were detected in any of the samples; the MDC for formaldehyde was 0.07 ppm, based on a sampling volume of 8.75 liters.

Air Pressure

Results for cabin air pressure measurements taken with a pocket altimeter are presented in Figure 3 (chart) and Table 4 (in-flight averages). The altimeter was calibrated to ground elevation and barometric pressure at take off. Mean air pressures during the three flights were similar: flight 9300, 654 mm Hg (range: 564-755 mm Hg); flight 9301, 660 mm Hg (range: 564-770); and flight 9301, 654 mm Hg (range: 560-752). Not all of these values may be exact, since altimeter readings are affected to some degree by large changes in relative humidity. The air pressures appeared to be relatively constant, except during ascent and descent. The lowest air pressures measured during the flights, 560 and 564 mm Hg, were equivalent to altitudes of 8218 ft and 8064 ft. The maximum cabin altitude according to the airplane cabin altimeter readings during the test flights was 8000 ft. The discrepancy between NIOSH measurements and airplane altimeter readings is due to the fact that the airplane altimeter readings were relative to standard sea level pressure (760 mm Hg), whereas NIOSH readings were relative to actual ambient air pressures at take off.

Carbon dioxide

CO_2 results are presented in Figure 4 (continuous monitoring by seat location) and Figure 5 (continuous monitoring--in-flight averages). The maximum readings on flight 9300, shortly before and after takeoff (> 4820 ppm) may have been instrument maximums; they were within 3% of the manufacturer's reported instrument maximum (4975 ppm). Some readings that would have been used to compute averages are missing due to battery failure. Due to instrument battery limitations discovered on flight 9300, the continuous monitoring for the second and third test flights (9301 and 9302) was not initiated until near, or shortly after, take off. Instantaneous (grab sample) readings were made with the direct-reading instrument prior to take off at seat 17D on flight 9302; these are included in Figure 4.

The in-flight TWA CO_2 concentrations for the three test flights are presented in Table 4 (range: 550-1191 ppm). The in-flight TWA for the "normal" flight (65% passenger load, 88 passengers) was 1191 ppm, which was greater than the TWAs of 791 and 550 ppm for the "worst case" flights (89% passenger load, 120 passengers). The reason for this is unknown. These results are not consistent with McDonnell Douglas ventilation measurements which indicated the fresh air ventilation rate per passenger was higher on flight 9300 (20 cfm/passenger) than the other two flights (15 cfm/passenger)--see above. It is possible that the average in-flight CO_2 concentration on flight 9300 was highest because it was unintentionally the worst-case for total gate time (1 hr 20 minutes), when airplane cabin ventilation is at a minimum, and CO_2 levels build up to maximums.

Peak CO_2 levels of 4882 and 4150 ppm were measured prior to take off on flights 9300 and 9302, respectively. However, within 30 minutes after take off on both flights the average CO_2 concentrations had dropped to less than 1000 ppm (see Figure 4).

Results of grab sampling for CO_2 with MSHA sample containers is presented in Table 5. Levels in four samples collected during flight 9301 ranged from 600-1400 ppm. CO_2 levels in five samples collected during flight 9302 were 1600-3500 ppm; the highest was while the airplane was at the gate prior to take off. These results were consistent with direct-reading instrument results. A sample collected outside the Alaska Airlines maintenance hanger measured 600 ppm CO_2, which indicates the possible presence of combustion products (ambient air is ordinarily about 350 ppm CO_2).

The in-flight TWA CO_2 level on flight 9300, and short-term pre-flight CO_2 levels on flights 9300 and 9302 exceeded the ASHRAE guideline of 1000 ppm. In-flight

TWA CO_2 levels on flights 9301 and 9302 were within the ASHRAE guideline. Flight 9300 was the only flight with both an average CO_2 level exceeding the ASHRAE guideline and reported symptoms (among three of four flight attendants); however, CO_2 levels above the guideline have been found to be typical on commercial airplanes.[1,2] The TWA CO_2 levels measured on the test flights were well below the occupational health criteria and FAA regulations for CO_2.

Carbon Monoxide

Direct-reading continuous monitoring measured very low TWA CO concentrations (≤ 1 ppm) during the test flights; however, the results were inconclusive due to instrument miscalibration. For example, monitoring results for the first-class galley, flight 9302, are presented in Figure 6. A substantial number of the in-flight CO measurements, at this and other locations sampled, were below zero (ranging to -6 ppm), indicating incorrect instrument zero calibration. It was later determined that the calibration problem resulted from using ambient air outside the Alaska Airlines maintenance hanger at Seattle/Tacoma airport to zero the instruments. Possibly because of vehicular and aircraft activity, CO levels at this location were apparently higher than usual outdoor levels in "clean" air. Although the dosimeter results were not useful quantitatively, a number of short-term peaks (5-10 ppm above the baseline), lasting several minutes to one-half hour, were measured in-flight during each of the test flights. The unexplained peaks indicated a possible source of CO exposure and the need for further investigation (see part C--Follow up Monitoring for Carbon Monoxide, below).

Results of grab air sampling for CO with MSHA containers is presented in Table 5. During flights 9301 and 9302 instantaneous CO measurements ranged from 2 to 6 ppm. All of the in-flight measurements were less than the ambient level of 9 ppm, measured at the Seattle/Tacoma airport, and well within the NIOSH REL-Ceiling Limit of 200 ppm and the altitude-adjusted NIOSH REL-TWA of 20 ppm.

Nitrogen dioxide

Two NO_2 measurements were made at three seat locations on each test flight. Nitrogen dioxide was not detected in three long-term measurements collected over the duration of each test flight (< 5 ppm for the 2-hour samples [9300 and 9301], <2.5 ppm for the 4-hour sample [9302]), or in three grab samples collected on each flight (<0.5 ppm).

Other gases--MSHA container samples

Results of 10 grab air samples collected with MSHA containers for other gases (oxygen, nitrogen, argon, hydrogen, methane, acetylene, ethylene, and ethane) are presented in Table 5. One sample was collected on the ground outside the Alaska Airlines hanger at Seattle/Tacoma airport, four samples during flight 9301, and five samples during flight 9302 (several samples for flight 9300 were lost in shipment).

Oxygen (20.71-20.95%), argon (0.93%) and nitrogen (77.97-78.22%) concentrations measured were similar or identical to expected concentrations in ambient air at ground level.[33] A trace of methane (< 100 ppm) was detected in all samples, but no acetylene, ethylene, and ethane (<1 ppm). The hydrogen concentrations were notable in that the results (range: 1 to 27 ppm) reported exceeded 0.5 ppm, the normal ground level ambient air concentration (clean air); the highest concentration was found at ground level outside the Alaska Airlines hangar.

The reason for the elevated hydrogen concentrations is unknown. However, free hydrogen is non-toxic and physiologically inert; when sufficient quantities are present (far greater than measured concentrations) it is a simple asphyxiant and an explosion hazard.[34]

Ozone

The results of direct-reading monitoring for ozone are presented in Figure 7. Continuous data are presented for flights 9300 and 9301, and the results for 12 instantaneous readings made during flight 9302 (continuous data were lost). The average ozone level measured during flight 9300 (0.014 ppm) was higher than that for flight 9301 (0.010 ppm) or flight 9302 (0.005). Short-duration ozone peaks were measured between take off and landing during all three flights. In all cases peak ozone measurements were less than the NIOSH and OSHA Ceiling Limits for ozone of 0.1 ppm (range: 0.058-0.093 ppm), although the maximum for flight 9300 (0.093 ppm) approached the limit. The results for the test flights were consistent with a 1989 DOT study of cabin air quality, which found an overall average ozone level of 0.02 ppm, and no flight with a level greater than 0.1 ppm.[1]

The reason for the apparent ozone peaks is unknown. The peaks, which were generally of several minutes duration, occurred at different times during each of the test flights: soon after take off (flight 9300), in the middle of the flight (flight 9301), and just before landing (flight 9302). The expected source of ozone on these flights was outside air, and the concentrations measured could have been ambient levels. The highest levels of ozone in the atmosphere naturally occur at upper altitudes, above 24,000 ft.[33] Ozone is also a constituent of "smoggy" air at low altitudes in urban areas, particularly during summer months. It is possible that some of the measurements were due to interferences, such as airborne particulate matter in the sub-micron size range.[35] Short-duration peaks in total particulate levels were measured during flight 9300 (see below), but not the other two flights.

Temperature and Relative Humidity

The results of direct-reading continuous monitoring of temperature and relative humidity at seat location 16D on the test flights are presented in Table 4 (in-flight averages), Table 6 (means and ranges, including gate time) and Figure 8 (chart). For ease of comparison to ASHRAE criteria, temperatures are reported in °F. Average in-flight temperature and relative humidity (RH) results did not vary significantly among the three test flights (range: 74-75°F and 20-21% RH). During each of the flights the highest temperature and RH readings were during gate time prior to take-off, so the averages reported in Table 6 (which include gate time) are somewhat higher (range: 75-76°F and 21-27% RH) than the in-flight averages. Wide variations in both temperature and relative humidity were measured, with maximum ranges for temperature and RH of 49°F (flight 9301) and 41% RH (flight 9302)--see Table 6.

At the measurement location (seat 16D), the temperature was relatively constant on flight 9300 (range: 4°F); but during flights 9301 and 9302 there were large temperature variations (ranges: 49°F and 32°F, respectively)--see Figure 6. For thermal comfort during temperature cycling, ASHRAE recommends that the temperature change rate not exceed 4°F/hr. On two of the three flights the temperature change rates immediately after take off (at seat 16D) greatly exceeded the ASHRAE recommendation: on flight 9301 the temperature fell from 81°F to 41°F in 16 minutes (rate: 160°F/hr), and on flight 9302 the temperature fell from 88°F to 57°F in 60 minutes (rate: 31°F/hr).

According to a representative of McDonnell Douglas, the observed temperature variations after take off were likely due to occupant adjustments of overhead "eyeball" vents. The air supplied to these vents comes directly from the air conditioning units, and can be as cold as -70°F at cruising altitude. For example, for flights 9301 and 9302, when the airplane was on the ground the cabin temperatures were warm (maximums of 84 and 89°F, respectively), and passengers probably opened nearly all the eyeball vents. After take off, vents left open over seat 16D probably created the rapid local decrease in temperature as the airplane approached cruising altitude. When nearby passengers felt a cold draft, it is likely the vents were closed, resulting in the subsequent rapid increase in local temperature.

Average temperatures were within the ASHRAE acceptable range of 74-80°F for occupant thermal comfort in the summer season (at 30% relative humidity). However, the low relative humidities in the cabin during flight, and relatively rapid temperature changes after take off, may be associated with passenger and crew discomfort. The temperature and relative humidity measurements were consistent with a 1989 DOT study of airplane cabin air quality, which found 90% of flights had an average RH <25%, and 60% of flights had average temperatures from 23 to 25°C (73-77°F).[1]

Total Particulates

The results of direct-reading continuous monitoring of total particulates (optical sensor) are presented in Table 4 (in-flight averages), and Figures 5 (charted averages) and 9 (charted by seat location). The average total particulate concentrations for the three test flights were low (range: 0.003-0.027 mg/m^3), and within ASHRAE guidelines. There was no cigarette smoking (a common source of particulates) on the flights monitored. For acceptable indoor air quality, ASHRAE recommends that supplied air at minimum meet the Environmental Protection Agency National Ambient Air Quality Standards: 0.075 mg/m^3 (annual geometric mean) and 0.260 mg/m^3 (maximum 24-hr TWA).[20]

The continuous monitoring results indicated that the average total particulate concentration was higher on flight 9300 (0.026 mg/m^3) than the other two flights (0.013 and 0.003 mg/m^3). Several short-duration peaks at two of the three seat locations (1-minute maximums: 0.128-0.245 mg/m^3) occurred in-flight on flight 9300; similar short-term peaks were not measured on the other two test flights, where no readings exceeded 0.05 mg/m^3. The reason for these results is unknown. The measured peaks on flight 9300 may have been due to occupant activities in the cabin or a brief exposure to higher ambient particulate concentrations (for example, crossing the plume of particulate matter from another airplane).

Volatile Organic Compounds (VOCs)

Four different methods (described in Table 2) were used to identify and quantify VOCs in the cabin air during the three test flights.

Method 1 (qualitative and quantitative)

Three area air samples (one per test flight) were collected and submitted for qualitative analysis. The major compound identified in all of the samples was ethanol (ethyl alcohol); other compounds, found in trace concentrations, were toluene, xylene isomers, siloxane compounds (such as octomethylcyclotetrasiloxane and decamethylcyclopentasiloxane), limonene, and an aliphatic hydrocarbon.

Eleven area air samples collected on the test flights were subsequently analyzed quantitatively for ethanol; results are presented in Table 7. The concentrations were corrected for average pressure of 656 mm Hg during sampling. The in-flight TWA ethanol concentrations on the three test flights were low (range: 0.9 - 4.6 ppm), well below the occupational exposure criterion of 1000 ppm (sampling times 78 to 180 min). No ethanol was detected in three samples (one/flight) collected prior to take off, with MDCs of 0.2 ppm to 0.5 ppm (for sampling times of 29 to 95 min). Since ethanol is a primary ingredient in alcoholic beverages, it is likely that service and consumption of alcoholic beverages during the flights was the source of the ethanol measured. Although the other substances identified were not quantified, the qualitative analyses indicated that they were present in much smaller concentrations than the ethanol.

Method 2 (qualitative)

Two grab sampling methods were used to determine if they were potentially useful for identifying unknown contaminants in cabin air during incident flights. Both methods were found to be unsatisfactory for this purpose. Two area air samples (one per flight) were collected with 1-liter airbags in the galley areas during food preparation on flights 9300 and 9301. No organic compounds were detected in the samples (this method was much less sensitive than other methods used). Two samples were collected with 50-mL MSHA containers in the galley area during food preparation on flight 9300. Analysis indicated that the beeswax plug used to seal the MSHA containers after sample collection contaminated the air samples with large concentrations of $C_{10}H_{16}$ hydrocarbon compounds.

Method 3 (qualitative)

Five area air samples were collected on the test flights for trace levels of VOCs; sample locations and times are given below. This thermal desorption tube method is extremely sensitive, for example, the LOD for benzene is less than 0.1 μg per sample.

Qualitative Air Sampling for VOCs-Method 3

FLIGHT	LOCATION	START	STOP
9300	Main cabin galley (meal preparation)	11:34	11:52
9301	Main cabin galley (meal preparation)	15:02	15:20
9302	Seat 17D	10:36	10:50
9302	Main cabin galley (meal service)	12:29	12:52
9302	Seat 17D (during descent)	15:50	16:06

All of the samples contained a similar mix of compounds, which included traces of cyclopentadiene, C_6H_{12} alkane, 1,1,1-trichloroethane, benzene, trichloroethylene, toluene, perchloroethylene, siloxane compound, xylenes, styrene, benzaldehyde, and caprolactam. Benzene and siloxane compounds appeared to be relatively the most abundant, but neither was quantifiable by method 1 (above).

Method 4 (quantitative, non-specific)

The results of direct-reading continuous monitoring of VOCs with a photo-ionization detector (PID) are presented in Table 4 (in-flight averages) and Figure 5 (charted averages) Figure 10 (charted by seat location). Results are expressed as total VOCs in ppm, toluene equivalent (the instrument was laboratory calibrated with 7.5 ppm toluene). It should be noted that the PID does not distinguish between potentially toxic and non-toxic VOCs; it measures all gases and vapors with an ionization potential below 10.5 electron volts.

The in-flight average concentrations of VOCs were 1.8 ppm, 2.8 ppm and 3.2 ppm, toluene equivalent, for flights 9300, 9301, and 9302, respectively. Both "worst case" test flights (9301 and 9302) had somewhat higher average VOC levels than the "normal" test flight (9300). The reason for this is unknown, but it may be due to the meal service on those flights. Tortellini was chosen for the worst-case test flights because crew members generally associated it with the highest odor levels during meal service.

Unusually high 1-minute averages for VOCs (176 ppm and 72 ppm, both as toluene equivalent) occurred at seat location 2C, flight 9301, from 17:33 to 17:34 (see Figure 10). The highest 1-minute average for VOCs measured at any other time during the three test flights was less than 8 ppm. The reason for these brief high concentrations is unknown, but no unusual odors or events were reported or observed on flight 9301. The readings may have been due to instrument interference, or an occupant activity in close proximity to the sensor, such as pouring an alcoholic beverage, opening a container of perfume, or using a (solvent-based) marking pen.

C. Follow up Monitoring for Carbon Monoxide

Flight information for Alaska Airlines commercial flights upon which Alaska Airlines and AFA representatives conducted monitoring for CO are presented in Table 8. Information presented includes flight number, date, airplane type and number, route, cruise altitude, and cabin altitude. Reported odor or illness incidents did not occur on any of the flights monitored. The monitoring was conducted on a total of 10 flights (13 flight segments) from September 27 to October 10, 1990. Flights on nine airplanes were monitored: seven flights on MD-80 700's, and one flight each on MD-80 900, Boeing 727-200, and Boeing 737 airplanes. Five of the nine airplanes had been involved in previously reported odor or illness incidents.

Results of direct-reading continuous monitoring for CO with dosimeters are summarized in Table 9. Between six and nine dosimeter samples were collected on each flight, at locations indicated (including cockpit left and right, first class and main cabin galleys, first class and main cabin seats, and main cabin aisle). The samples were area measurements unless otherwise indicated (5 personal samples for main cabin flight attendants were collected).

For 22 of the 64 samples collected (noted in Table 9), results should be considered approximate because the minimum instrument readings were either negative (< 0 ppm) or > 1 ppm (range: 2-6 ppm), indicating instrument zero drift. TWA CO concentrations measured in a total of 5 personal samples collected on flights 168, 169, and 218 were low (range: <1 - 5 ppm), all well below the altitude-adjusted NIOSH REL-TWA of 20 ppm. The corresponding peak CO concentrations for the personal samples ranged from 3 to 25 ppm, all well below the NIOSH REL-Ceiling Limit of 200 ppm. TWA CO concentrations measured in 59 area samples collected on the 10 flights ranged from <1 to 7 ppm. All of the area CO concentrations measured were well below the altitude-adjusted NIOSH REL-TWA of 20 ppm. The corresponding peak CO concentrations for the area samples ranged from <1 to 20 ppm, all well below the NIOSH REL-Ceiling Limit of 200 ppm.

A potential source for the apparent CO peaks found in both area and personal dosimeter sample data was not identified; however, the consistent finding of apparent CO peaks up to 25 ppm on all flights monitored indicated an interference problem with the instruments, or a common CO source. A representative of the dosimeter manufacturer indicated that certain radio frequencies or other gases or vapors could have caused the peaks.

To determine if the short-term peaks measured consistently on Alaska Airlines flights were actually CO, NIOSH investigators conducted a follow up visit during which sealed and unsealed dosimeters were used at each sampling location. Two commercial flights were monitored, one on an MD-80 700 (two segments) and one on a Boeing 727-200 (flight information is presented in Table 10). Locations monitored were cockpit left, cockpit right, first class galley, main cabin flight attendant (personal sample), main cabin seat 11C, and main cabin galley. The TWA CO concentrations measured at all sampling locations were <1 ppm (results for both flights combined). No peaks greater than 4 ppm were measured on the two MD-80 flight segments (sealed and unsealed dosimeters), and with one exception, the 727-200 flight (flight 183).

At one location during flight 183, a substantial peak was measured, which allowed comparison of sealed and unsealed dosimeters and MSHA container sampling results. The paired results (for a portion of the flight) are presented in Figure 11. The audible alarm for the unsealed dosimeter worn by the main cabin flight attendant sounded at 18:20 hours, when the flight attendant entered the forward lavatory. The flight attendant immediately notified a nearby NIOSH investigator, who took both of the flight attendant's personal dosimeters back into the lavatory, and collected three grab samples with MSHA containers next to the dosimeters between 18:20 and 18:22 (concurrent dosimeter results, sealed 30-34 ppm, unsealed 0 ppm). No strong or unusual odor was present during this period. Both dosimeters were carried to main cabin seat 6B at 18:24 (the unsealed dosimeter dropped to < 5 ppm within several minutes), where another MSHA container samples was collected. No CO was detected in the four grab samples which were collected with MSHA containers (<5 ppm). These results indicated that the peak measured on flight 183 was due to a gas or vapor, not electrical interference (hence no peak was measured with the sealed dosimeter). According to the instrument manufacturer (National Draeger, Inc., Pittsburgh, PA), the electrochemical sensor in the dosimeter will respond to a variety of organic compounds (the dosimeters were equipped with the manufacturer's pre-filters to reduce interferences).

Medical

A. Analysis of incident log and incident reports

Number of incidents

Between July 1989 (the date of the first entry on the log) and April 30, 1991, the end of the time period evaluated, there were 89 "incidents" recorded.* Three of the logged incidents involved an odor or smoke but no reported symptoms; two others involved employees other than flight attendants (one - on the ground - involved three fleet service personnel, and one - in flight - involved two passengers and a passenger service coordinator); and another appeared to be a redundant report, with an incorrect date, of a previously logged incident. These six incidents will be excluded from subsequent analyses. In four of the remaining 83 incidents involving illness among flight attendants, symptoms were not specified, so these will be excluded from those analyses involving specific symptoms.

Temporal distribution and geographic factors

Thirty (36%) of the 83 incidents occurred during the three-month period April-June 1990, with each of these months having ten incidents; no other month had more than five (Table 11). On seven occasions, each in a different month, two or three incidents occurred on the same day. Although on two occasions the same airplane was involved in two incidents the same day, on none of the seven days did any two incidents involve the same flight attendants.

In 21 (25%) of the 83 incidents, an exposure was noted; these included turbulence (3 incidents); airborne diffusion of identified substances, such as hydraulic fluid, jet fuel, kerosene, deicing fluid, or oil (7); smoke from an oven or auxiliary power unit (3); smoke or fumes from unidentified sources (4); and odors associated with an identified potentially toxic source (4). (Air samples collected with evacuated containers during four incidents in 1990 reportedly contained methylene chloride, carbon disulfide, and acetone, but even if these results were not the result of sample contamination, as suspected, the reported concentrations were too low to account for any acute symptoms.) The 62 incidents without an identifiable exposure show a calendar distribution similar to

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* The medical portion of this report is based on incident reports through April 30, 1991, medical records of persons involved in those incidents, and other information pertinent to the time period studied. Our findings were reported in June 1991. The company incident log dated September 23, 1992, shows that incidents continued to occur after April 1991 (at a relatively low rate in 1991, and at an intermediate rate in 1992). We have not updated any of the other relevant information, however, and have therefore not further evaluated these additional incidents, although this final report contains some additional analyses (not included in the June 1991 report) of the data for the time period evaluated.

that of the 83 incidents, with 26 (42%) occurring in the April-June 1990 period (Table 11).

Eighty (96%) of the 83 incidents occurred among Seattle-based flight attendant crews; about 85% of the airline's flight attendants are based in Seattle. Seven (9%) of the 83 incidents occurred on flight segments to, from, or within Alaska; the other 91% occurred on flights within the continental states or to or from Mexico. Depending on the season, 20-25% of the airline's flight segments begin and/or end in Alaska. .

The calendar pattern of illness episodes did not correspond with that of numbers of flights (Table 11). The period with the greatest number of flight segments was June-August 1990. The busiest two months in 1990 - July and August - came after the three months with the most incidents. During those three months, the rate of occurrence of incidents was on the order of one per 1000 flight segments. Overall, from November 1989 to April 1991, the rate was 0.5 per 1000.

Aircraft

Of the 56 airplanes staffed by Alaska Airlines flight attendants during the time period evaluated, 37 (66%) were involved in at least one illness incident.** Of the 83 incidents, 45 (54%) occurred in Alaska Airlines MD-80 700's, even though these airplanes comprised only 14% of the company's fleet (Table 12). The incident-per-plane ratio (5) for the MD-80 700's was substantially greater than those for other aircraft types (0.6-1.3), including the MD-80 900's (1.3), which differed functionally from the MD-80 700's (with relevance to the flight attendants' work environment) primarily in that the MD-80 900's had two additional seats (137 total), and most lacked serving carts. Although airplane number 784 was initially of particular interest because it was involved in 12 incidents, every MD-80 700 was involved in at least 2 incidents; the median was 6.

Two other airplanes, a Boeing 737 and a MD-80 900 were each involved in 3 incidents, none of which had an identifiable exposure. Seven Boeing 727's and 3 MD-80 900's were each involved in 2 incidents. Curiously, only 8 of the 19 incidents on the MD-80 900's occurred prior to December 1990, but the 11 that occurred from December 1, 1990, to April 30, 1991, comprised 69% of all incidents during that time period. Actual aircraft-type- and airplane-specific attack rates were not calculated because appropriate denominator data - number of

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** One MD-80 was involved in 6 incidents as a 700 series plane (number 783), and one incident after it was designated a 900 series plane following scheduled reconfiguration of its cabin. For the purposes of our analyses, this last incident was counted as occurring in a MD-80 900 and not included in totals for MD-80 700's or airplane number 783. None of the other 7 MD-80 700's which were reconfigured to 900's during the study period were involved in a recorded incident after reconfiguration.

flight segments for each aircraft type (or individual airplane) - were not readily available. All airplanes were reportedly used about the same amount, however.

For the 62 incidents without an identifiable exposure, the pattern of occurrence among the various aircraft was similar to that of all 83 incidents (Table 12). Again, each MD-80 700 was involved in at least 2 incidents (median: 3).

Altitude

The aircraft altitude at which in-flight symptoms occurred was recorded for 32 of the 83 incident flights. In 7 cases, symptoms occurred at an altitude of 10,000 feet or less. In the 25 others, they occurred at 33,000-37,000 feet; in 9 of these, this was 3,000-6,000 above the planned cruise altitude. There are no records, however, regarding actual cruise altitude for the remaining incident flights or for comparable, non-incident flights.

Load factor

Incidents of illness occurred on flights that were nearly empty, as well as on flights that were full. Overall, the average load factor (percent of seats occupied), was not significantly greater for incident flights than for all flights, although monthly differences ranged from -26 to +23 for all 83 incident flights, and from -31 to +23 for those with no identified exposure (Table 13). With respect to average load factor in any specific month, those incident flights without an identified exposure did not differ substantially from all incident flights (except for January 1990, August 1990, March 1991--months in which comparisons were not meaningful because there was no more than one incident flight without an identified exposure).

Flight attendant assignments

Of the approximately 1300 flight attendants who had worked at Alaska Airlines during the period November 1989, to April 1991, 79% never worked on an illness incident flight. For the 83 incident flights, there were 271 flight attendants represented, of whom 227 worked one incident flight, 34 worked two, 6 worked three, and 4 worked four. Thus, there was a total of 329 flight attendant assignments to these flights. One hundred ninety-two flight attendants were reported to have been ill. Of the 227 flight attendants who worked only one incident flight, 148 (64%) were reported to have had symptoms. Of the 34 who worked two flights, 22 (65%) were symptomatic both times, and the rest were symptomatic once (4 the first time, 8 the second). Of the 6 who worked three flights, 4 were symptomatic all three times, and 2 were symptomatic on two flights. Of the 4 who worked four flights, 1 was symptomatic all four times, and

3 were symptomatic on three flights. Thus, there were 233 separate episodes of illness among the 329 flight attendant assignments, an overall attack rate of 71%.

The average number of flight attendants on the 83 flights was four; according to Alaska Airlines, this is also the average for all flights. Even on airplane number 784, which appears to have a risk of an incident ten times that of the fleet as a whole, the probability of an incident would average (over the year) about one per thousand flight segments.

Assuming 9000 flight segments per month (the average for 1990), an average flight attendant work schedule of 16 days per month, and an average of four flight segments per day, and assuming *either* that assignment of flight attendants to flights is random (which is not the case), or that illness incidents occur randomly, the probability of any specific flight attendant being on one of the 83 incident flights during the 18-month period November 1989-April 1991 would be 0.59. This means that 59% of flight attendants would be expected to have been on an incident flight. Yet, only 21% of the flight attendants actually worked an incident flight, suggesting that at least one of the assumptions was wrong, most likely the one that incident occurrence is random. Similarly, the calculated probabilities of a flight attendant being on two, three, and four incident flights would be 35%, 21%, and 12% respectively, compared to actual rates of 2.6%, 0.5%, and 0.3%, respectively.

Odors and symptoms

An odor was reported on 20 (24%) of all 83 incident flights, on 10 (6%) of the 62 flights without an identified exposure, and on 10 (48%) of those with an identified exposure. The most common individual symptoms were light headedness/dizziness and headache (Table 14). Other neurologic and generalized symptoms were also common; irritative and respiratory symptoms were less prominent. Nausea was relatively common, but other gastrointestinal symptoms were not.

In 15 incidents, the pattern of symptoms (most of which were categorized as neurologic or respiratory - see footnote 9 on Table 14) was suggestive of the hyperventilation syndrome, a constellation of symptoms associated with the metabolic and physiologic effects of an excessive and changing rate and/or depth of breathing.[36,37,38,39,40,41,42] Hyperventilation can be due to a variety of pulmonary, metabolic, central nervous system, or other disorders.[36,40,42] Acute hyperventilation can result from an insufficient supply of oxygen to the blood,[42] but in healthy persons the most common cause is psychologic distress.[36,37,40-42] (Panic attacks involve similar symptoms,[40] but none of the medical records contained any information suggesting that the affected flight attendants met the other diagnostic criteria for panic disorder.[43])

An odor was reported in 4 (27%) of the 15 incidents involving apparent hyperventilation and, comparably, in 16 (24%) of the other 68 incidents. Among the 62 incidents without an identified exposure, 4 (40%) of the 10 odor-associated incidents involved hyperventilation, compared to 10 (19%) of the 52 incidents without an odor. This difference is not statistically significant (prevalence ratio = 2.1, 95% confidence interval: 0.8-5.3) and, in any case, would not show odors to be a precipitating event for most of the episodes of apparent hyperventilation. Finally, since the symptoms of hyperventilation are variable and can be due to other causes, the number of incidents involving hyperventilation should be considered an estimate rather than an exact count; there could be more or fewer such incidents.

B. Analysis of medical records

Number and representativeness

As of July 1, 1991, workers' compensation claim records were received from Alaska Airlines for 60 flight attendants, but 11 of these contained no medical data, and another 2 contained no medical information pertinent to the incident in which the flight attendant was involved. One of these 13, and 4 of the remaining 47, were for persons not listed on the incident log. Medical documents received from other sources involved only one flight attendant not included among the compensation records. Thus, incident-related medical records were available for 4 flight attendants not listed in the log and 44 listed (2 as not symptomatic). These 44 constitute only 23% of the 192 affected flight attendants listed in the log, so the medical findings may not be representative of all affected flight attendants. Indeed, one might assume that those flight attendants who filed a workers' compensation claim would be among the most severely affected.

Diagnoses

Two of the 48 records contained no diagnosis, and 4 others indicated diagnoses (consistent with the reported symptoms and/or examination findings) not necessarily related to work as a flight attendant. Two others had diagnoses ("altitude sickness," and "flight illness, unknown etiology") that were flight-related but did not specifically indicate a chemical exposure. In the remaining 40 cases, at least one physician related the symptoms, directly or indirectly, to an exposure on an aircraft, although in 16 of these the diagnosis was qualified by the words "alleged," "possible," "suspicion of," or "rule out" (medical jargon meaning that the diagnosis should be considered but is not the most likely).

Four cases, all from the same incident, were initially diagnosed as carbon monoxide (CO) poisoning based on elevated levels of carboxyhemoglobin (COHb) 24 hours after the incident, but considering carboxyhemoglobin's half-life of 4-5 hours,[44,45,46] the reported levels (16.4-20.3%) were biologically implausible that long after the putative exposure, and they were subsequently found to have been due to analytical error.

Another case of CO poisoning was diagnosed in a flight attendant who had a carboxyhemoglobin level of 18% (normal: < 2%; smokers have levels of 5% or more[44-46]). This flight attendant had been involved in an incident two months earlier and, though continuing to work, had been ill for a few days at the time of the blood test. Although the flight attendant was a smoker, a COHb level of 18% - if accurate - is suggestive of some additional exposure. The available records provided no information to document a potential source, either at work or elsewhere.

Eighteen other flight attendants had a recorded COHb result. Only one was elevated, 3.3% in a non-smoker, but blood specimens were often not obtained until several hours after the incident flight. The blood with a COHb level of 3.3% was obtained about 14 hours after the incident flight, indicating that if the flight were the cause, the COHb level at the time would have to have been much higher, probably 25-30%. A sustained CO exposure well above 100 ppm for 8 hours would have been required to achieve a COHb level of 25-30%.[28] This flight attendant had persistent, unexplained neurologic symptoms, but even if these were due to CO poisoning, it is not clear what the source of such a severe exposure would have been on the airplane. There was no smoking on the flight, no odor or "exposure" was noted, and none of the other flight attendants or passengers were reportedly affected.

Blood gases

Six flight attendants had blood oxygen saturation measured by oximetry; all results were in the 97-99% range (normal: 96-100%).[47] Five others had arterial blood gas measurements recorded; all had oxygen saturation and tension (PO_2) well within the normal range. Two had a slightly elevated pH and a low or borderline carbon dioxide tension (PCO_2), consistent with respiratory alkalosis resulting from acute hyperventilation.[36-40, 42] This diagnosis was not mentioned on their medical records, and in neither case was there sufficient symptom information on the record to determine, retrospectively, if their illnesses were suggestive of this condition.

Neurologic tests

Eight persons' records had results of psychometric testing. In five cases there was no indication of brain dysfunction; in three cases there were either cognitive (thinking) or motor (movement) abnormalities. Each of these three flight attendants had persistent neurologic symptoms. Specific information about the acute illness on the incident flight was sparse in one case. In one of the other cases the episode was suggestive of hyperventilation, but this does not explain the subsequent neurologic problems.

Six persons' records had results of magnetic resonance imaging (MRI) of the head; in at least five cases this was done at the same facility, with the results in all six cases interpreted by the same radiologist (in the other two cases the findings were quoted in the medical record, but the MRI report itself was not present). All six cases showed symmetrical "mild," "subtle," or "diffuse" increased intensity in the white matter of one or more areas of the brain. These findings were not considered definite abnormalities by the radiologist, but were noted to be consistent with edematous (fluid accumulation) or inflammatory changes. Three of these five flight attendants had abnormal results on their psychometric tests. Two of the other three flight attendants (who had no record of psychometric testing) also had other MRI abnormalities of uncertain significance.

Other tests and examination findings

Many of the flight attendants had routine biochemical and hematologic tests, urinalyses, spirometry, electrocardiography, and chest x-rays, and some had toxicologic (drug) screens or other specialized diagnostic tests. None of these test yielded abnormal results relevant to determining the cause of the flight-associated illnesses. Except for the previously mentioned individuals with persistent neurologic problems, physical examinations yielded few relevant findings. Four persons had inflammation of the nasal mucosa or throat (consistent with an irritant exposure or upper respiratory infection), one had an initially elevated diastolic blood pressure that dropped within an hour (consistent with physical or psychologic stress), and another had tenderness in the anterior cervical (front of the neck) lymph node area on one side (more suggestive of an acute infection than a chemical exposure).

Some flight attendants also had a battery of immunodiagnostic blood tests that, taken as a whole, are generally considered by the mainstream medical community as not being meaningfully interpretable.[48] That aside, the available records from the physician who ordered the tests contain no indication that the test results were interpreted as identifying any specific aircraft-related chemical exposure.

CONCLUSIONS

Results of previous environmental monitoring by Alaska Airlines and McDonnell Douglas aboard Alaska Airlines flights (done before the materials and procedural changes), and monitoring by during this investigation by NIOSH investigators, Alaska Airlines, and AFA representatives (done after the majority of the materials and procedural changes), did not reveal a health hazard due to cabin air quality. While there was an initial indication that a source of CO might be present, follow up monitoring found that apparent peaks measured with the electrochemical CO dosimeters were of short duration, occurred on nearly all flights, and were probably due to gas or organic vapor interferences.

The interfering gases or vapors (probably VOCs) were not identified; however, they were found on nearly all non-incident flights monitored. Potential sources of organic vapors in the occupied areas include alcoholic beverages, cleaning products, furnishings, meal service, perfumes, deodorants, and lavatories. TWA concentrations of VOCs on the test flights were well below those that would cause noticeable effects in most people.

Environmental monitoring results, consistent with previous studies of commercial aircraft cabin air quality, indicated that cabin conditions commonly may not meet all ASHRAE comfort criteria; one of three test flights had an average CO_2 level exceeding 1000 ppm, two of three had rapid rates of temperature change, and all three had an average relative humidity below the comfort range. CO_2 levels prior to takeoff on two of the three test flights were well above 1000 ppm, indicating insufficient ventilation during gate time. Relatively large changes in air pressure were measured, but there was no indication that the cabin air pressures represented a health hazard or a deviation from MD-80 design and operation criteria. Previous studies of aircraft cabin air quality have found that these conditions are typical.

A plausible environmental source for the illness incidents was not found with either an inspection of a "problem" airplane ventilation system or a review of commercial cleaning products and other supplies in use (after the materials changes). For example, a plastic oven tray used to serve meals was found to emit a variety of VOCs at oven temperatures, but under worst-case working conditions exposures of health significance were not found.

Evaluation of air quality during incident flights was limited by their unpredictable and very infrequent occurrence among the approximately 40 airplanes involved. No practical, acceptably sensitive and selective air sampling method (for unknown contaminants), suitable for grab or continuous sampling, was found. Thus, it was not possible to arrange for satisfactory monitoring of air quality during an incident. Results of the 250-mL evacuated container grab sampling method used by Alaska Airlines during incident flights indicated that the air samples had been contaminated either by the containers or during the laboratory analysis (some of the contaminants were common laboratory solvents). NIOSH investigators advised the company (in June

1990) that this method.did not appear to be useful. Neither the 1-liter airbag, nor the MSHA container grab air sampling methods evaluated by NIOSH during the test flights were potentially useful for trace VOCs due to lack of sensitivity, and for the latter, due to contamination problems from the beeswax plug.

The acute symptoms reported by Alaska Airlines flight attendants were more like those reported among U.S. Air Force flight crew members involved in cockpit "exposure" incidents[49] than those found in a survey of flight-associated symptoms among flight attendants from three U.S.-based airlines.[50] In the Air Force study, various substances - most frequently oil - were identified as the origin of the smoke, fume, or odor reported, but in 36 (40%) of the 89 incidents the source remained unknown. In the flight attendant survey, fatigue, throat discomfort, musculoskeletal pains, and eye problems were all more prevalent than dizziness among the 1330 participants. This suggests that the Alaska Airlines incident reports, at least in large part, reflect unusual occurrences, not merely the recording of the most common work-related symptoms.

Neither the medical data nor the environmental findings support the hypothesis that CO exposure was a cause of any of the in-flight incidents. There are no medical or flight history data to suggest that abnormally low cabin pressure, humidity, or oxygen concentration were appreciable causative factors. A report prepared by a consultant to the AFA suggests ozone as a potential cause of the illnesses. If ozone were, in fact, a major contributory factor, irritant and respiratory effects, not neurologic and generalized systemic symptoms, would predominate;[50,51,52,53] and one would expect a greater likelihood of incidents among flights at higher latitudes,[50] which was not the case.

Based on the limited altitude information available, it is not possible to draw any definitive conclusions regarding the role of altitude in the reported illnesses, but the occurrence of some incidents at relatively low altitude and the absence of any mention of loss of cabin air pressure in the incident reports do not suggest low cabin air pressure as a cause of the illnesses.

The neurologic problems of unknown etiology, but temporally related to flight-associated incidents, are of concern. Although these most likely represent conditions unrelated to a flight-associated exposure, it is not possible to establish retrospectively the absence of such an exposure. None of the known toxic substances to which flight attendants might be episodically exposed (vehicle exhaust on the ground; fuels, lubricants, and other fluids and materials used in aircraft; smoke or other emissions from galley appliances or malfunctioning electrical or mechanical equipment; or substances plausibly brought aboard by passengers or stored in the cargo compartment), however, would likely be present in sufficient concentrations in the cabin air to cause this kind of persistent neurologic effect other than by some postulated (but thus far undocumented) idiosyncratic or immunologic reaction.

Although probable explanations for some of the illnesses among flight attendants have been identified, the cause of most of the incidents remains undetermined, as does the reason for their increased rate of occurrence during the Spring of 1990 (but not, apparently, 1991). The decreased rate of occurrence after June 1990 followed Alaska Airlines implementation of the materials and procedural changes made in response to incident reports, but since there were no significant differences between the pre- and post-change environmental findings, we could not document that these changes were responsible for the decrease. Neither the incident reports nor the environmental investigations provide a satisfactory explanation for the seemingly higher rate of incidents in MD-80 700's collectively, or in airplane number 784. None of the records available to us, nor our own environmental evaluation, however, has addressed the possible roles of physiologic, ergonomic, work organizational, or non-occupational psychologic stresses as contributors to the illness episodes. A comprehensive evaluation that would address all these factors is beyond the scope of NIOSH's health hazard evaluation program.

RECOMMENDATIONS

1. Alaska Airlines should continue to maintain a log of all reported illness incidents on its commercial flights. This log should include pertinent information such as time, date, crew members affected, symptoms reported, severity and duration of symptoms, route, flight number, load factor, cruising altitude, cabin altitude, airplane identification, time at gate, comments, and exposures identified. It is entirely possible that Alaska Airlines' incidence of flight-related illness is not unusual for a commercial airline, but only by keeping records over time can comparisons be made. (This recordkeeping would be appropriate for any commercial airline).

2. The company should continue to investigate possible causes of illness incidents in a timely manner. Given the results of this investigation, it will probably not be fruitful to focus solely on air contaminants; future investigations should include examination of the possible roles of other occupational stressors that can produce symptoms and complaints sometimes blamed on contaminated air. These other stressors should include other environmental (lighting, noise, vibration), ergonomic, and psychosocial (human relations, job satisfaction, organizational factors) stressors.

3. Alaska Airlines should utilize a joint labor/management safety and health committee to direct the future investigations of employee health complaints and illnesses and to advise the company on implementation of appropriate controls for specific job stressors which may be identified.

4. Fresh air ventilation to airplane cabin areas should be increased during gate time to reduce CO_2 levels and dilute air contaminants. To the extent possible, the air supplied should be free of carbon monoxide, fuel vapors, and other contaminants which are normally present near aircraft and service vehicles. Alaska Airlines should also consider installation of continuous CO_2 monitoring devices in selected airplanes (in the return or recirculated air plenums) for the purpose of gathering more information about cabin ventilation efficiency during routine flights.

5. Alaska Airlines should continue the process of reviewing all commercial chemical products used in or around aircraft for environmental and health considerations prior to purchase or use. Employee representatives (including flight attendants and end users of the products) should be formally involved in the chemical review and selection process.

REFERENCES

1. Nagda, N, R Fortmann, M Koontz, S Baker, and M Ginevan [1989]. Airliner cabin environment: contaminant measurements, health risks, and mitigation options. Washington, D.C.: Report prepared for the U.S. Department of Transportation, Report No. DOT-P-15-89-5.

2. National Research Council [1986]. The airliner cabin environment: air quality and safety. Washington, D.C.: National Academy Press.

3. NIOSH [1984]. NIOSH manual of analytical methods, 3rd edition, vol. 1 and 2, with 1985, 1987 and 1989 supplements. Eller, P., Editor. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 84-100.

4. Kreiss KK, Hodgson MJ [1984]. Building associated epidemics. In: Walsh PJ, Dudney CS, Copenhaver ED, eds. Indoor air quality. Boca Raton, FL: CRC Press, pp 87-108.

5. Gammage RR, Kaye SV, eds. [1985]. Indoor air and human health: Proceedings of the Seventh Life Sciences Symposium. Chelsea, MI: Lewis Publishers, Inc.

6. Woods JE, Drewry GM, Morey PR [1987]. Office worker perceptions of indoor air quality effects on discomfort and performance. In: Seifert B, Esdorn H, Fischer

M, et al, eds. Indoor air '87, Proceedings of the 4th International Conference on Indoor Air Quality and Climate. Berlin Institute for Water, Soil and Air Hygiene.

7. Skov P, Valbjorn O [1987]. Danish indoor climate study group. The "sick" building syndrome in the office environment: The Danish town hall study. Environ Int 13:399-349.

8. Burge S, Hedge A, Wilson S, Bass JH, Robertson A [1987]. Sick building syndrome: a study of 4373 office workers. Ann Occup Hyg 31:493-504.

9. Kreiss K [1989]. The epidemiology of building-related complaints and illness. Occupational Medicine: State of the Art Reviews. 4(4):575-592.

10. Norback D, Michel I, Widstrom J [1990]. Indoor air quality and personal factors related to the sick building syndrome. Scan J Work Environ Health 16:121-128.

11. Wallace LA, Nelson CJ, Dunteman G [1991]. Workplace characteristics associated with health and comfort concerns in three office buildings in Washington, D.C. In: Geshwiler M, Montgomery L, and Moran M, eds. Healthy buildings. Proceedings of the ASHRAE/ICBRSD conference IAQ'91. Atlanta, GA. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

12. Haghighat F, Donnini G, D'Addario R [1992]. Relationship between occupant discomfort as perceived and as measured objectively. Indoor Environ 1:112-118.

13. NIOSH [1991]. Hazard evaluation and technical assistance report: Library of Congress Madison Building, Washington, D.C. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, NIOSH Report No. HETA 88-364-2104 - Vol. III.

14. Skov P, Valbjørn O, Pedersen BV [1989]. Influence of personal characteristics, job-related factors, and psychosocial factors on the sick building syndrome. Scand J Work Environ Health 15:286-295.

15. Boxer PA [1990]. Indoor air quality: A psychosocial perspective. J Occup Med 32(5):425-428.

16. Baker DB [1989]. Social and organizational factors in office building-associated illness. Occupational Medicine: State of the Art Reviews. 4(4):607-624.

17. CDC [1988]. NIOSH recommendations for occupational safety and health standards 1988. MMWR 37(S-7): 1-29 (1988).

18. ACGIH [1992]. 1992-1993 Threshold Limit Values for chemical substances and physical agents and Biological Exposure Indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

19. Code of Federal Regulations [1989]. Air contaminants-permissible exposure limits. Title 29 Code of Federal Regulations, 29 CFR Part 1910.1000, OSHA 3112, Washington, DC: U.S. Government Printing Office, Federal Register.

20. ASHRAE [1990]. Ventilation for acceptable indoor air quality. Atlanta, GA: American Society of Heating, Refrigerating, and Air-conditioning Engineers. ANSI/ASHRAE Standard 62-1989.

21. ASHRAE [1981]. Thermal environmental conditions for human occupancy. Atlanta, GA: American Society for Heating, Refrigerating, and Air-conditioning Engineers. ANSI/ASHRAE Standard 55-1981.

22. 14 CFR Part 25.831 [1992]. Code of Federal Regulations. Washington, D.C.: U.S. Government Printing Office.

23. Zenz, C, [1988]. Occupational medical considerations in the aviation industry. In: Zenz, C, ed. Occupational medicine, principles and practical applications, 2nd Ed. Chicago, IL: Year Book Medical Publishers, pp. 910-912.

24. 14 CFR Part 25.841 [1992]. Code of Federal Regulations. Washington, D.C.: U.S. Government Printing Office.

25. O'Donnell, A, Donnini, G and Nguyen, V. Air quality, ventilation, temperature and humidity in aircraft. ASHRAE Journal, April 1991 (42-46).

26. 14 CFR Part 25.831(a)(2) [1992]. Code of Federal Regulations. Washington, D.C.: U.S. Government Printing Office.

27. Hathaway G, et al, eds. [1991]. Carbon monoxide. In: Proctor and Hughes' Chemical hazards of the workplace, 3rd ed. New York, NY: Van Nostrand Reinhold, pp 141-144.

28. NIOSH [1972]. Criteria for a recommended standard: occupational exposure to carbon monoxide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health. HSM (NIOSH) Publication No. 73-11000.

29. National Research Council [1986]. The airliner cabin environment: air quality and safety. Washington, D.C.: National Academy Press, p 131.

30. 14 CFR Part 25.831(a)(1) [1992]. Code of Federal Regulations. Washington, D.C.: U.S. Government Printing Office.

31. Levin H [1989]. Building materials and indoor air quality. Occupational Medicine: State of the Art Reviews. 4(4):667-694.

32. Mage D and Gammage R [1985]. Evaluation of changes in indoor air quality occurring over the past several decades. In: Indoor air and human health, Gammage R and Kaye S, eds. Chelsea, MI: Lewis Publishers, pp 5-38.

33. Manahan S. Environmental chemistry, 4th ed. Monterey, CA: Brooks/Cole Publishing Co, p 287.

34. Parmeggiani, L, ed. [1983]. Encyclopedia of occupational health and safety, third edition. Geneva, Switzerland: International Labour Office. Volumes 1 and 2, pp. 1086-1087.

35. Sederquist, R [1987]. Operating and instruction manual for MAST model 727-3 ozone monitor. Reno, NV: Mast Development Co, Air Monitoring Division, product information.

36. Misra JC, Alexander S [1978]. Hyperventilation syndrome: a brief review. JAMA 240:2093-2096.

37. Hill O [1979]. The hyperventilation syndrome. Brit J Psychiat 135:367-368.

38. Lancet [1982]. Hyperventilation syndrome (editorial). Lancet ii:1438-1439.

39. Lum LC [1987]. Hyperventilation syndromes in medicine and psychiatry: a review. J R Soc Med 80:229-231.

40. Cowley DS, Roy-Byrne PP [1987]. Hyperventilation and panic disorder. Am J Med 83:929-937.

41. Plum F, Posner JB [1988]. Disturbances of consciousness and arousal. Chapter 457. In: Wyngaarden JB, Smith LH Jr., eds. Cecil textbook of medicine. 18th ed. Philadelphia, PA: W.B. Saunders Co., pp. 2075-2076.

42. Phillipson EA [1991]. Disorders of ventilation. Chapter 217. In: Wilson JD, Braunwald E, Isselbacher KJ, Petersdorf RG, Martin JB, Fauci AS, Root RK, eds. Harrison's principles of internal medicine. 12th ed. New York, NY: McGraw-Hill, p. 1121.

43. American Psychiatric Association [1987]. Diagnostic and statistical manual of mental disorders. 3rd ed., rev. Washington, DC: American Psychiatric Association, pp. 235-239.

44. Amdur MO, Doull J, Klaassen CD, eds. [1991]. Casarett and Doull's toxicology. 4th ed. New York, NY: Macmillan Publishing Co., pp. 267-268.

45. Baselt RC [1988]. Biological monitoring methods for industrial chemicals. 2nd ed. Littleton, MA: PSG Publishing Co., p. 69.

46. Meredith T. Vale A [1988]. Carbon monoxide poisoning. Br Med J 296:77-79.

47. Wallach J [1986]. Interpretation of diagnostic tests. 4th ed. Boston, MA: Little, Brown and Co., pp. 15-16.

48. American College of Physicians [1989]. Clinical ecology. Ann Int Med; 111:168-178.

49. Rayman RB, McNaughton GB [1983]. Smoke/fumes in the cockpit. Aviat Space Environ Med 54:738-740.

50. Reed D, Glaser S, Kaldor J [1980]. Ozone toxicity symptoms among flight attendants. Am J Ind Med 1:43-54.

51. Mohler SR [1986]. Aerospace medicine. Chapter 20. In: Last JM, ed. Maxcy-Rosenau public health and preventive medicine. 12th ed. Norwalk, CT: Appleton-Century-Crofts, pp. 877-878.

52. Hathaway G et al, eds. [1991]. Ozone. In: Proctor and Hughes' chemical hazards of the workplace. 3rd ed. New York, NY: Van Nostrand Reinhold, pp. 450-452.

53. Smith AB, Zenz C [1988]. Other important and widely used chemicals. Chapter 47. In: Zenz C, ed. Occupational medicine: principles and practical applications. 2nd ed. Chicago, IL: Year Book Medical Publishers, p. 753.

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Appendix I

Adjustment of the NIOSH REL for CO for Work at Altitude

In the NIOSH document *Criteria for a Recommended Standard...Occupational Exposure to Carbon Monoxide*, the Coburn, Foster, Kane (CFK) equation was used to develop the NIOSH REL. The REL-TWA for CO of 35 parts per million (ppm) was the maximum exposure level that was calculated to result in an acceptable (≤5%) end of shift COHb level for workers exposed at sea level, sedentary level of work activity, up to 8 hours/day. The CFK equation is:

$$[CO] \text{ that results in 5\% COHb} = \frac{1316\{AC - V_{CO}B + a(V_{CO}B - AD)\}}{1 - a}$$

The variables in the above equations are defined as:

$$A = \frac{P_{c\text{-}O2}}{M(O_2Hb)} \qquad B = \frac{1}{D_L} + \frac{P_L}{V_A}$$

$$a = e^{-AT/V_bB}$$

C = COHb concentration at time T; 0.01 mL COHb/mL blood (5% COHb).

D = background COHb level at time=0; 0.0015 mL COHb/mL blood (0.75%).

V_{CO} = rate of endogenous CO production; 0.007 mL/min.

V_b = blood volume; 5500 mL.

O_2Hb = oxyhemoglobin concentration; 0.2 mL/mL blood.

M = ratio of affinity of CO vs. O_2 to hemoglobin; 218.

T = length of workshift in minutes; 480 minutes.

D_L = CO diffusion rate through lungs for sedentary level of activity; 30 mL/min/mm Hg.

V_A = lung ventilation rate for sedentary level of activity; 6000 mL/min.

P_L = dry barometric pressure in the lungs in mm Hg. In the NIOSH criteria document, NIOSH used the standard atmospheric pressure at sea level minus the pressure of water vapor at body temperature (760 mm Hg - 47 mm Hg = 713 mm Hg).

$P_{c\text{-}O2}$ = partial pressure of oxygen in the capillaries; 100 mm Hg.

Adjustment of the NIOSH REL

Many of the CFK equation variables are constants based on physiological processes. Some of the variables can be adjusted for the typical work environment of flight attendants at altitude. For flight attendants working an 8-hour shift at a cabin altitude of 8000 ft with a light level of work activity, the CFK equation predicts that an acceptable ($\leq$ 5%) COHb level will be maintained if CO exposure does not exceed 20 ppm, as an 8-hr TWA. To calculate this adjusted REL-TWA, the following assumptions were made:

Level of Work Activity (D_L and V_A)

The values for D_L and V_A representing three categories of physical work activity, sedentary, light, and heavy:

Work Activity Level	D_L	V_A
Sedentary	30 mL/min/mm Hg	6000 mL/min
Light	40 mL/min/mm Hg	18000 mL/min
Heavy	60 mL/min/mm Hg	30000 mL/min

The above values for a light work activity level were used to represent the work level of flight attendants.

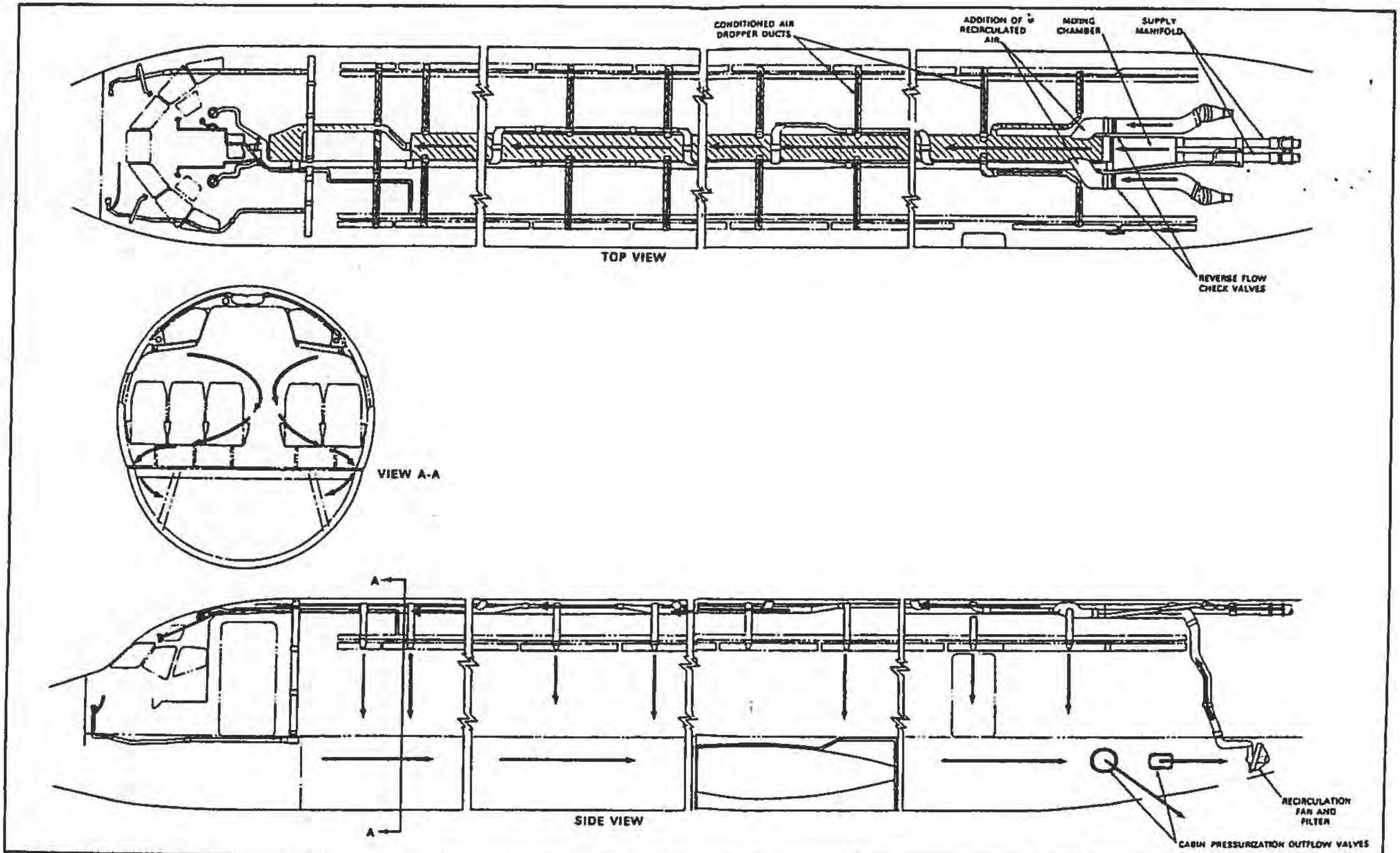
Altitude (P_L and $P_{C\text{-}02}$)

The P_L and $P_{C\text{-}02}$ variables are directly affected by altitude. At the MD-80 maximum cruising altitude of 37,000 ft, the cabin altitude is 8,000 ft. The cabin altitudes for other Alaska Airlines airplanes (such as the Boeing 727-200), are less than 8,000 ft at their respective maximum cruising altitudes. A cabin altitude of 8000 ft was used to adjust the REL; resulting in the following changes in P_L and $P_{C\text{-}02}$:

$$P_L = 562 \text{ mm Hg} - 47 \text{ mm Hg} = 515 \text{ mm Hg.}$$

$$P_{C\text{-}02} = P_L \times 0.21 - 45$$

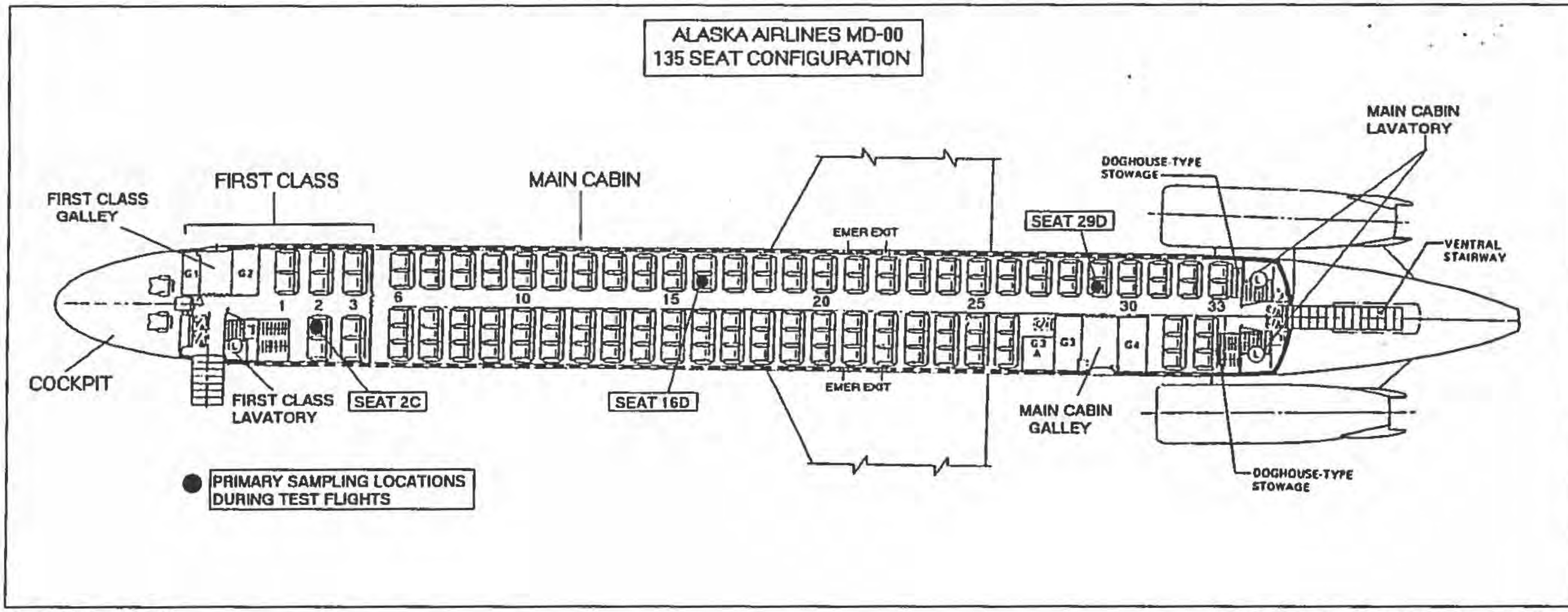
Figure 1
MD-80 Cabin Air Distribution
Alaska Airlines HETA 90-226



Cabin Air Distribution

Figure courtesy of McDonnell Douglas Corporation

Figure 2
Alaska Airlines MD-80 700 Series Cabin Layout
Alaska Airlines, HETA 90-226

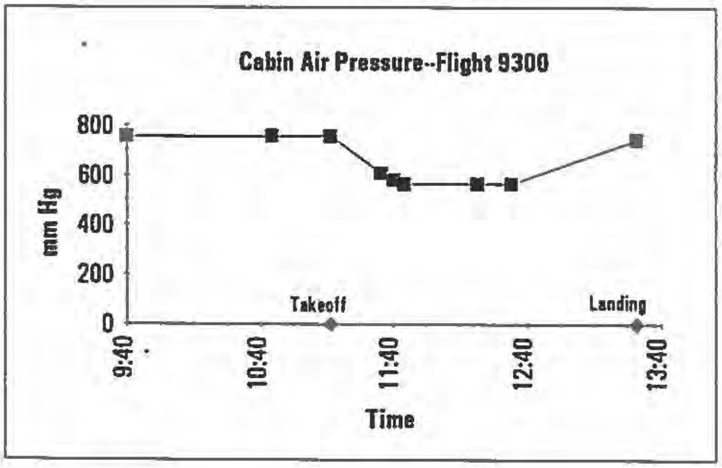


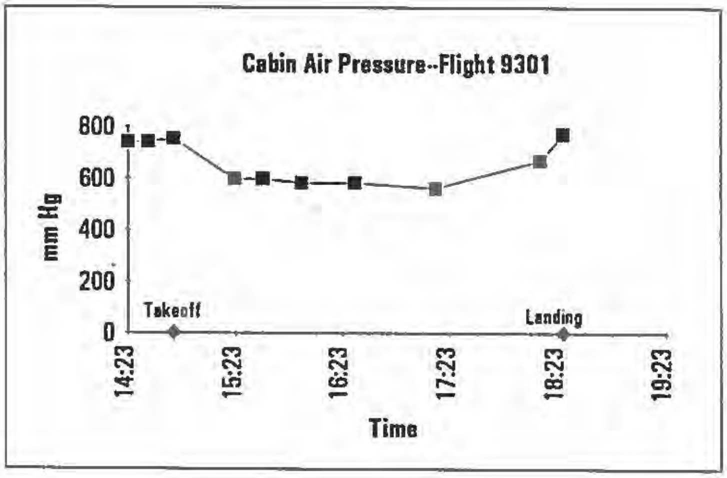
Alaska Airlines MD-80

Adapted from figure provided by Alaska Airlines

Figure 3
Cabin Air Pressure Measurements for Three Test Flights
July 10-11, 1990

Alaska Airlines HETA 90-226





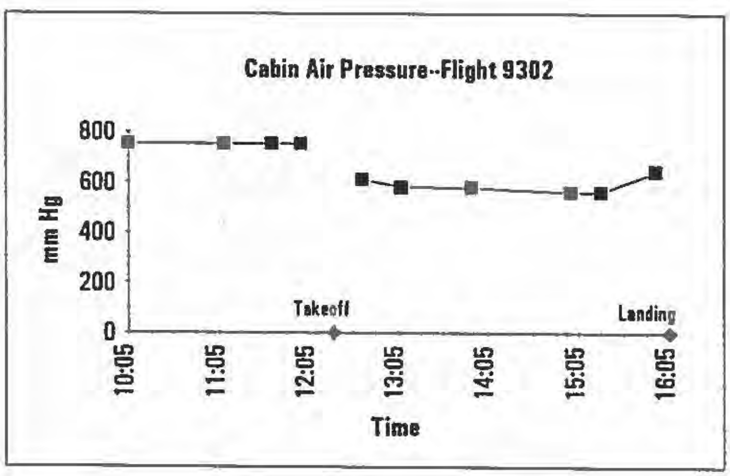
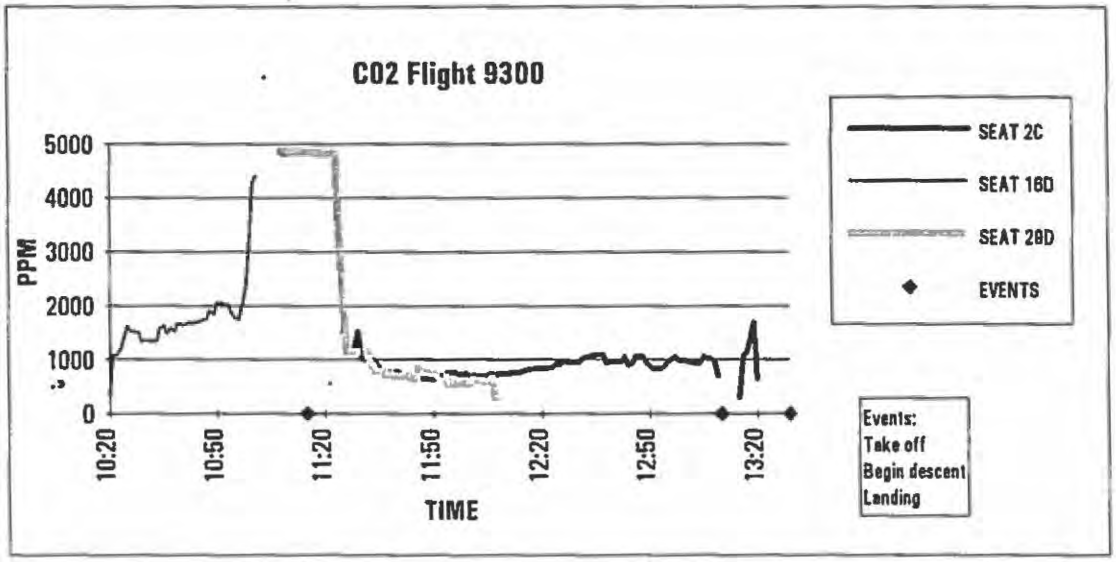
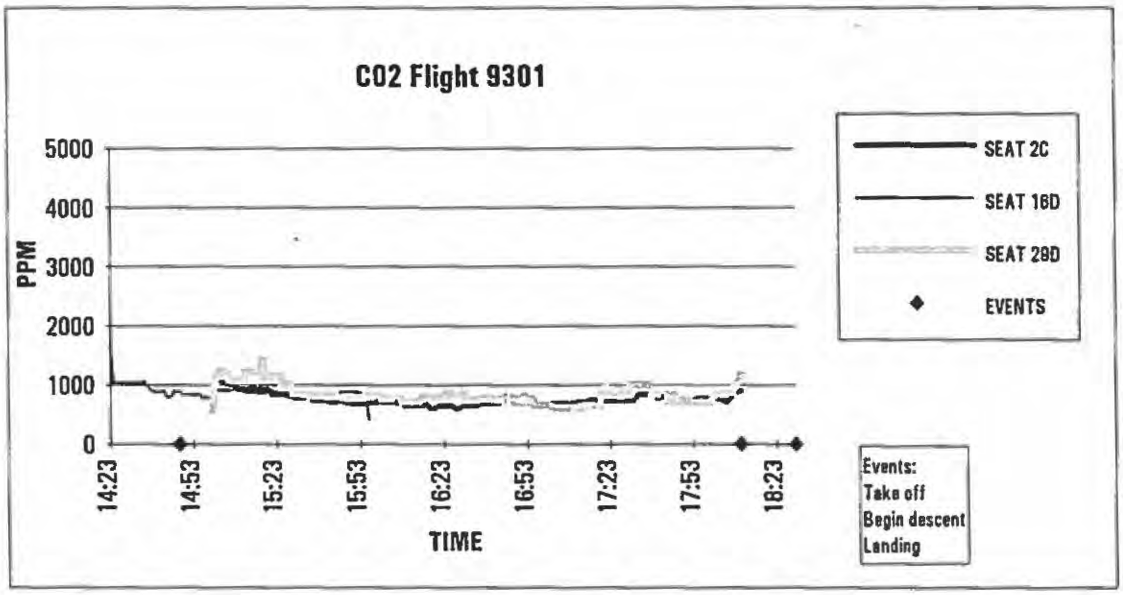


Figure 4
CO2 Measurements by Seat Location--Test Flights
July 10-11, 1990
Alaska Airlines HETA 90-226





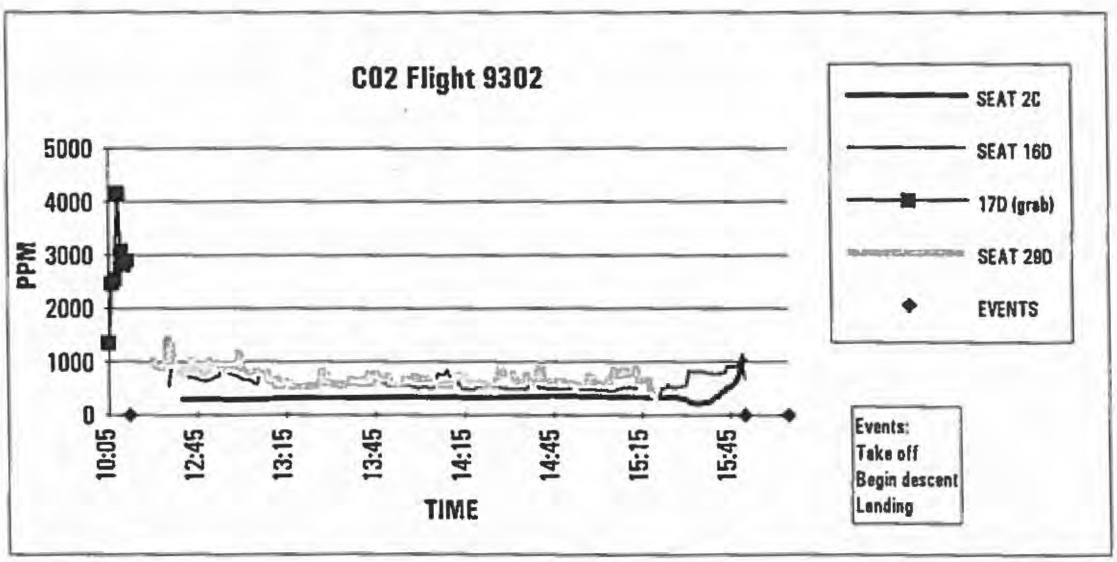
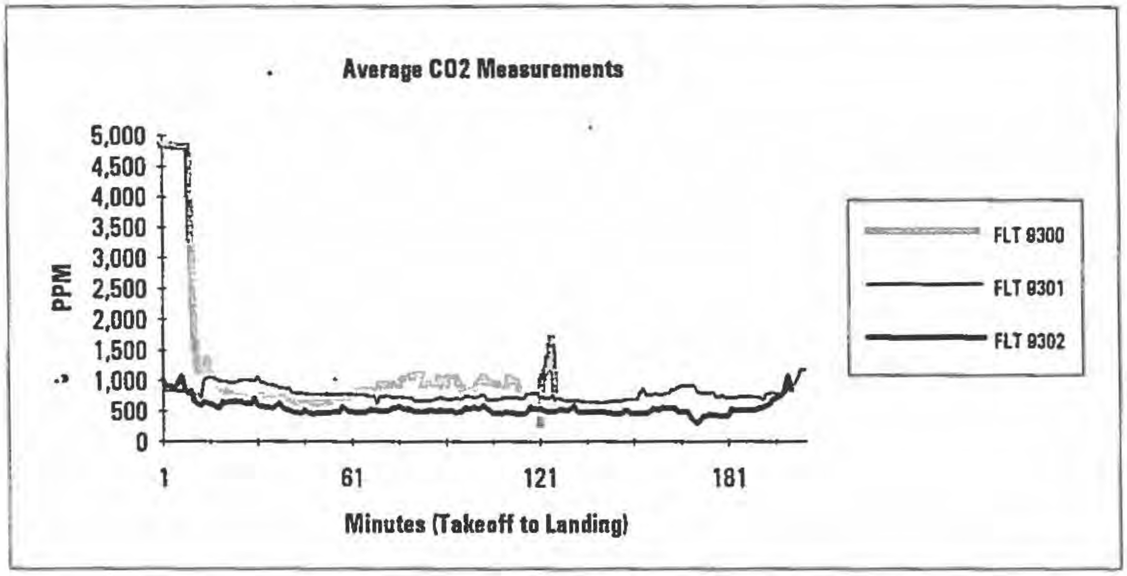
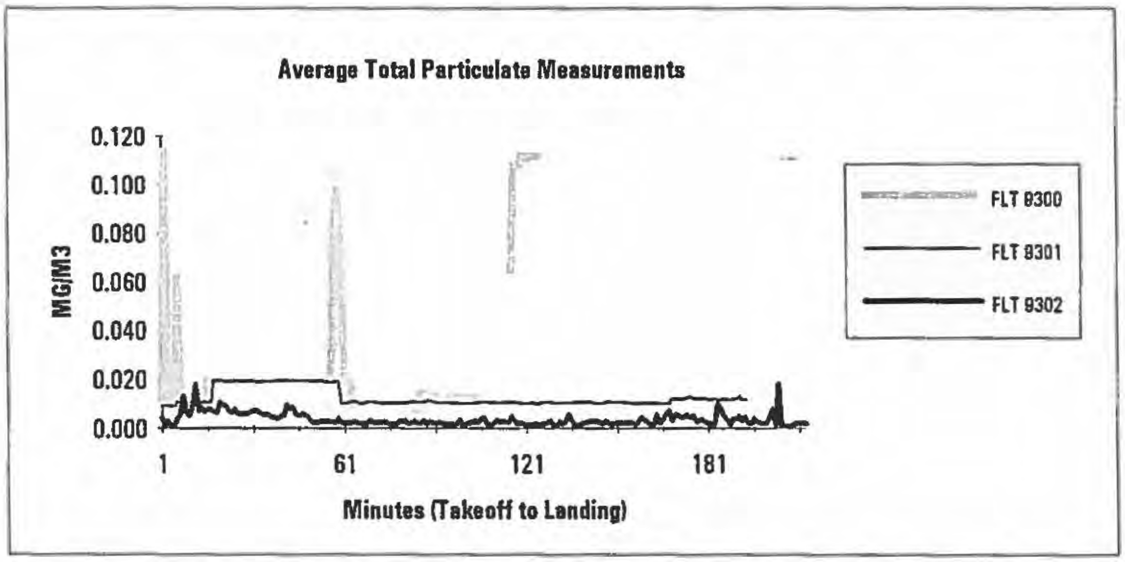


Figure 5
Average Measurements for Test Flights (Take off to Landing)
July 10-11, 1990
Alaska Airlines HETA 90-226





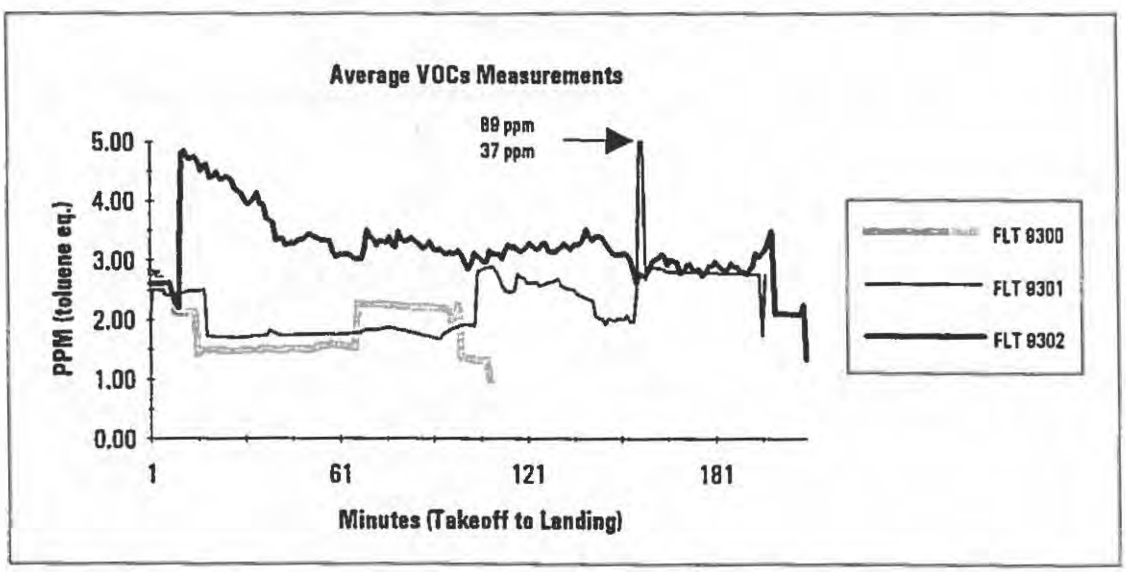


Figure 6
Example of Miscalibrated CO Dosimeter Results--Test Flight 9302
July 11, 1990

Alaska Airlines HETA 90-226

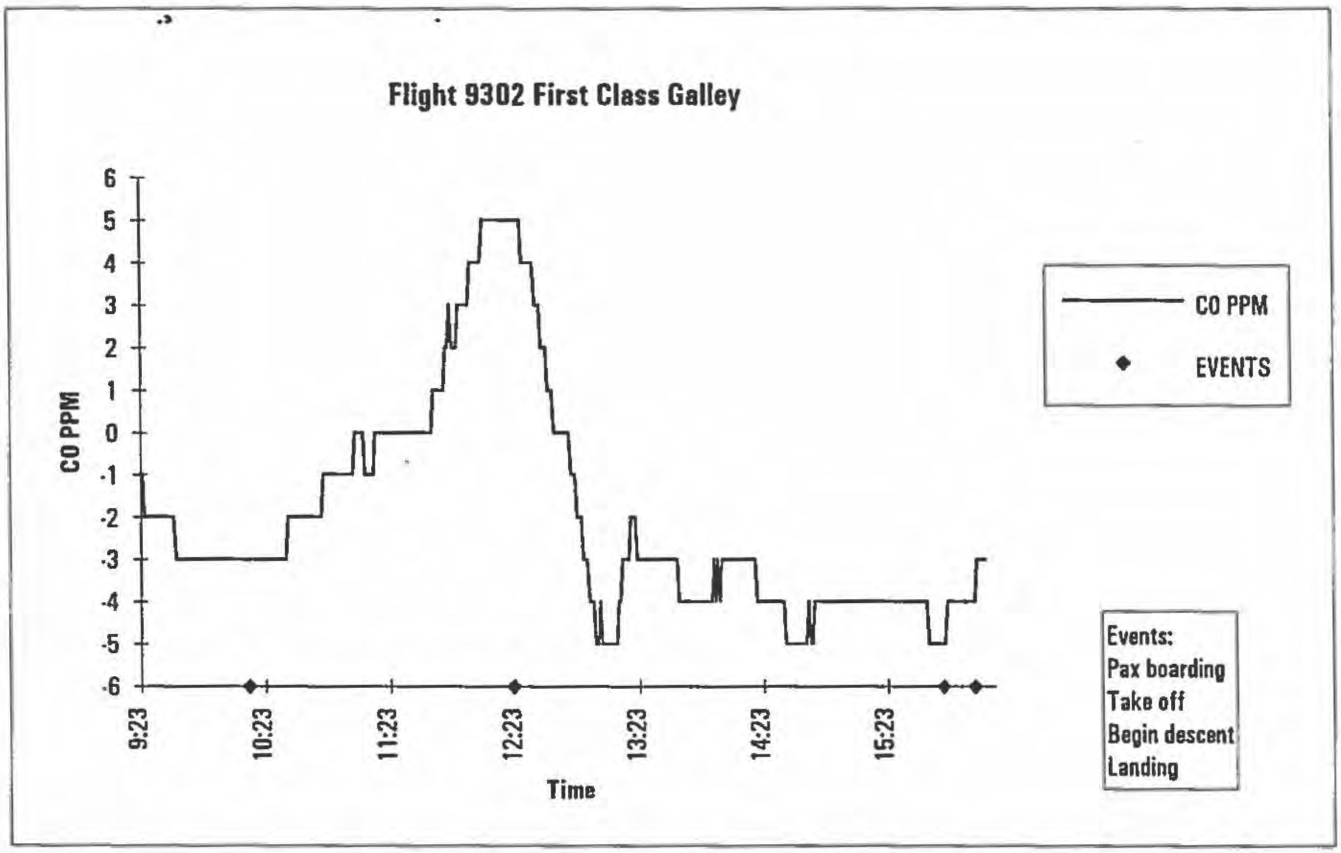
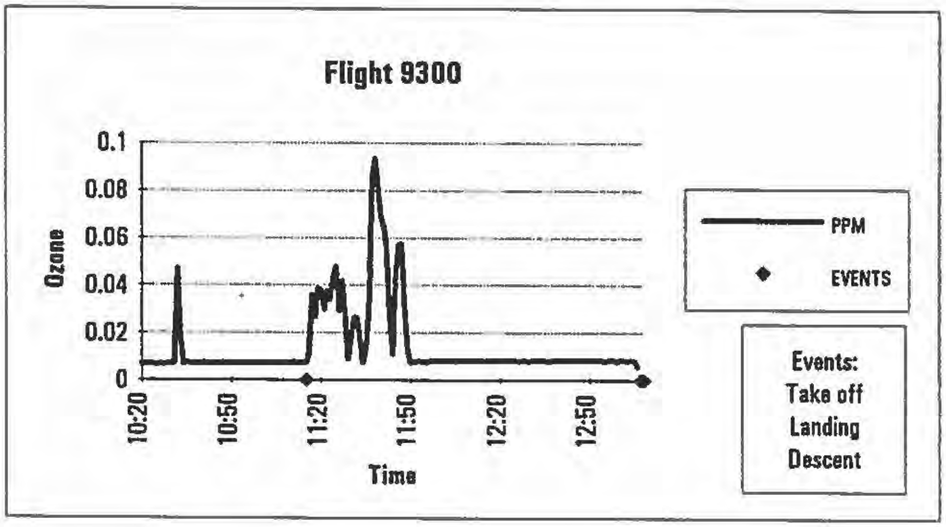
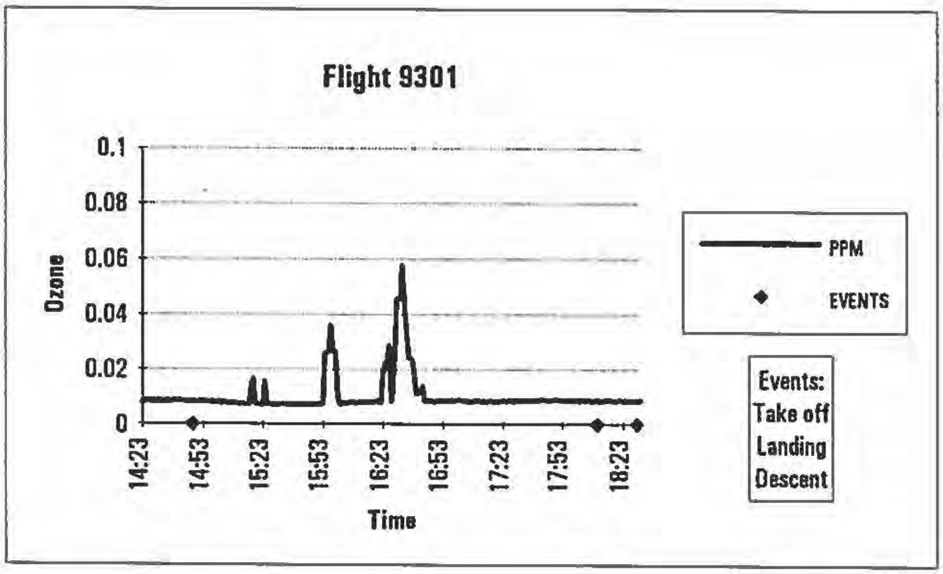


Figure 7
Results of Direct-Reading Ozone Measurement
Test Flights
July 10-11, 1990

Alaska Airlines, HETA 90-226



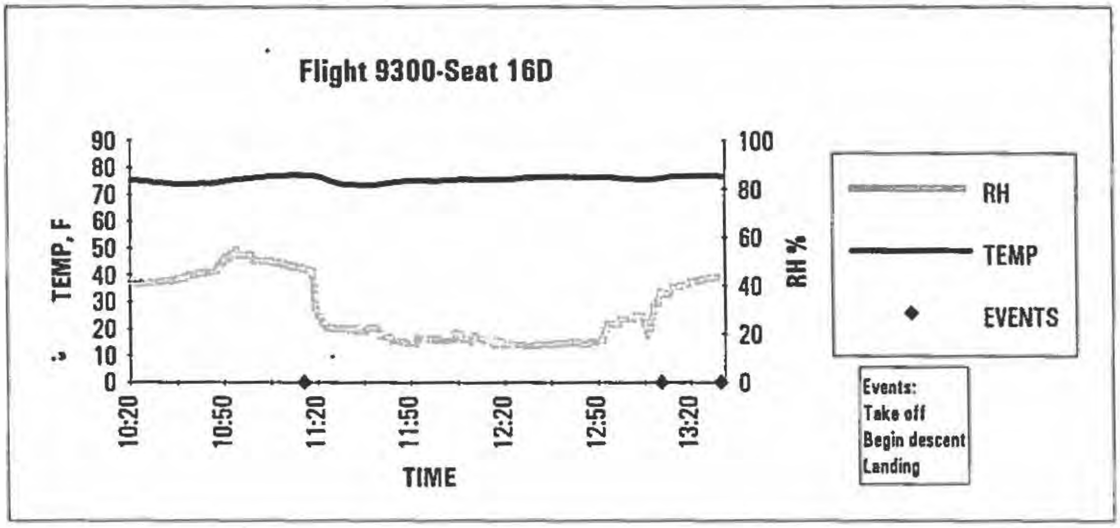


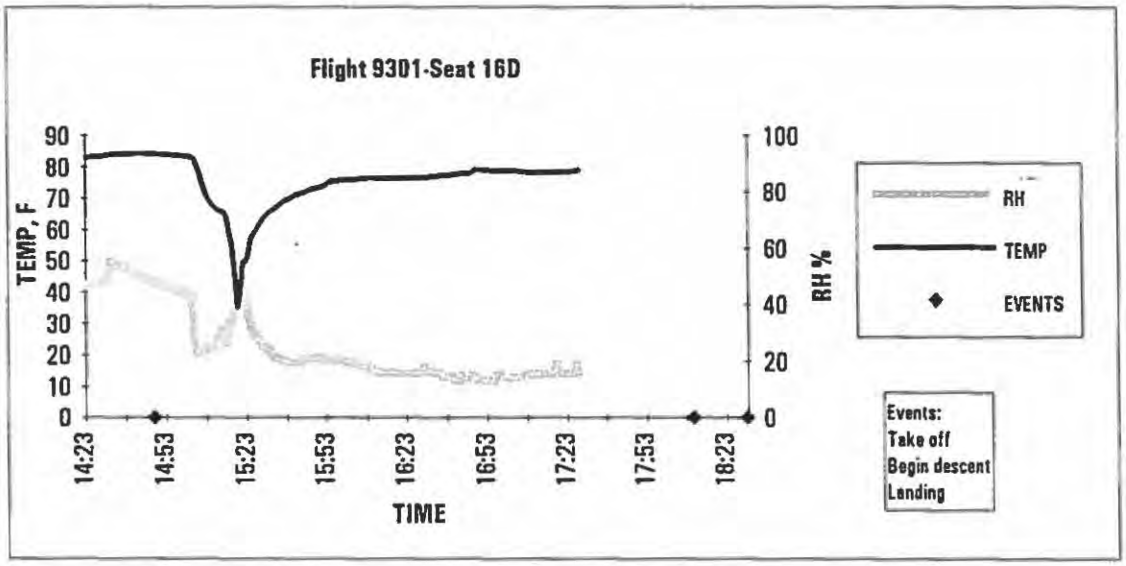
SUMMARY

Flight and Location	Sampling Times		OZONE (PPM)			
	Start	Stop	Mean	Min	Max	Max-time
Flt 9300--Seat 16D	10:20	13:06	0.014	0.006	0.093	11:38
Flt 9301--Seat 16D	14:23	18:32	0.01	0.007	0.058	16:33
Flt 9302--Seat 16D *	10:05	15:56	0.005	<0.001	0.060	15:56

* Datalogger record lost, results are for 12 instantaneous readings.

Figure 8
Temperature and Relative Humidity Measurements--Test Flights
July 10-11, 1990
Alaska Airlines HETA 90-226





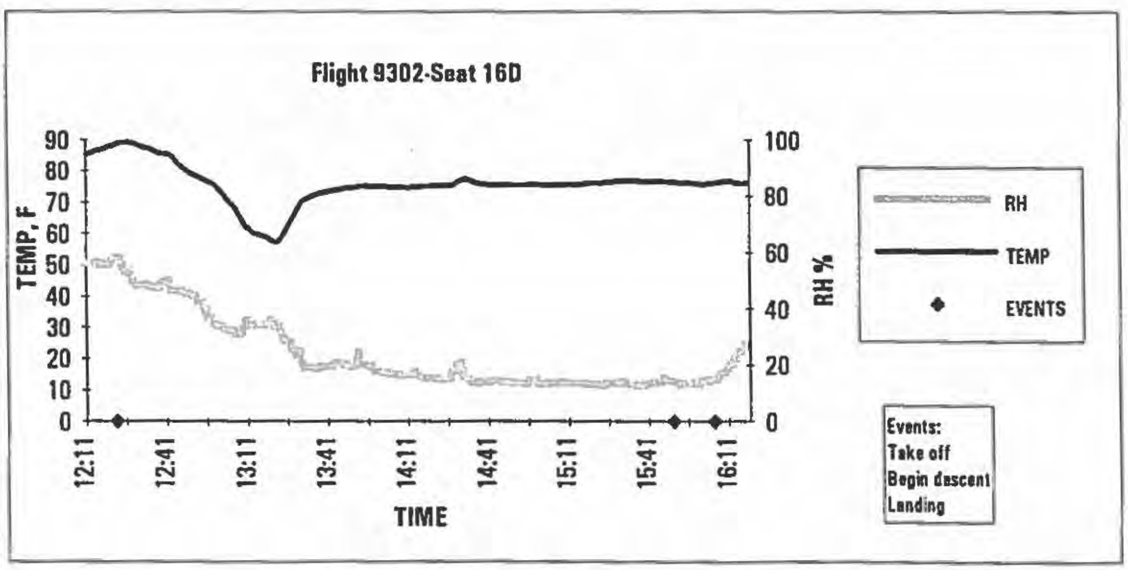
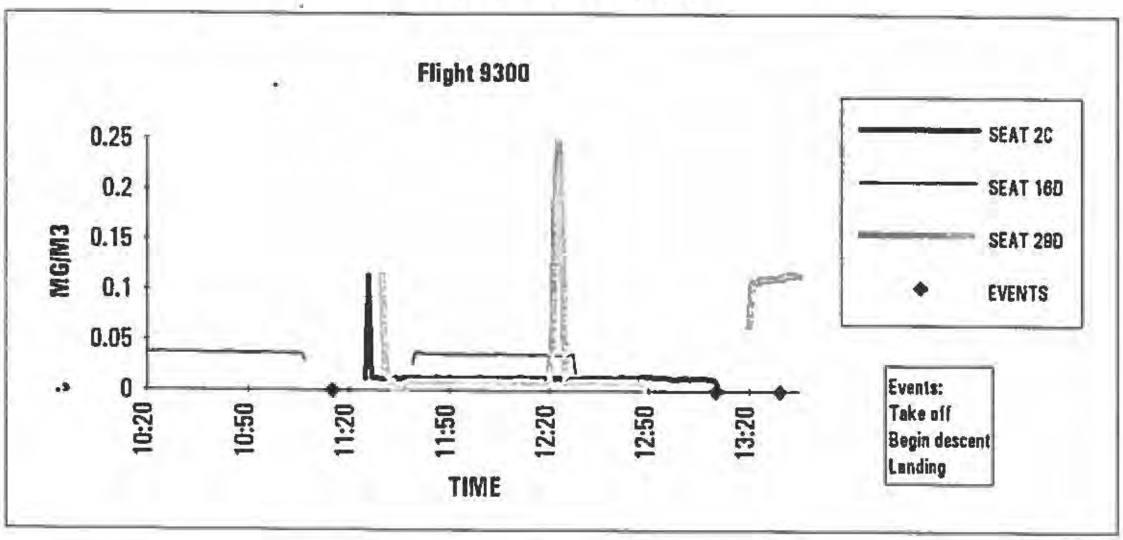
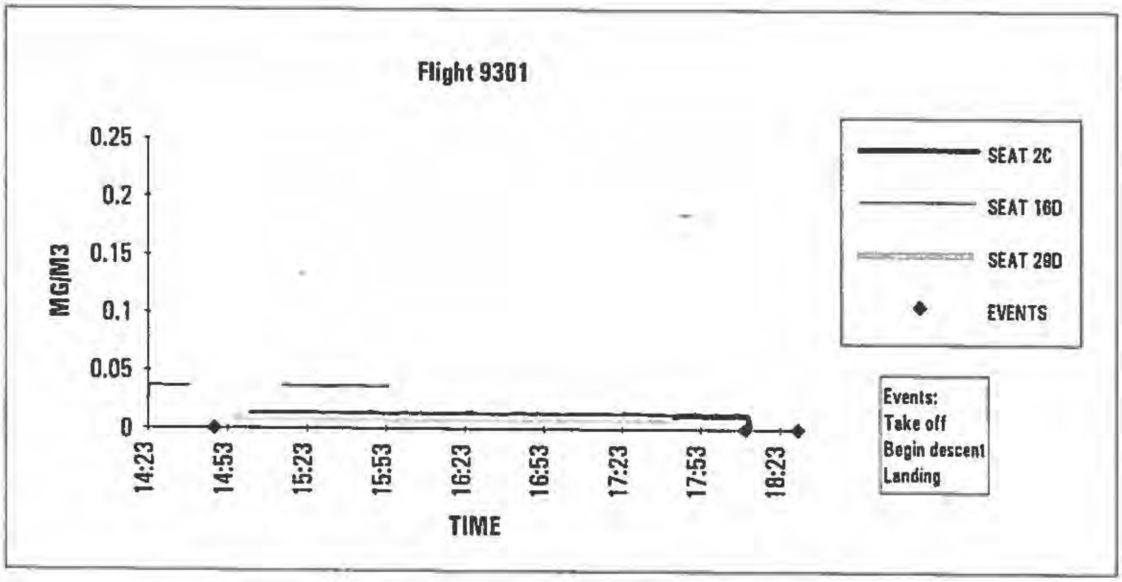


Figure 9
Total Particulate Measurements by Seat Location--Test Flights
July 10-11, 1990
Alaska Airlines HETA 90-226





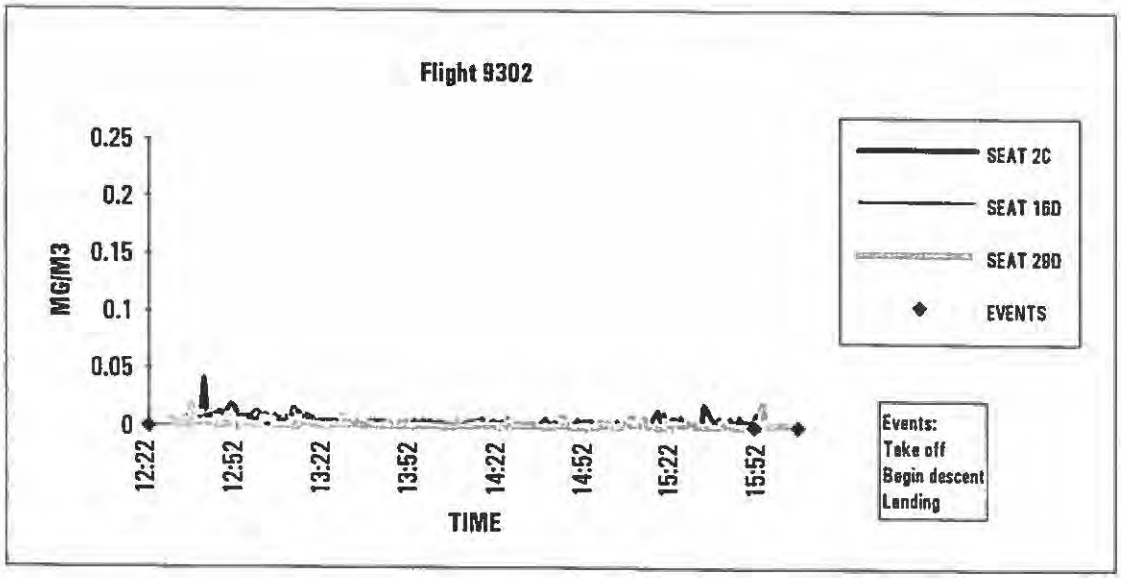
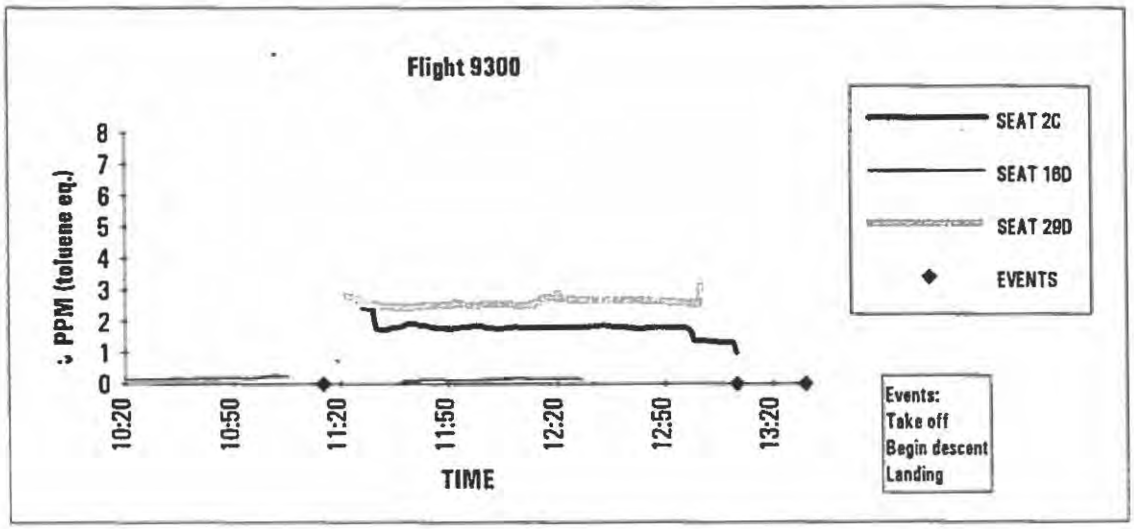
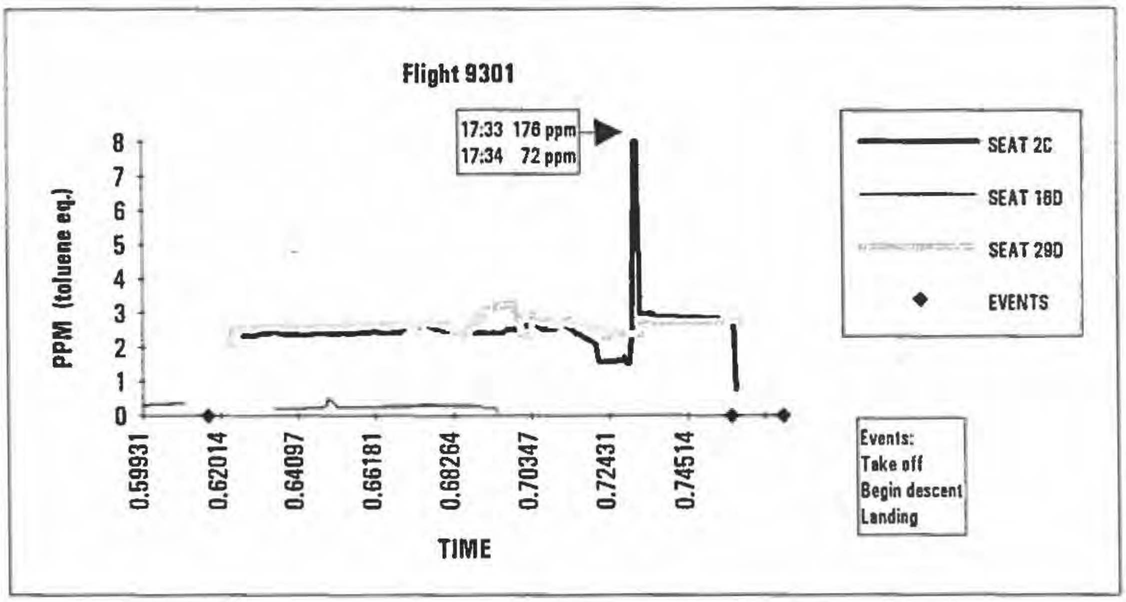


Figure 10
VOCs Measurements (PID) by Seat Location--Test Flights
July 10-11, 1990
Alaska Airlines HETA 90-226





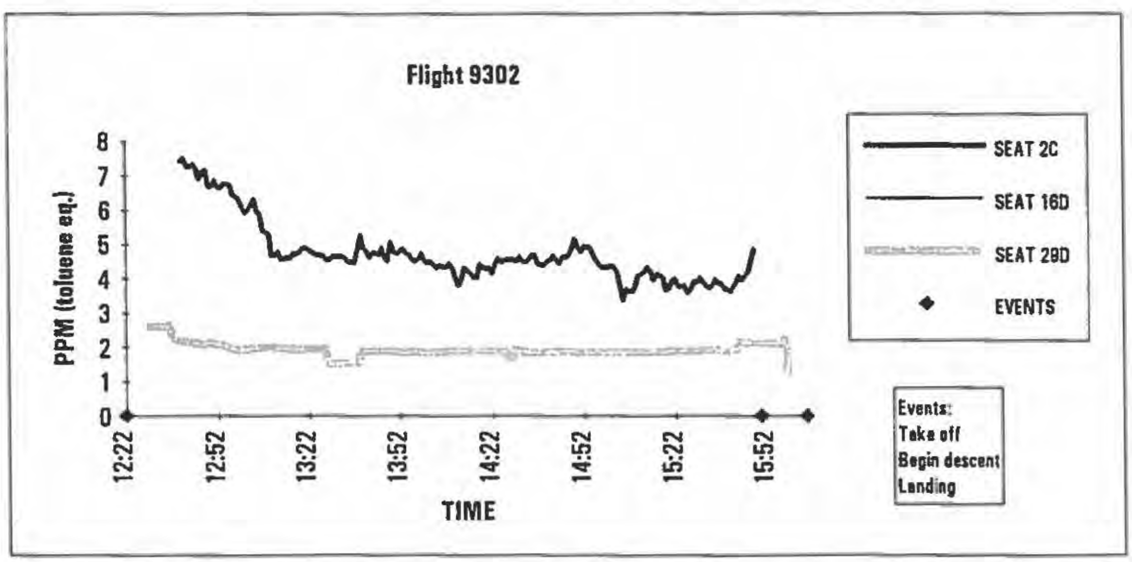


Figure 11
Paired Dosimeter and Grab Sample Results for CO
Main Cabin Flight Attendant--Flight 183
November 19, 1990
Alaska Airlines HETA 90-226

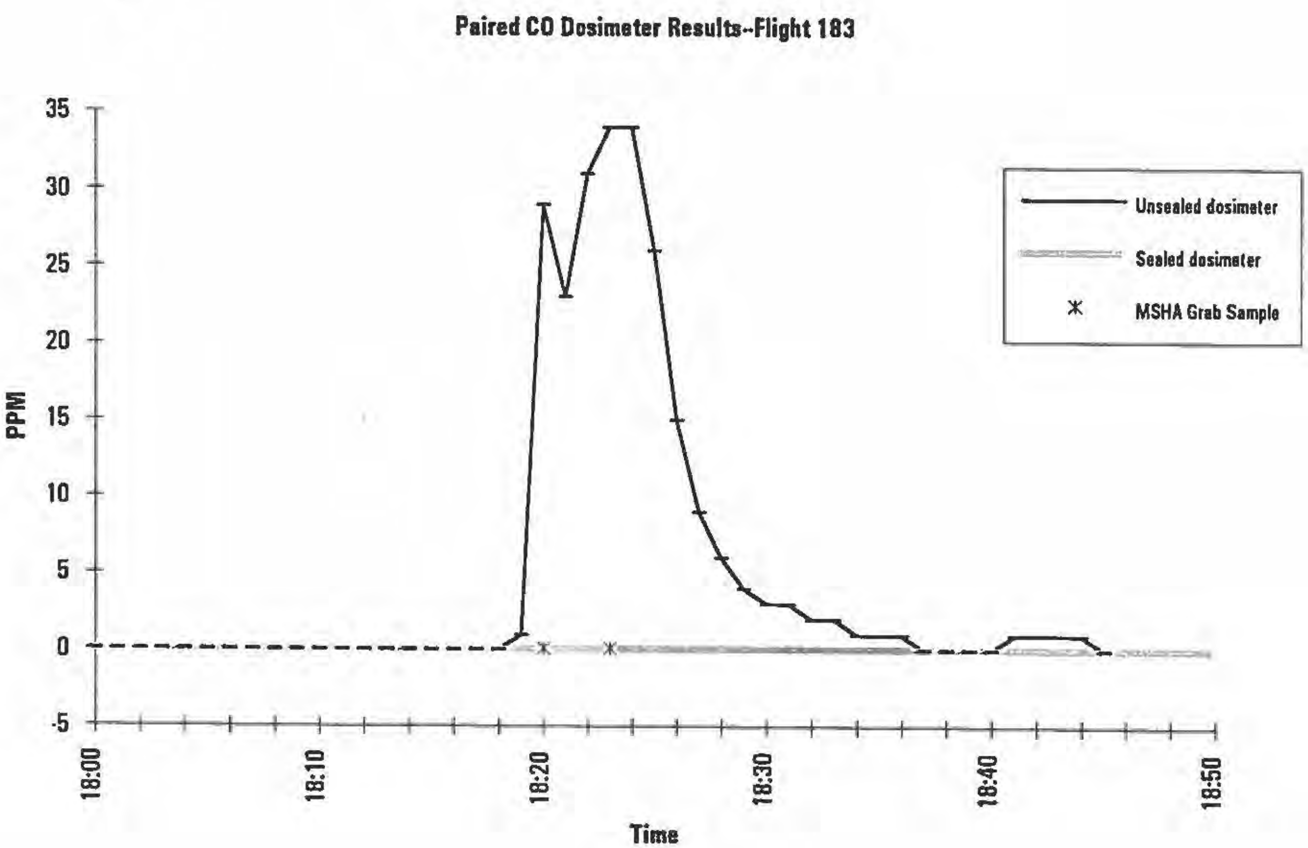


Table 1
Flight Conditions during Three Test Flights
July 10-11, 1990
Alaska Airlines HETA 90-226

FLIGHT CONDITIONS	TEST FLIGHT 9300	TEST FLIGHT 9301	TEST FLIGHT 9302
Date	7/10/90	7/10/90	7/11/90
Criteria	"Normal"	"Worst case"	"Worst case"
Airplane number (both were MD-82s)	784	784	785
Route	Seattle/Burbank	Burbank/Seattle	Seattle/(Calif.)/Seattle [1]
Passenger capacity	135	135	135
First class passengers	10	9	9
Coach passengers	78 [2]	111 [2]	111 [2]
Passenger Load (%)	65%	89%	89%
Flight Attendent Crew	4	4	4
Flight crew boarding	9:45	13:30	9:50
Passenger boarding	10:40	13:30	10:15
Push back	11:05	14:39	10:44
Total gate time	1:20 [3]	1:09	0:54
Take off	11:15	14:48	12:22
Attain cruising altitude	11:45	16:36	15:04
Begin final descent (seat belt light)	13:10	18:10	15:50
Landing	13:29	18:30	16:05
Total flight time	2:14	3:42	3:43
Cruising altitude, ft	37,000	37,000	37,000
Maximum cabin pressure, mm Hg (time)	755 (11:05)	770 (18:30)	751 (12:00)
Minimum cabin altitude, ft	453	558	558
Minimum cabin air pressure, mm Hg (time)	564 (12:07)	562 (17:15)	560 (15:10)
Maximum cabin altitude, ft	8,333	8,310	8,310
Cabin Cleaning	RON and rug shampoo [4]	Normal turn cleaning	RON and rug shampoo
Beverage service start	11:25	Not available	12:34
Meal service start	12:15	Not available	13:15
Meal service end	Not available	Not available	13:54
Meal served	Hot Lunch	Hot meal-tortellini	Hot meal-tortellini

NOTES:

[1]-Airplane flew to California, returned (without landing) by extended flight path.

[2]-Included typical mix of men, women, and children.

[3]-Gate time was unintentionally longer than normal.

[4]-RON equals regular overnight cleaning.

Table 2, Page 1
Air Sampling and Analytical Methods
Alaska Airlines HETA 90-226

Analyte or Environmental Parameter	LOD	Sampling and analytical method	Notes
Air Pressure	NA	Direct-reading measurements were made with a Thommen TX Pocket Alimeter (analog barometer), 0-6000m, Revue Thommen AG, Switzerland. Instrument was calibrated daily to a known elevation. (with reference to ground barometric pressure at take off.)	
Aldehydes (qualitative)	0.5 ug/sample	Samples were collected at 0.05 lpm on Orbo 23 sorbent tubes, analysis by NIOSH Method 2539.	
Carbon Dioxide	50 ppm	Direct-reading continuous measurements were made with Gastech Portable CO2 Indicators (infrared sensor), Model RI-411A, Gastech Inc., Newark, California. Instrument range 0-4975 ppm.	
Carbon Monoxide	1 ppm	Direct-reading continuous measurements were made with Draeger CO Dataloggers (electrochemical sensor), Model 190, National Draeger Inc.,	1,2
Gases: oxygen, nitrogen, argon, carbon dioxide, carbon monoxide, methane, hydrogen, acetylnene, ethylene, and ethane	1-100 ppm, (see results)	Grab samples were collected with MSHA 50-mL evacuated glass bottles, and analyzed by gas chromatography with flame ionization and/or thermal conductivity detectors. Samples were analyzed by MSHA, Gas Analysis Laboratory, Pittsburg, Pennsylvania.	3
Nitrogen Dioxide	0.5 ppm	Direct-reading grab measurements were made with Draeger Nitrogen Dioxide 0.5/c detector tubes, and long-term measurements with Draeger Nitrogen	
Oxygen	5%	Direct-reading grab sample measurements were made with Draeger Oxygen 5%/B detector tubes, and an the Edmont-Wilson Oxygen Analyzer (electrochemical sensor), Model 60-025, Edmont-Wilson, Coshoction, Ohio.	1
Ozone	0.02 ppm	Direct-reading continuous measurements were made with Mast Ozone Monitor (UV absorption sensor), Model 727-3, Mast Development Co., Reno, Nevada. Two lpm nominal flow rate.	

NOTES:
1 - Sample results were corrected for an average cabin pressure of 656 mm Hg.
2 - Personal sampling was also conducted on selected flights.
3 - MSHA containers were found to be unsuitable for general VOCs due to contamination of samples (see text).
GC/MS - gas chromatography/mass spectrometry

Air Sampling and Analytical Methods

Alaska Airlines HETA 90-226

Analyte or Environmental Parameter	LOD	Sampling and analytical method	Notes
Temperature and Relative Humidity	0-100% RH -10 to 60 C	Direct-reading continuous measurements were made with a Rustrak POD 29-03 probe (thin film capacitive and thermistor sensors), Gulton Industries, Manchester, NH	
Total particulates	0.001 mg/m3	Direct reading continous measurements were made with Real-Time Aersol Monitor (near-infrared scattering optical detector), Model RAM-1, GCA Environmental Instruments, Bedford, Massachusetts.	
Volatile organic compounds - Method 1 (qualitative and quantitative)	5 ug/sample	Samples collected at 0.2 lpm on charcoal tubes, analysis by NIOSH Method 1500 with modifications. Qualitative analysis by GC/MS (30-m DB-1 fused silica capillary column). Selected compounds were quantified, with correction	
Volatile organic compounds - Method 2 (qualitative)	NA	Grab samples were collected at 0.02 lpm in 1-liter Mylar airbags, and with MSHA 50-mL containers. Analysis for selected VOCs by GC/MS. Results were compared to lab-room air blank and standards prepared by Scott	2,3
Volatile organic compounds - Method 3 (qualitative)	0.1 ug/sample	Grab samples were collected on Carbotrap 300 thermal desorption tubes, with analysis by thermal desorber interfaced directly to GC/MS.	
Volatile organic compounds - Method 4 (quantitative, non-specific)	<0.1 ppm	Direct reading continous measurements were made with Photovac TIP monitor (photoionizaton detector (PID) with 10.6 eV lamp), calibrated to 7.5 ppm toluene, Photovac International Inc., Deer Park, New York.	

NOTES:

1 - Sample results were corrected for an average cabin pressure of 656 mm Hg.

2 - Personal sampling was also conducted on selected flights.

3 - MSHA containers were found to be unsuitable for general VOCs due to contamination of samples (see text).

GC/MS - gas chromatography/mass spectrometry

Table 3
Summary of Exposure Limits and Health Effects

Alaska Airlines
HETA 90-226

Substance	NIOSH REL *	OSHA REL**	FAA	Primary Health Effects
Carbon dioxide (ppm)	5,000	10,000	30,000	Simple asphyxiant (potentially fatal), increased respiration, central nervous system effects
Carbon monoxide (ppm)	35	35	50	Reduces oxygen carrying capacity of the blood, resulting in cardiac and central nervous system effects (headache, weakness, dizziness, mental confusion, etc.), death.
Oxygen (%)	19.5-25 A			Deviation from normal (21.5%) may represent the presence of other substances. Concentrations lower and higher than specified range represent hazardous atmospheres based on asphxiation and fire hazards, respectively.
Ozone (ppm)	0.1 C	0.1	0.25 C 0.1 ***	Respiratory tract irritation, cough, shortness of breath, chest pain.
Nitrogen dioxide (ppm)	1.0 STEL	1.0 STEL		Respiratory tract irritation, pulmonary edema, severe exposures may cause death.
Nuisance particulates (total dust, mg/m3)		15		Respiratory irritation.

* as 10-hr TWA, except as noted.
** as 8-hr TWA, except as noted.
*** 3-hr TWA
A-acceptable range for continuous concentrations.
C- ceiling limit not to be exceeded at any time
STEL-short term exposure limit, 15-min TWA

Table 4

Summary of In-Flight Averages for Environmental Quality Parameters--Test Flights
July 10-11, 1990

Alaska Airlines HETA 90-226

Analyte [1]	Units	FLT 9300	FLT 9301	FLT 9302
Air pressure [2]	mm Hg	654	660	654
Carbon dioxide	ppm	1191	791	550
Carbon monoxide [2]	ppm	**	3	4
Hydrogen [2]	ppm	**	10	13
Nitrogen dioxide [2]	ppm	ND	ND	ND
Oxygen [2]	%	**	20.75	20.84
Ozone	ppm	0.017	0.015	0.005 [2]
Relative humidity	%	21	20	21
Temperature	(deg. F)	75	74	75
Total particulates	mg/m3	0.026	0.013	0.003
VOCs [3]	ppm	1.8	2.8	3.2

[1] TWA of direct-reading continuous measurement (unless otherwise indicated).

[2] Average of direct-reading grab sample measurements.

[3] as toluene equivalent

** = data lost

ND = none detected

Table 5
MSHA Container Sample Results--Test Flights
July 10-11, 1990

Alaska Airlines HETA 90-226

FLIGHT	DATE	LOCATION	TIME	O2	N2	Ar	CO2	CO	CH4	H2
				Percent			PPM			
9300	7/10/90	Outside AA hanger--pre-flight		20.79	78.18	0.93	600	9	Trace [2]	27
9301	7/10/90	MC, near seat 29D	16:35	20.73	78.22	0.93	1200	4	Trace	19
		MC, near seat 16D	16:38	20.82	78.19	0.93	600	2	Trace	1
		MC, near seat 16D	18:26	20.72	78.21	0.93	1400	3	Trace	7
		FC, near seat 2C	16:41	20.71	78.22	0.93	1300	4	Trace	12
9302	7/11/90	MC, near seat 17D	10:40	20.70	78.02	0.93	3500	5	Trace	13
		MC galley, oven door open	12:29	20.77	78.13	0.93	1800	2	Trace	9
		MC, foward seat during meal	13:07	20.95	77.96	0.93	1600	3	Trace	7
		MC, aft seats during meal	13:07	20.93	77.97	0.93	1800	3	Trace	7
		FC galley, after meal	15:16	20.86	78.00	0.93	2100	6	Trace	28
		LOD for sample set		0.01	0.01	0.01	50	1	1	1
		Normal ambient air, sea level [1]		20.95	78.08	0.93	340	0.12	1.6	0.5

[1] Levels in dry air without gross pollution (Manahan, Environmental Chemistry 1984)

[2] Non-quantifiable trace amount detected.

Table 6
Summary of Temperature and Relative Humidity Measurements--Test Flights
July 10-11, 1990

Alaska Airlines HETA 90-226

Flight and Location	Sampling Times[1]		Temperature (F)			Rel Humidity (%)		
	Start	Stop	Mean	Min	Max	Mean	Min	Max
Flt 9300--Seat 16D	10:20	13:30	76	73	77	27	14	49
Flt 9301--Seat 16D	14:23	17:27[2]	76	35	84	23	12	50
Flt 9302--Seat 16D	10:05	16:30	75	57	89	21	11	52

[1] Sampling included some gate time.

[2] Measurement ended during flight.

Table 7
Results of Area Air Sampling for VOCs–Test Flights
July 10-11, 1990
Alaska Airlines
HETA 90-226

Flight (Takeoff, Landing)	Location	Sampling Times		Time	Ethanol*
		Start	Stop	(min)	ppm
9300 (11:15, 13:29)	Seat 2C	11:42	13:12	90	2.1
	Seat 17D	9:32	11:07	95	ND<0.2
	Seat 17D	11:52	13:10	78	0.9
	Seat 29D	11:30	13:14	104	0.9
9301 (14:48, 18:30)	Seat 2C	15:11	18:08	177	4.6
	Seat 17D	14:07	14:36	29	ND<0.5
	Seat 16D	15:10	18:10	180	2.0
9302 (12:22, 16:05)	Seat 2C	12:50	15:48	178	1.5
	Seat 17D	9:26	10:51	85	ND<0.2
	Seat 16D	12:49	15:50	181	3.6
	Seat 29D	12:50	15:50	180	3.7
NIOSH REL					1000
ACGIH TLV					1000
OSHA PEL					1000

* Concentrations corrected for average cabin pressure of 656 mm Hg.

Table 8
Flight Information--CO Follow up Monitoring
September 27-November 19, 1990

Alaska Airlines HETA 90-226

FLT NO.	DATE	AIRCRAFT TYPE	AIRCRAFT NO.	FLT SEGMENT	ROUTE	CRUISE ALT, FT	CABIN ALT, FT [1]	PREVIOUS INCIDENT [2]
Monitoring conducted by Alaska Airlines and AFA:								
192	9/27/90	MD-80 700	784	1	SEA/SNA	33,000	6,500	yes
175	9/27/90	MD-80 900	940	1	SNA/OAK,	31,000	5,300	no [3]
				2	OAK/SEA	35,000	7,500	
168	9/28/90	MD-80 700	784	1	SEA/OAK	37,000	7,900	yes
169	9/28/90	MD-80 700	785	1	OAK/SEA	35,000	7,200	yes
168	10/3/90	MD-80 900	942	1	SEA/OAK	33,000	6,350	no
169	10/3/90	MD-80 700	779	1	OAK/SEA	35,000	7,300	yes
218	10/8/90	MD-80 900	946	1	SEA/ONT	33,000	7,200	yes
FRY	10/8/90	MD-80 700	780	1	ONT/SEA	35,000	7,300	yes
65	10/10/90	BOE 737	744	1	SEA/KTN,	31,000	5,600	no
				2	KTN/SIT	18,000	21 [4]	
				3	SIT/JNU	16,000	18 [4]	
76	10/10/90	BOE 727-200	327	1	JNU/SEA	37,000	6,300	no
Monitoring conducted by NIOSH:								
176	11/19/90	MD-80 700	779	1	SEA/PDX	19,000	2,500	yes
				2	PDX/SJE	37,000	8,000	
183	11/19/90	BOE 727-200	307	1	SJE/SEA	35,000	5,700	no

[1] Cabin altitude at cruising altitude (airplane cabin altimeter)
[2] Indicates if airplane was involved in a previously reported air quality incident.
[3] Airplane was involved in an incident after the time period covered by NIOSH study.
[4] Cabin altitude was at or about sea level.

AIRPORT KEY:

JNU	-Juneau, AK
KTN	-Ketchikan, AK
OAK	-Oakland, CA
ONT	-Ontario, CA
PDX	-Portland, OR
SEA	-Seattle/Tacoma, WA
SIT	-Sitka, AK
SJE	-San Jose, CA
SNA	-John Wayne Int'l, CA

Table 9, Page 1
Results of CO Monitoring with Dosimeters*
September 27- October 10, 1990
Alaska Airlines HETA 90-226

FLT	DATE	AIRCRAFT	PUSH	BEGIN	SAMPLE	SAMPLING TIME		CO CONC., PPM [1]		PEAK	NOTES
		TYPE	BACK	DESCENT	LOCATION	START	STOP	TWA [2]	PPM [3]	TIME	
192	9/27/90	MD80 700	7:50	9:58	Cockpit	7:50	10:37	<1	6	7:57	A (-1)
					FC galley	7:57	10:33	<1	7	7:58	
					FC galley	7:50	10:31	1	9	7:56	
					FC Seat 3	7:50	10:34	<1	12	7:55	
					MC galley	7:50	10:37	<1	6	7:58	
					MC seat 21F	7:50	10:38	<1	8	7:56	
175	9/27/90	MD80 900	14:00	14:40	Cockpit left	13:45	17:42	<1	2	17:42	B
			15:45	17:15 [4]	Cockpit right	13:05	17:04	<1	2	13:19	B
					FC galley	13:45	17:44	1	20	14:32	C
					FC galley	15:35	17:45	1	5	16:40	
					FC aisle seat 1D	13:45	17:43	6	8	16:07	A (3), B
					FC seat 3C	13:45	17:38	<1	2	16:38	B
					MC jumpseat 33D	13:45	17:40	<1	1	17:40	B
					MC galley	13:45	17:40	<1	<1		A (-1), B
168	9/28/90	MD80 700	7:07	8:34	Cockpit left	6:45	9:09	6	13	7:00	A (2), D
					FC galley	6:45	9:05	1	5	6:58	D
					FC aisle seat 3C	6:05	8:26	<1	3	6:15	D
					FC win seat 1F	6:45	9:05	7	12	6:58	A (4), D
					MC galley	6:45	9:08	1	5	7:07	D
					MC seat 21D	6:05	8:27	2	7	6:14	D
					MC aisle seat 33D	6:45	9:05	<1	5	6:53	D

*Data collected by Alaska Airlines and AFA Representatives

[1] Concentrations were corrected for assumed average cabin pressure of 656 mm Hg, except as noted.

[2] Time-weighted average.

[3] Peak 1-minute average (see text: peaks may have been due to interferences).

[4] Approximate time.

NOTES:

A- Results should be considered approximate due to apparent instrument zero drift (minimum, ppm)

B-Results include both flight segments.

C-Instrument audible alarm sounded, galley ovens were not on.

D-21 min taxiway hold/SEA

Table 9, Page 2
Results of CO Monitoring with Dosimeters*
September 27- October 10, 1990
Alaska Airlines HETA 90-226

FLT	DATE	AIRCRAFT	PUSH BACK	BEGIN DESCENT	SAMPLE LOCATION	SAMPLING TIME START	SAMPLING TIME STOP	CO CONC., PPM [1] TWA [2]	CO CONC., PPM [1] PEAK [3]	PEAK TIME	NOTES
169	9/28/90	MD80 700	12:32	14:02	Cockpit left	12:08	14:33	<1	9	13:42	
					Cockpit right	12:08	14:30	1	3	12:12	
					FC galley	12:08	14:29	<1	16	13:04	
					FC win seat 1F	12:08	14:29	<1	2	12:09	
					FC aisle seat 3C	12:08	14:26	<1	1	12:09	
					MC aisle seat 21D	12:08	14:26	7	9	12:10	A (6)
					MC aisle seat 33C	12:08	14:27	<1	<1	12:09	A (-1)
					MC aisle seat 33D	12:08	14:24	<1	<1	12:09	
					MC galley	12:08	14:24	5	7	12:09	A (4)
168	10/3/90	MD80 900	7:03	8:45 [4]	Cockpit left	6:50	9:11	<1	2	6:51	E
					FC galley left	6:45	9:06	2	8	6:46	E
					FC galley right	6:50	9:12	<1	1	6:51	E
					MC flt attendant	6:50	9:12	<1	3	8:01	A (-1), E
					MC flt attendant	6:50	9:13	1	3	7:22	E
					MC aisle	6:45	9:13	1	3	8:27	E
169	10/3/90	MD80 700	12:40	14:00	Cockpit left	12:15	14:51	2	5	12:46	
					Cockpit right	12:15	14:55	<1	2	12:50	A (-1)
					FC galley left	12:15	14:50	<1	3	12:48	
					FC galley right	12:15	14:51	1	5	12:22	
					MC flt attendant	12:15	14:52	<1	2	12:19	
					MC flt attendant	12:15	14:46	5	25	12:20	
					MC aisle seat 16C	12:15	14:53	1	3	12:16	
218	10/8/90	MD80 900	6:45	8:48	Cockpit left	6:39	9:15	2	8	6:55	
					Cockpit right	6:39	9:20	<1	7	9:18	A (-2), F
					FC galley left	6:39	9:15	<1	3	6:48	
					FC galley right	6:39	9:16	<1	5	6:48	
					MC aisle seat	6:39	9:15	2	10	6:54	
					MC flt attendant	6:39	9:19	<1	7	8:09	A (-2)
					MC galley	6:39	9:17	3	22	7:26	A (2)

*Data collected by Alaska Airlines and AFA Representatives

[1] Concentrations corrected for assumed average cabin pressure of 656 mm Hg, except as noted.

[2] Time-weighted average.

[3] Peak 1-minute average (see text: peaks may have been due to interferences).

[4] Time is approximate.

NOTES:

A- Results should be considered approximate due to apparent in

E-25 min taxiway hold, and 8 min gate hold at SEA

F-Dosimeter was covered by a napkin.

Table 9, Page 3

Results of CO Monitoring with Dosimeters*

September 27- October 10, 1990

Alaska Airlines HETA 90-226

FLT	DATE	AIRCRAFT	PUSH BACK	BEGIN DESCENT	SAMPLE LOCATION	SAMPLING TIME START	SAMPLING TIME STOP	CO CONC., PPM [1] TWA [2]	CO CONC., PPM [1] PPM [3]	PEAK TIME	NOTES
FRY	10/8/90	MD80 700	15:20	17:22	Cockpit left	15:00	17:51	<1	5	15:09	G
					Cockpit right	15:00	17:52	<1	<1	15:01	A (-1), G
					FC galley left	15:00	17:54	<1	2	15:18	A (-2), G
					FC galley right	15:00	17:54	6	9	15:20	A (3), G
					MC galley-strap	15:00	17:54	<1	1	15:20	A (-1), G
					MC aisle seat 11D	15:00	17:53	<1	3	15:18	A (-1), G
65	10/10/90	BOE 737	7:30	9:22	Cockpit left	7:05	13:30	4	12	7:24	A (2), H
			11:30	11:55	Cockpit right	7:05	13:31	3	12	7:27	H
			13:15	13:32	MC win seat 10A	7:05	13:25	4	13	9:34	A (2), H
					MC win seat 10F	7:05	13:25	1	9	9:35	H
					MC aisle seat 15D	7:00	13:24	5	10	12:30	A (4), H
					MC flt attendant	7:00	13:28	1	7	9:36	H
					MC aft entry door	7:05	13:25	<1	13	13:24	A (-1), H
76	10/10/90	BOE 727-200	15:35	18:05	MC flt attendant	15:15	17:46	<1	2	15:36	
					Other locations	data lost during download					

*Data collected by Alaska Airlines and AFA Representatives

[1] Concentrations corrected for assumed average cabin pressure of 656 mm Hg, except as noted.

[2] Time-weighted average.

[3] Peak 1-minute average (see text: peaks may have been due to interferences).

[4] Time is approximate.

NOTES:

A- Results should be considered approximate due to apparent instrument zero drift (minimum, ppm)

G-Ferry flight with no passengers.

H-Concentrations were corrected for assumed average cabin pressure of 696 mm Hg.

Table 10

Results of CO Monitoring with Sealed and Unsealed Dosimeters--Two Commercial Flights

November 19, 1990

Alaska Airlines HETA 90-226

FLT	DATE	AIRCRAFT TYPE	PUSH BACK	BEGIN DESCENT	SAMPLE LOCATION	SAMPLING TIME START	SAMPLING TIME STOP	CO CONC., PPM [1] TWA [2]	CO CONC., PPM [1] PEAK	PEAK TIME	NOTES
176	11/19/90	MD80 700	13:09	13:40	Cockpit left	11:42		<1	2	12:11	A(-2)
			14:26	15:36	*Cockpit left (sealed)*	11:43		<1	<1		A(-2)
183	11/19/90	BOE 727-200	16:55	18:14							
					Cockpit right	11:42		<1	4	12:57	A(-2)
					Cockpit right (sealed)	11:45		<1	1	12:50	A(-5)
					FC galley	11:42		<1	3	18:15	A(-1)
					FC galley (sealed)	11:44		--	--		B
					MC flight attendant	11:40		<1	34	18:23	C
					MC flight attendant (sealed)	11:45		<1	<1		
					MC jumpseat 11C	11:41		<1	2	11:42	
					MC jumpseat 11C (sealed)	11:44		<1	<1		A (-1)
					MC galley	11:40		<1	2	12:50	A(-1)
					MC galley (sealed)	11:43		<1	1	12:51	

[1] Concentrations were corrected for assumed average cabin pressure of — mm Hg.

[2] Time-weighted average (both flights combined)

FC-First Class

MC-Main Cabin

NOTES:

A- Results should be considered approximate due to instrument zero drift (minimum, ppm)

B-Datalogger results were lost.

C-Instrument audible alarm (set for 15 ppm) sounded during peak.

Table 11
Illness Incidents by Month of Occurrence
July 1989 - April 1991

Alaska Airlines HETA 90-226

Year	Month	All Incidents[1]	Incidents without identified exposure[2]	Flight segments, entire system
1989	July	1	0	
	August	0	0	
	September	0	0	
	October	0	0	
	November	2	2	8143
	December	5	2	8538
1990	January	2	0	8967
	February	4	3	7952
	March	5	5	8907
	April	10	8	8540
	May	10	8	8950
	June	10	10	9484
	July	4	3	10043
	August	3	1	10137
	September	5	3	8562
	October	5	5	9041
	November	4	4	8558
	December	5	3	8971
1991	January	1	1	8856
	February	0	0	7895
	March	3	1	8827
	April	4	3	8549
	Total	**83**	**62**	

1 - Excludes 5 incidents that involved no illness among flight attendants and one redundant incident report (see text).
2 - See text.

Table 12
Illness Incidents by Aircraft Type
July 1989 - April 1991

Alaska Airlines
HETA 90-226

AIRCRAFT	NUMBER OF PLANES	NUMBER OF INCIDENTS AND INCIDENTS-PER-PLANE RATIO			
		All incidents[1]		Incidents without identified exposure[2]	
		Number	Ratio	Number	Ratio
BOEING 727					
100 series	4[A]				
200 series	26	16	0.6	11	0.4
BOEING 737	7	6	0.9	3	0.4
MD-80[B]					
700 series	8	42	5	34	4
Plane # 784	1	12	12	10	10
All others	7	30	4	24	3
900 series	15	19	1.3	14	0.9
TOTAL	**56[C]**	**83**	**1.5**	**62**	**1.1**

1 - Excludes 5 incidents that involved no illness among flight attendants and one redundant incident report (see text).

2 - See text.

A - On long-term lease; not staffed by Alaska Airlines flight attendants.

B - See footnote under Results and Discussion, Medical, Aircraft.

C - Excludes the Boeing 727-100 series.

Table 13
Monthly Average Passenger Load Factors[1]
January 1990 - April 1991

Alaska Airlines
HETA 90-226

MONTH	ALL FLIGHTS	INCIDENT FLIGHTS			
		All incidents[2]		Incidents without identified exposure[3]	
1990					
January	47	32[A]	(-15)[4]	-	-
February	47	41	(- 6)	41	(- 6)
March	53	59	(+ 6)	59	(+ 6)
April	50	58	(+ 8)	59	(+ 9)
May	50	66	(+16)	61	(+11)
June	58	53	(- 5)	53	(- 5)
July	60	72	(+12)	67	(+ 7)
August	64	38	(-26)	83[A]	(+19)
September	56	70	(+14)	71	(+15)
October	49	72	(+23)	72	(+23)
November	52	55	(+ 3)	55	(+ 6)
December	55	46	(- 9)	46	(- 9)
1991					
January	50	37[A]	(-13)	37[A]	(-13)
February	54	-	-	-	-
March	57	49	(- 8)	26[A]	(-31)
April	60	46	(-14)	46	(1-14)
OVERALL	54	56[B]	(+ 6)	57[C]	(+ 7)

( ) = Numerical differences between average load factor for incident flights and that for all flights.

NOTES:

1 - Percentage of seats occupied.
2 - Excludes 5 incidents that involved no illness among flight attendants and one redundant incident report (see text). Load factors not available for 1 of 4 flights in February 1990, 1 of 10 in May 1990, and 2 of 5 in December 1990.
3 - See text. Load factor not available for 1 of 8 flights in May 1990.
4 - (average load factor for incident flights minus average load factor all flights)
A - Based on only 1 incident.
B - Standard error = 2.6
C - Standard error = 2.8

Table 14
Reported Symptoms Among Flight Attendants[1]
July 1989 - April 1991

Alaska Airlines
HETA 90-226

Symptom	Number and (%) of Incidents in which Symptom was Reported	
	All incidents[2]	Incidents without identified exposure[3]
Lightheadedness/dizziness	46 (55)	39 (63)
Headache	46 (55)	33 (53)
Other neurologic[4]	46 (55)	37 (60)
Other generalized[5]	35 (42)	27 (44)
Nausea	29 (35)	22 (36)
Other gastrointestinal[6]	8 (10)	5 (8)
Irritative[7]	22 (27)	13 (21)
Respiratory[8]	11 (13)	9 (15)
Suggestive of Hyperventilation[9]	15 (18)	14 (23)

NOTES:

1 - As described in incident reports; a symptom was considered present if reported to have occurred in one or more flight attendants on an incident flight.
2 - Excludes 5 incidents that involved no illness among flight attendants, one redundant incident report, and 4 other incidents in which symptoms were not specified (see text).
3 - See text; excludes 3 incidents in which symptoms were not specified.
4 - Any sensory, motor (movement), perceptual, or cognitive (thinking, remembering) effect.
5 - Fatigue, lethargy, feeling hot or cold.
6 - Vomiting, abdominal pains, diarrhea.
7 - Eye, nose, or throat discomfort; cough.
8 - Shortness of breath, chest tightness, breathing difficulty.
9 - Typical symptoms (references 36-42) include lightheadedness; numbness or tingling around the mouth, hands and feet; shortness of breath; impaired concentration; altered perception or consciousness; trembling; palpitations and rapid heart beat; chest pain; fatigue; anxiety; and spasms of the hands and feet. Milder cases would not necessarily have all of these symptoms.

Delivering on the Nation's Promise:
Safety and Health for all People...
Through Prevention

NIOSH