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Occupational Illness Among Flight Attendants Due to Aircraft Disinsection

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Addendum October 30, 2003 – Added sentence underlined

On page 32 : Cease spraying pesticides in the crew rest area (bunk room). The bunk area is a location with minimum airflow where flight crew lie down on pesticide-treated surfaces to rest. Dermal and airborne exposures in the crew rest area are likely to be especially problematic and should be eliminated. <u>To implement this recommendation airlines should seek, and must receive, permission from the relevant national quarantine authorities to cease spraying pesticides in the crew rest area.</u>

EXECUTIVE SUMMARY

Background

The California Department of Health Services (CDHS) Occupational Health Branch conducts statewide surveillance of acute pesticide illness among workers. Between August 2000 and August 2001, CDHS received physician reports of six incidents involving 17 flight attendants who reported exposure to pesticides used during aircraft disinsection. Aircraft disinsection involves applying pesticides inside an aircraft to kill insects that may be on board and may be a threat to the health of humans, plants, animals, and agriculture. Airlines perform this procedure to comply with quarantine regulations of some countries. CDHS undertook an investigation to: (1) determine if the reported illnesses were caused by pesticide exposure; (2) identify factors that may have contributed to documented illnesses; and (3) make recommendations to prevent future cases of pesticide poisoning.

Results

A total of 12 flight attendants met the case definition for work-related pesticide illness. The 12 cases occurred in three separate incidents. Two incidents involved one flight attendant each and the third involved ten flight attendants. Two incidents (11 cases) involved a residual application of a synthetic pyrethroid formulation including the insecticide permethrin, solvents, and a surfactant. In the third incident, the method of disinsection could not be determined by CDHS. The residual disinsection process involved spraying the aircraft cabin and cargo hold with 34.4 liters of a solution of 2.2% permethrin. The most common signs and symptoms experienced by flight attendants were respiratory (N=12), nervous system (N=11), dermatological (N=9), eye (N=9), cardiovascular (N=5), and gastrointestinal (N=6).

Findings

Residual disinsection poses a hazard to flight attendants. Residual disinsection resulted in illness among 12 flight attendants exposed to the aircraft cabin environment after disinsection. The documented acute illnesses likely understate the health risks of this procedure because many barriers to acute illness recognition and reporting exist.

The conditions of use (i.e., the aerosol application of a pesticide in a confined space) significantly contributed to the human health hazard of residual disinsection. Residual disinsection procedures involved placing flight attendants in a pesticide-treated area with few industrial hygiene measures to limit their exposure**.** Post-disinsection aircraft ventilation procedures and administrative measures did not effectively limit flight attendants' exposure. A wide range of pesticide exposure levels routinely occurred on treated aircraft, including the potential for greater than “average” exposures. Flight attendants’ illnesses may have been exacerbated because they were unable to remove themselves from exposure and seek medical care in a timely way.

Current assumptions about the human health impacts of residual disinsection underestimate the risks of this procedure. In addition to the potential for acute illness, there may be cumulative health impacts of flight attendants’ exposure to pesticides. There is also some evidence that the mixture of exposures incurred by flight attendants may increase the toxicity of the pyrethroid exposure in the aircraft cabin environment. Although there is no evidence indicating these other exposures were directly related to the acute illnesses reported by CDHS, these multiple but poorly characterized interactive factors may influence the health of flight crew. The public health impact of residual disinsection is not limited to the risk of acute pesticide-related illness among flight attendants, but also includes other workers and the passenger population.

The relative efficacy of aircraft disinsection in preventing vector-borne disease is not well described. Although pyrethroids are considered to be highly effective insecticides, the available data raise questions about the relative efficacy of aircraft disinsection in preventing vector-borne disease.

Recommendations

National and international health agencies should: (1) Conduct research to assess the relative efficacy of disinsection in preventing vector-borne diseases; and (2) Identify and recommend implementation of sustainable, nontoxic alternative methods of minimizing the importation of disease vectors in aircraft cabins.

All airline industry employers should: (1) Educate all potentially exposed workers about the hazards of aircraft disinsection; (2) Restrict entry for all workers to the aircraft cabin after disinsection; (3) Implement and enforce maximal ventilation procedures on every treated aircraft; (4) Institute quality control measures for every pesticide application; (5) Cease spraying pesticides in the crew rest area (bunk room); (6) Notify in advance passengers who may be exposed to a pesticide-treated aircraft of the procedure and the potential health risks; (7) Schedule flights to countries that require disinsection so that the number of aircraft treated is minimized; and (8) Initiate active illness surveillance among exposed workers and passengers.

BACKGROUND

Pesticide Illness Surveillance

The Sentinel Event Notification System of Occupational Risk (SENSOR) Project is conducted by the California Department of Health Services (CDHS) Occupational Health Branch[a] through the support of the National Institute for Occupational Safety and Health and the U.S. Environmental Protection Agency. The goal of the SENSOR project is to prevent pesticide illness among workers. SENSOR staff utilize a physician-based reporting system to conduct statewide surveillance of acute pesticide illness among workers. Selected reports are followed up by workplace investigations and interviews with workers, employers, and others involved in the incidents.

CDHS initiated the investigation described in this report in response to physician reports of illness among flight attendants who reported exposure to pesticides used during aircraft disinsection. Between August 2000 and August 2001, CDHS received reports of six incidents involving 17 flight attendants.[b] All illness reports received by CDHS involved flight attendants working for one employer while on flights traveling between Los Angeles, California and Sydney, Australia and between San Francisco, California and Narita, Japan. The purpose of CDHS' investigation was to: (1) determine if the reported illnesses were caused by pesticide exposure; (2) identify factors that may have contributed to documented illnesses; and (3) make recommendations to prevent future cases of pesticide poisoning.

Aircraft Disinsection

Aircraft "disinsection" involves applying pesticides inside an aircraft to kill insects that may be on board and may be a threat to the health of humans, plants, animals, and agriculture. Airlines perform this procedure to comply with quarantine regulations of some countries. Currently 18 countries require aircraft disinsection of all (N=12) or selected (N=6) inbound flights, and most countries reserve the right to do so should they perceive a threat to their public health,

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[a] CDHS is mandated to investigate the causes of morbidity and mortality from work-induced diseases and develop recommendations for improved control of work-induced diseases (California Health and Safety Code 105175-105180).

[b] An incident is an event or set of circumstances that results in reported illness in one or more individuals. CDHS received six incident reports: four were a Doctors First Report of Injury or Illness, one was a Pesticide Incident Report, and one was made directly to CDHS by a flight attendant who called the SENSOR toll-free pesticide hotline number. These six incidents involved illness reports for 17 flight attendants. Five of the six incidents involved only one reported illness, and CDHS did not attempt to identify other workers who may have become ill in these incidents. One incident involved 12 reported illnesses identified as follows: one illness was reported directly to CDHS, and when contacted by CDHS, the flight attendant involved identified a co-worker who had also reported illness; the remaining 10 illness reports were identified by the Association of Flight Attendants who contacted CDHS subsequent to hearing about CDHS' investigation.

agriculture or environment.[1] Of the 18 countries that currently require disinsection, 11 require the pesticide to be applied while passengers are on board, and seven permit the use of an aerosolized spray while passengers are not on board. In 1996, the U.S. Environmental Protection Agency determined it was doubtful that the benefits of disinsection in occupied cabins exceeded the risk of such use.[2] Currently, the U.S. government does not require any disinsection procedure to be performed,[1] and there are no pesticides registered for use in the U.S. for aircraft disinsection.[3]

All methods of aircraft disinsection involve applying a synthetic pyrethroid (e.g., permethrin or d-phenothrin) inside the aircraft cabin. Synthetic pyrethroids are widely used broad-spectrum insecticides.[4] Pyrethroids are neurotoxins that exert their effect by interacting with ion channels in the membranes of the nervous system.[5,6] Although pyrethroids can have a high inherent toxicity, human toxicity is limited because pyrethroids are rapidly broken down in the blood and liver to their inactive components.[4]

There are two approaches to disinsection used in the airline industry: (1) the pesticide is applied by flight attendants in the presence of passengers after the plane leaves the gate (Blocks-Away) and/or before it lands (Top-of-Descent); and (2) the pesticide is applied by ground crew prior to passenger and crew boarding (Pre-flight and Residual) (Table 1). The residual method is the only approach designed to leave a long-lasting (up to 56 days) pesticide residue in the aircraft cabin.

Table 1. Aircraft disinsection methods[7]

Approach	Method	Pesticide applicator	Timing of application	Active ingredient	Long-lasting?
Flight attendants and passengers present during pesticide application	Blocks away	Flight attendant	Aircraft is taxiing from the gate	2% d-phenothrin	No
	Top-of-descent*	Flight attendant	Aircraft is landing	2% d-phenothrin	No
Flight attendants and passengers NOT present during pesticide application	Pre-Flight*	Ground workers	Aircraft is on the ground; application immediately before passengers and flight crew board	2% permethrin	No
	Residual**	Ground workers	Aircraft is on the ground; application shortly before, or up to 56 days prior to boarding, depending on the flight	2% permethrin	Yes (up to 56 days)

* Pre-flight and top-of-descent methods are normally done in combination with each other.

** When an aircraft has not been treated with a residual application within the past eight weeks, in-flight spraying is required prior to landing or disembarkation.

METHODS

Data collection

To investigate the reports of illness among flight attendants following aircraft disinsection, SENSOR project staff:

- **Interviewed flight attendants with illness reports**. CDHS attempted to contact all 17 flight attendants with a reported illness. Flight attendants were contacted three or more times at their homes and asked to participate in a voluntary phone interview.

- **Obtained medical records.** CDHS requested medical records from the treating physician(s) for all 17 flight attendants.[8]

- **Interviewed employer representatives.** CDHS staff[c] conducted an on-site investigation at the employer's aircraft maintenance center. Eight employer representatives were present at the meeting and were interviewed about the aircraft disinsection work process, tasks, and exposure control measures. Follow-up information was collected from employer industrial hygiene staff by phone and e-mail.

- **Interviewed employee representatives**. Four representatives from the Association of Flight Attendants (AFA) were present at the CDHS on-site investigation conducted at the employer's aircraft maintenance center. AFA representatives were interviewed about the aircraft disinsection work process, tasks, and exposure control measures. Follow-up information was collected from employee representatives including industrial hygiene staff by phone and email. CDHS staff also attended an informational meeting about aircraft disinsection convened by and for AFA members.[d]

- **Conducted a walk-through of a 747- 400 aircraft**. All incident reports involved flight attendants working on a 747- 400 aircraft.[e] During the on-site visit, CDHS staff conducted a brief walk-through of a 747- 400 in the presence of employer and employee representatives.

- **Viewed a video of the aircraft disinsection process**. CDHS staff viewed a video that documented the disinsection of a 747- 400. The video,

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[c] The on-site investigation was conducted by Patrice Sutton, M.P.H., Research Scientist, Rupali Das, M.D., M.P.H., Public Health Medical Officer, and Ximena Vergara, Research Associate on June 18, 2002.

[d] The informational meeting took place in June 2002.

[e] The employer reported that all flights between Sydney and Los Angeles and Narita and San Francisco would have involved travel on a 747 - 400. The aircraft observed may or may not have been involved in the illness incidents reported to CDHS.

made by the employer, included approximately ten minutes of footage of the disinsection process inside the passenger cabin, crew bunk area, and cargo hold.[f]

- **Reviewed employer written records**. CDHS reviewed written materials about aircraft disinsection provided by the employer, including the pesticide products used, application policy and procedures, safety and health programs, results of environmental monitoring conducted by the employer, aircraft ventilation rates, logs of visits to the employer's medical facilities in San Francisco and Los Angeles, and additional reference material.

- **Reviewed the scientific literature.** CDHS staff reviewed the literature on aircraft disinsection and synthetic pyrethroid exposure and illness.

- **Developed a mathematical model to estimate the effect of aircraft ventilation on the concentration of permethrin in the aircraft cabin air after disinsection**. The model was developed by Dr. Mark Nicas, Adjunct Assistant Professor, School of Public Health, University of California, Berkeley. A description of the methodology is presented in Appendix 2.

Evaluation Criteria

- **Case definition of pesticide-related illness:** All illness reports were evaluated according to the case definition for work-related pesticide illness established by the National Institute for Occupational Health and Safety (NIOSH), U.S. Centers for Disease Control and Prevention.[9] The NIOSH definition of a case is: acute onset of symptoms that are dependent on the formulation of the pesticide and involve systemic signs or symptoms, dermatologic lesions, and/or ocular lesions. For a report to be classified as a case of work-related pesticide illness, all of the following criteria must be met: (1) exposure must occur while working; (2) exposure must be documented; (3) adverse health effects must be documented; and (4) there must be evidence in the scientific literature supporting a causal relationship between pesticide exposure and adverse health effects.

- **Exposure route(s) and control measures**: All illness reports were evaluated according to the presence of one or more routes of pesticide exposure, and the presence, use and efficacy of measures to limit flight attendant pesticide exposure.

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[f] The video documented residual disinsection of an aircraft on December 11, 1997 in Sydney, Australia. The video depicted the same residual disinsection procedure being implemented at the time the illnesses reported to CDHS occurred.

RESULTS

Illness Reports

Of the 17 flight attendants with a reported illness, CDHS completed interviews with six. CDHS obtained symptom data for 15 flight attendants through medical records and/or interviews. A total of 12 flight attendants met the NIOSH definition for work-related pesticide illness based on (1) timely, self-reported evidence of exposure made to a licensed health care professional; (2) the presence of two or more new post-exposure abnormal signs and/or test or laboratory findings reported by a licensed health care provider, or the presence of two or more abnormal symptoms occurring after exposure; and (3) the presence of symptoms and signs that are consistent with the known toxicology of the pesticide formulation applied to the aircraft. For five illness reports, there was insufficient information available to confirm or rule out that the flight attendants' illnesses were pesticide-related.

The 12 cases occurred in three separate incidents. Two incidents involved one flight attendant each and the third involved ten flight attendants. Two incidents (11 cases) involved a residual application of permethrin. In the third incident, the method of disinsection could not be determined by CDHS. All 12 cases of pesticide illness involved exposure to a pesticide that was applied on aircraft traveling from Australia (Sydney) to the U.S. (Los Angeles).

Of 12 cases, eight flight attendants experienced symptoms immediately or shortly after boarding the aircraft and two within an hour of boarding. Specific information on the timing of onset of symptoms was missing for two flight attendants. The most common signs and symptoms experienced by were respiratory (N=12), nervous system (N=11), dermatological (N=9), eye (N=9), cardiovascular (N=5), and gastrointestinal (N=6) (Table 2).

There were no incident-specific, quantitative exposure data available. For two incidents (11 cases), only the time that the residual application was completed was documented in writing in the aircraft cabin. For the third incident (one case), pesticides were applied to the aircraft on the day that the flight attendant became ill, but CDHS had no information on the method of application or time that it was completed. Of 12 flight attendants who became ill, four detected odor at the time of their exposure. For one incident (involving ten flight attendants), it was reported that pesticide residues were visible on aircraft cabin surfaces.

Table 2. Signs* and symptoms among 12 flight attendants*** with pesticide-related illness from aircraft disinsection**

Signs		No.			No.
	Respiratory			**Eye**	
	Runny nose	1		Conjunctivitis	2
✓	Upper respiratory pain/Irritation	1		**Skin**	
	Wheezing	1	✓	Erythema/Flushing	1
Symptoms		**No.**			**No.**
	Cardiovascular			**Miscellaneous**	
	Palpitations	5	✓	Fatigue	1
	Skin			**Nervous/Sensory**	
	Pruritis	5	✓	Headache	9
✓	Irritation/Pain	4	✓	Hyperactivity/Anxiety/ Irritability	6
✓	Erythema/Flushing	2	✓	Tingling hands/feet/elsewhere	6
	Edema/Swelling	1	✓	Dizziness	5
✓	Rash	1		Ataxia	4
				Confusion	4
	Eye			Muscle weakness	4
✓	Pain/Irritation/ Inflammation	8		Profuse sweating	3
	Lacrimation	3	✓	Fasciculations	2
	Pruritis	2		Muscle rigidity	2
				Slurred speech	2
	Gastrointestinal				
✓	Nausea	5		**Respiratory**	
✓	Anorexia	3		Shortness of breath	7
	Abdominal pain/Cramping	1	✓	Upper respiratory pain/Irritation	6
✓	Diarrhea	1		Cough	4
✓	Vomiting	1		Pain on deep breathing	4
				Runny nose	3
	Renal/Genitourinary			Wheezing	1
	Polyuria	1			
	Oliguria/Anuria	1			

* Signs are objective findings that were observed by a health care provider, e.g., flushing, wheezing, conjunctivitis, etc.

** Symptoms are health effects reported by the patient that could not be, or were not, observed by a health care provider.

*** More than one symptom or sign may be reported by one individual.

✓ Sign or symptom related to permethrin or pyrethroid exposure reported in the published literature.[10,11,12,13,14]

Pesticide Application Process

All 12 cases of pesticide illness occurred during the period August 2000 to March 2001. During this period, the employer contracted out the residual disinsection process to another airline that implemented the procedure in Sydney.[g] The Australian government required aircraft to be treated with a synthetic pyrethroid (permethrin) formulation at least every 56 days. The employer did not limit treated aircraft to routes that required disinsection, but also used these aircraft on other international or U.S. domestic routes.

The residual disinsection process involved spraying the aircraft cabin and cargo hold with 34.4 liters of a solution of 2.2% permethrin (Table 3).

Table 3. Pesticide formulation applied to aircraft

Ingredient	Function	% by weight (w/w)
permethrin *25:75 cis:trans*	active ingredient	2.2
hydrocarbon liquid	organic solvent carrier	0.8
nonoxinol 9	emulsifier/surfactant	1.4
water	diluent	95.6

The pesticide solution was mixed by pouring 700 ml of the product (an emulsifiable concentrate) into each of two 16.5 L containers of water. The pesticide solution was mixed and loaded outside the aircraft. Next, it was poured into two types of application equipment: (1) ultra-low volume (ULV) spray-mist "Cold Fogging" applicators,[15] which were pulled through the aircraft on wheeled carts (Figure 1); and (2) a hand-held sprayer[16] (Figure 2). The foggers were used for most surfaces (e.g., seats, walls, overhead compartments), and the hand-held sprayer was used for the galleys, crew rest (bunk) area, bathrooms, cockpit, carpet, and cargo hold. Approximately 29 L of the pesticide solution was applied to the passenger and crew sections of the aircraft, and the remaining 5.4 L was applied to the cargo hold. The disinsection process was conducted by three applicators in about 35-45 minutes. During the application process, the aircraft doors were closed and the aircraft ventilation system was off.

[g] The employer's procedures for residual disinsection have changed. Disinsection is currently performed by a different contractor in Hong Kong according to procedures outlined in Appendix 1.

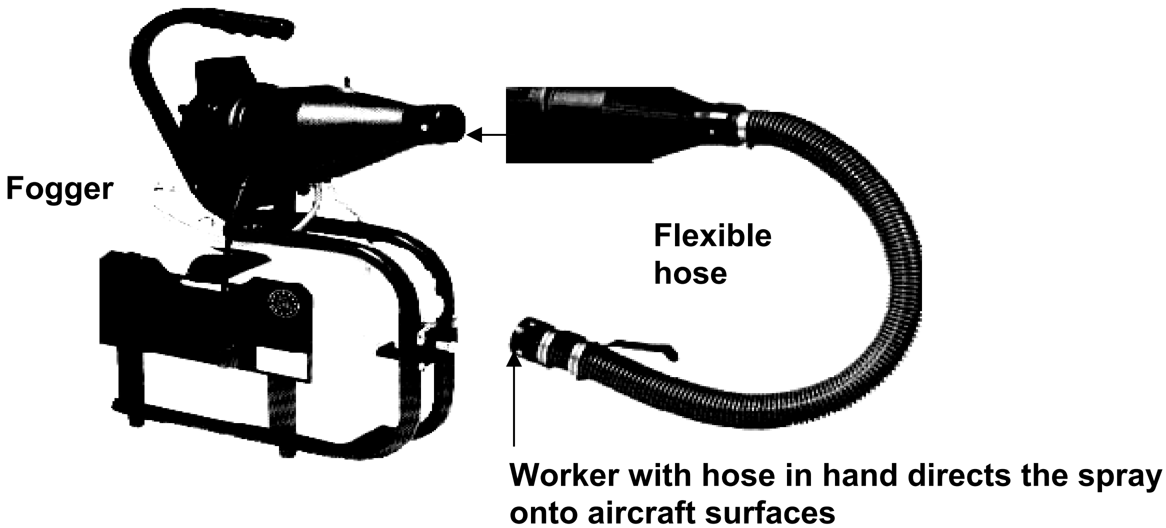

Figure 1. Pesticide spray-mist fogger. The fogger holds three gallons (11.4 L) of pesticide solution. ***A flexible hose was attached to the nozzle of the fogger. Two workers each pulled a fogger through the aircraft on a wheeled cart while holding the flexible hose and directing the spray onto all surfaces and the overhead storage bins. The pesticide solution was dispensed through the flexible hose as an aerosol with a particle size in the 5-40 micron range.***

Figure 2. Hand-held sprayer. ***The sprayer applied a pesticide mist at the rate of 6.4 ounces per minute to the galleys, crew rest area, bathrooms, cockpit, carpet, and cargo hold.***

Figure 3. Crew rest area. ***A hand-held sprayer was used to apply the pesticide on top of and under the bunk cushions.***

Table 4 outlines the residual disinsection process that occurred at the time of the documented incidents. The steps were:

- **Pre-disinsection cleaning:** After landing in Sydney, the aircraft was moved away from the gate and a cleaning crew boarded the aircraft. The workers cleaned the aircraft and removed pillows, blankets, headsets, and other non-stationary material from the aircraft.

- **Disinsection:** Three pesticide applicators applied the permethrin solution to the aircraft as previously described.

- **Ventilation:** From zero to 15 minutes after the residual pesticide application was completed, the doors to the aircraft were opened.[h] To ventilate the aircraft, one or both of the following methods were permitted: (1) the doors to the aircraft remained opened (i.e., "natural ventilation") and no supplemental ventilation was used, and/or (2) the doors to the aircraft were closed and the air conditioning was turned on with the recirculating fans off.[i] The minimum ventilation period required by the employer was one hour. For one of the incidents documented by CDHS (ten cases), the air conditioning system was used for ventilation, and the aircraft was ventilated for at least one hour. In this incident, air was re-circulated throughout the cabin during the ventilation period. For the other two incidents (two cases), CDHS could not determine the type of ventilation used (i.e., natural ventilation and/or the air conditioning system) or the duration of the ventilation period.

- **Aircraft towed to gate:** Following the ventilation period, the aircraft was towed to the gate. During this time, the doors to the aircraft were closed and the air conditioning was on.

- **Aircraft positioned at gate:** At the gate, one or more doors to the aircraft were open and the air conditioning was on.

- **Flight crew boards*:*** During boarding, one or more doors to the aircraft were open and the air conditioning was on. In two incidents documented by CDHS, flight attendants with pesticide-related illnesses were exposed to the aircraft cabin 45 minutes (one case) to two hours (ten cases) after the residual

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[h] The report of an employer audit on August 12, 1999, states that the doors to the aircraft were opened immediately after the disinsection process was completed. The written policy specifies that the doors are to remain closed for 15 minutes after the disinsection process.

[i] The employer's written procedures state: "Upon completion of aircraft treatment, 1) Ensure that 15 minutes waiting period is allowed before ventilating the aircraft. 2) At the discretion of aircraft maintenance technician, ventilate aircraft for a minimum of 1 hour using **one or both** of the methods below: a) Open as many aircraft doors as required to start ventilation process … b) close doors and start APU (auxiliary power unit), run air conditioning system with recirculating fans off. Record ventilation "start time" on the disinsection certificate" (emphasis added). The 747- 400 has three "air-packs" or air-conditioning units. One, two, or all three air-packs may have been in use on a given day.

application was completed. The precise time between disinsection and flight attendant exposure could not be determined for the third incident (one case).

Flight attendant training regarding the procedure consisted of one page of information in the flight attendant's manual. A fact sheet on the issue was also distributed by the employer in November 2000.

Pesticide Exposure Control Measures for Flight Attendants

- **Engineering:** The protocol specified a minimum of one hour of ventilation after the pesticide application. Ventilation could be accomplished by opening the cabin doors and/or provided by the aircraft's air conditioning system. The method of aircraft ventilation was discretionary. The protocol did not specify that dilution ventilation be provided with the air-conditioning system set at the maximum rate of air exchange (11 air changes per hour).

- **Administrative:** The pesticide application was performed by ground crew before flight attendants boarded the aircraft. Therefore, flight attendants were not present during the application process. In addition, for an unspecified period in the Fall of 2000, aircraft were reportedly assessed by ground crew for damp surfaces and odor prior to passenger boarding. The results of these quality assurance assessments were not available to CDHS for review. Audits of the disinsection procedure were conducted by the employer on August 12, 1999, and September 7-10, 2000.

- **Personal Protective Equipment:** No personal protective equipment was required, recommended, or in use by flight attendants.

Table 4. Residual disinsection work process in Sydney, Australia, August 2000 to March 2001

	Work Process					
	Pre-disinsection cleaning	**Disinsection**	**Ventilation***	**Aircraft towed to gate**	**Aircraft positioned at gate**	**Flight crew boards**
Workers on aircraft:	Cleaners	Applicators	Maintenance	Maintenance	Maintenance, cleaning, catering, other ground crew	Flight crew, maintenance, cleaning, catering, ground crew
Door status:	Unknown	Doors closed except for entry door	Doors open if only natural ventilation used Doors closed if air conditioning system used for ventilation	Doors closed	One or more doors open	One or more doors open
APU/air conditioning status:**	Unknown	APU off; air conditioning off	APU off and air conditioning off for 0-15 minutes; *** APU off and air conditioning off if only natural ventilation used; APU started and air conditioning on if being used for ventilation	APU on; air conditioning on	APU on; air conditioning on	APU on; air conditioning on

* To ventilate the aircraft, one or both of the following methods were permitted: (1) the doors to the aircraft were opened (i.e., "natural ventilation") and no supplemental ventilation was used, and/or (2) the doors to the aircraft were closed and the air conditioning was turned on with the recirculating fans off.

** APU = auxiliary power unit. The APU is a small gas turbine mounted in the tail cone of the aircraft with an electric generator supplying electric power to the aircraft when the plane is on the ground. The APU supplies airflow to three air-conditioning packs that cool and dehumidify the cabin air.

*** The employer conducted an audit of the disinsection procedure on August 12, 1999. During the audit, the doors were open for ventilation immediately after disinsection was completed. According to the written policy, a 15-minute "waiting period" would normally precede the ventilation period. During the waiting period, the aircraft doors remain closed, and maintenance personnel would be the only workers boarding the plane.

Non-Incident Related Ambient Levels of Permethrin

There were no environmental samples collected from the aircraft involved at the time that the incidents documented by CDHS occurred. The available data were limited to permethrin levels in 140 samples collected from these or similar aircraft (747 - 400s) following residual disinsection at other times. Between April 1997 and May 2001, the employer health and safety staff collected wipe samples of surfaces, pieces of fabric and materials, and air samples. On September 3, 2001, a flight attendant collected surface wipe samples on one aircraft. Aircraft chosen for testing by employer health and safety staff were reportedly selected based on convenience and were considered to be representative of typical conditions.

Samples were collected from a total of 11 planes from 15 minutes up to 28 hours after the aircraft were disinsected in Sydney using 34.4 liters of a 2.2% permethrin solution.[j,k] Permethrin was present on aircraft cabin surfaces up to 28 hours after the pesticide was applied (Table 5). No samples were collected later than 28 hours after the pesticide application. Permethrin levels on surfaces, fabric, and materials were highly variable, with six orders of magnitude difference between the lowest and the highest levels (range 15 to 35,980,000 ug/m^2). Ninety-five percent of the surface, fabric, and materials samples were 1,596,104 ug/m^2 permethrin or less. The highest level of permethrin (35,980,000 ug/m^2) was measured on carpet associated with a visible residue on the cabin floor (Figure 4).

Nineteen of 22 air samples (86%) collected up to approximately four hours post-disinsection had detectable levels of permethrin (Table 6). The highest level of permethrin measured in air [1040 micrograms per cubic meter air (ug/m^3)] was in a sample collected during the period approximately 15 to 96 minutes post-disinsection. Permethrin was not present at levels above the limits of detection[l] in any of the 27 air samples collected in the time period three to 28 hours after disinsection.

[j] The same product was used for disinsection prior to environmental sampling on April 3, 1997, December 12, 1997, and December 16, 1997. A second product was used to disinsect the aircraft prior to sampling on April 18, 24-27, 2001, and May 2, 2001. The two pesticide products were applied as a 2.2% solution of permethrin, and the applications were conducted according to the same procedures.

[k] A total of 15 air samples for "total hydrocarbons" were also obtained in 1997. The reported results ranged from "below the limits of detection for the applicable analytical method" up to 1.7 parts per million.

[l] The limits of detection for air samples collected in 1997 were not reported. The limits of detection for air samples collected in 2001 were reported as 0.15 ug/m^3. Data on the absolute amount of permethrin detectable were not reported.

Table 5. Surface, materials, and fabric permethrin levels in the aircraft cabin post-residual disinsection (N=91 samples from eight aircraft)

Type of sample	No. aircraft sampled	Total no. samples	Permethrin (ug/m^2)		
			Range	Mean	Median
Surface (e.g., wipe samples of arm rests, walls, floor runners)	7*	68	15 – 4,186,000	178,026	750
Materials (e.g., blankets, headsets, tissues, paper towels)	2	13***	230 – 35,980,000	4,307,803	84,130
Fabric (pieces cut out of seat covers)	1**	10	2500 – 110,000	39,430	10,250
Total all surfaces, materials, and fabric	8***	91****	15 – 35,980,000	589,313	1,600

Source: Results of sampling conducted by employer April 3, 1997, December 12, 1997, April 24 to May 2, 1997, and by a flight attendant on September 3, 2001.

* A total of nine aircraft were sampled, but results of permethrin on surfaces for two aircraft are missing. 64 surface samples were collected by the employer on six aircraft; four surface samples were collected by a flight attendant on one aircraft.

** A total of two aircraft were sampled, but results of permethrin on fabric seat covers for one aircraft are missing.

*** A total of ten aircraft were sampled, but results of surface and/or fabric samples are missing for two aircraft.

**** Four of 13 materials samples were not reported in ug/cm^2 and so were not included in this calculation. The values of these samples were: sticker 57 ug/sample; tissue 560 ug/sample; and 2 paper towels each < LOD.

Table 6. Air levels of permethrin in the aircraft cabin post-residual disinsection (N=49 samples from ten aircraft)

Time interval post-residual disinsection (hours)	Number of samples	Permethrin (ug/m^3)
0-3.5	5	2.2 – 230
	17	< LOD* – 1040
3-18	12	All < LOD
4-15.5	6	All < LOD
20-28	5	All < LOD
25-30	4	All < LOD
Total	**49**	

*LOD = Limits of detection

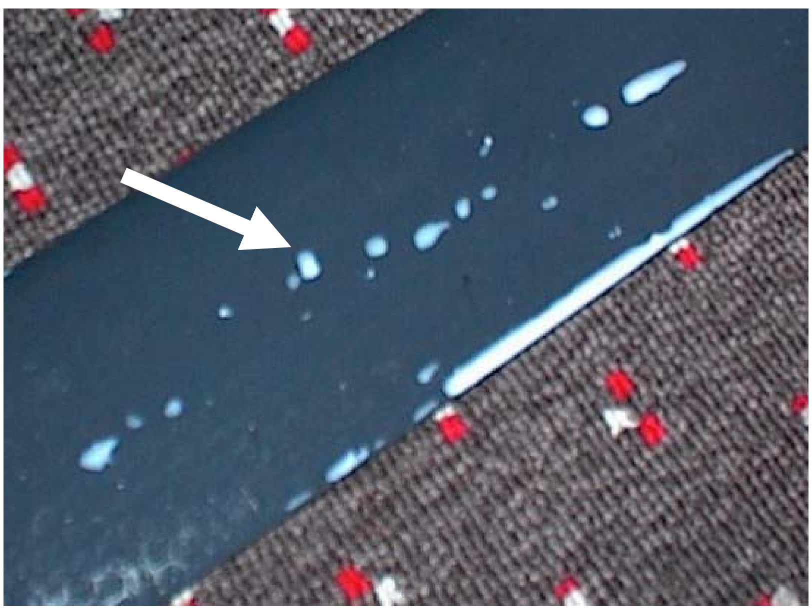


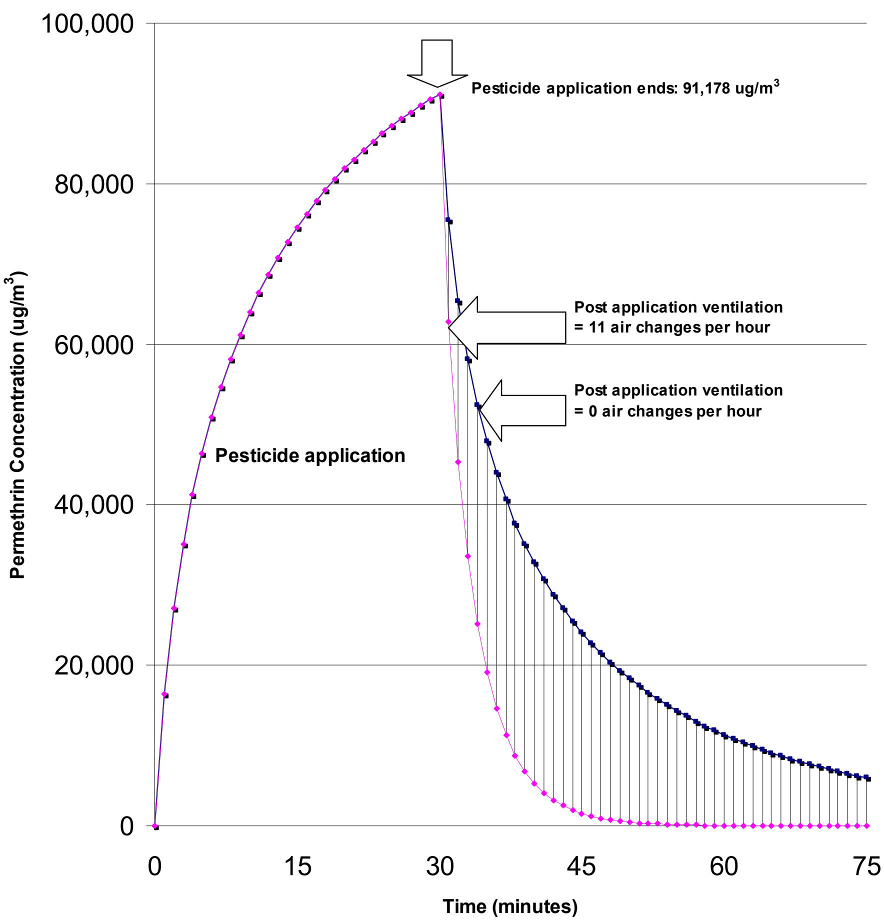
Figure 4. Cabin floor post-residual disinsection. The cloudy, white liquid is the residue of the 2.2% permethrin solution applied to the aircraft. Source: Employer Health and Safety staff

Model of Pesticide Release in the Aircraft Cabin

A model estimating the concentration of permethrin in the aircraft cabin air during the pesticide application (0-30 minutes) and during the 45-minute period following the application was developed as described in Appendix 2. The results of the model are presented in Figure 5. Two scenarios are presented: (1) no mechanical dilution ventilation is supplied to the aircraft cabin in the 45-minute period after the application ends (zero air changes per hour (ACH)); and (2) 11 ACH is supplied in the 45-minute period following the application.

Based on the concentration of permethrin released over time, and the volume of air, and rate of ventilation in the aircraft cabin, at the end of the application, the permethrin concentration in the aircraft cabin was estimated to be 91,178 ug/m^3. Forty-five minutes after the application is completed, the air concentration of permethrin is estimated to be 5,988 ug/m^3 if there was no supplied mechanical ventilation (zero ACH), and 1.6 ug/m^3 if 11 ACH were supplied to the aircraft.

Figure 5. Model of permethrin levels in aircraft cabin air during and 45 minutes after residual disinsection (29 L of 2.2% permethrin applied)



DISCUSSION

The illness reports documented by CDHS indicate that residual insecticide applications can result in illness among workers exposed to the aircraft cabin environment after disinsection. Recommended procedures for residual aircraft disinsection are established by the World Health Organization (WHO) Expert Committee on Vector Biology and Control. [7, 17,18] The WHO's recommendations are based on two health-related assumptions: (1) the human toxicity of permethrin is low; and (2) the conditions of use will result in exposures to concentrations too low to cause acute illness.[m] The WHO's assumptions have not been validated with crew or passenger-related exposure or illness data.[19 (pp.110, 279)] In addition, the available toxicity data for permethrin have not undergone complete public review. [20] The illnesses documented in the incidents reported to CDHS indicate that one or both of WHO's assumptions about the human health impacts of residual disinsection are not valid.

1. Human Toxicity of Permethrin

Acute health impacts of permethrin and pyrethroid exposure reported in the literature

There is documentation in the literature of acute illness following human exposure to permethrin. The signs and symptoms of exposure to permethrin include irritation of the eyes and upper respiratory tract, and irritation, burning, and itching of the skin, and urticaria.[11,12] Exposure to synthetic pyrethroids can cause abnormal sensations on exposed skin, contact dermatitis, dizziness, nausea, anorexia, fatigue, mild disturbances of consciousness, muscular fasciculations, and at high doses, pulmonary edema, convulsions, and coma.[13]

Aerosolized pyrethroid insecticides used for disinsection may trigger "non-specific" bronchoconstriction and respiratory symptoms in asthmatics.[7] Two cases of pyrethroid exposure provoking an asthmatic reaction have been reported.[21, 22] Salome et al, demonstrated significant adverse effects on lung function, airway hyperresponsiveness, and chest, nose, and eye symptoms among asthmatic individuals exposed to pyrethroid/solvent formulations.[23] The authors conclude that the mechanism by which insecticide aerosols affect the airways is not clear, but may be related to the formulation, rather than pyrethroid toxicity per se.

Flight attendants' signs and symptoms

Flight attendants' illnesses followed exposure to a pyrethroid formulation, including permethrin, solvents, and a surfactant. Exposure to chemical mixtures may have additive, synergistic, or antagonistic health effects. Although many of the signs and

[m] The WHO states, "Given the understanding of the mode of action of pyrethroids and low exposure from aircraft disinsection it is unlikely that this procedure will precipitate or influence any pre-existing disease in passengers or crew". [7 (p.24)]

symptoms among flight attendants were related to permethrin or pyrethroid exposure (Table 2), the relative contribution of each of the constituents of the pesticide formulation to the observed health impacts is not known. Symptomatology may also include solvent-related toxicity,[24] and surfactant-related skin irritation.[25] The ratio of isomers present in the product also greatly influences toxicity;[5,20] the extent to which the isomeric ratio in the same product may vary between batches is not known.

Anxiety may influence the manifestations and reporting of symptoms with any medical condition, including those following pesticide exposure.[26,27] For example, flight attendants' reports of palpitations (N=5) are consistent with anxiety-related symptoms (Table 2). One of three incidents documented by CDHS involved a group of flight attendants with some symptoms and characteristics of mass psychogenic illness (headache, dizziness, nausea, drowsiness, and reports of an unusual odor). [28] However, mass psychogenic illness is not consistent with these illnesses because a physical agent capable of causing the illnesses, a permethrin formulation, was present in all cases, and only three of ten flight attendants reported an unusual odor in this incident.[29,30]

Relationship between pesticide exposure and flight attendants' illness

The evidence supporting the role of pesticide exposure in causing the illnesses in these incidents includes: (1) all of the illnesses occurred shortly after the onset of pesticide exposure; (2) all of the illnesses were documented by a licensed health care practitioner; (3) workers' signs and symptoms (Table 2) were consistent with the recognized health impacts of permethrin and pyrethroid exposure (e.g., respiratory, nervous system, dermatological, eye, and gastrointestinal); (4) all cases experienced two or more recognized signs and/or symptoms of exposure to the pesticide formulation; and (5) illnesses were documented in three separate incidents. Therefore, the contribution of psychosocial factors was likely to have had a secondary, if any, role in these illnesses.

The illnesses documented in this report are also consistent with acute human health effects experienced by workers exposed to pyrethroids in other occupational settings.[13] In the three-year period 1998-2000, CDHS identified 60 cases of work-related illness due to pyrethroid exposure in other non-aircraft work settings. We could identify no other documented reports of adverse human responses to aircraft disinsection in the literature. However, the cases verified by CDHS are consistent with anecdotal reports of illness among flight attendants exposed to aircraft cabins after residual disinsection. According to self-reports collected and compiled by the AFA, flight attendants (and in some cases, passengers and pilots) reported symptoms consistent with exposure to pyrethroid pesticides on 237 flights from August 1, 2000 - July 31, 2001. [31] Of these, 224 (95%) followed residual spray applications. The employer recorded 38 cases of "insecticide poisoning" among flight attendants based in Los Angeles during the calendar years 2000 and 2001. Pesticide illness tracking conducted by the employer and the AFA[n] does not fully document the incidence of illness related to aircraft disinsection due to methodological limitations (e.g., incomplete and inconsistent reporting, lack of medical documentation, and standardized case definition, etc.).

2. Conditions of Use

Routes of exposure

Residual disinsection results in pesticide residues in the aircraft cabin air and on surfaces. Therefore, flight attendants can be exposed to pesticides through inhalation, skin absorption, and ingestion. Permethrin is absorbed into the body faster when inhaled or ingested, compared to exposure through the skin.[32] In the incidents documented in this report, flight attendants became ill shortly after boarding the aircraft. The rapid onset of symptoms suggests that inhalation was a route of exposure for the flight attendants in these incidents, since they were unlikely to be eating, drinking, smoking or otherwise ingesting the pesticide immediately after boarding. Inhalation exposure is also supported by employer monitoring data, which consistently demonstrated that permethrin persists in the air up to four hours following disinsection (Figure 4).

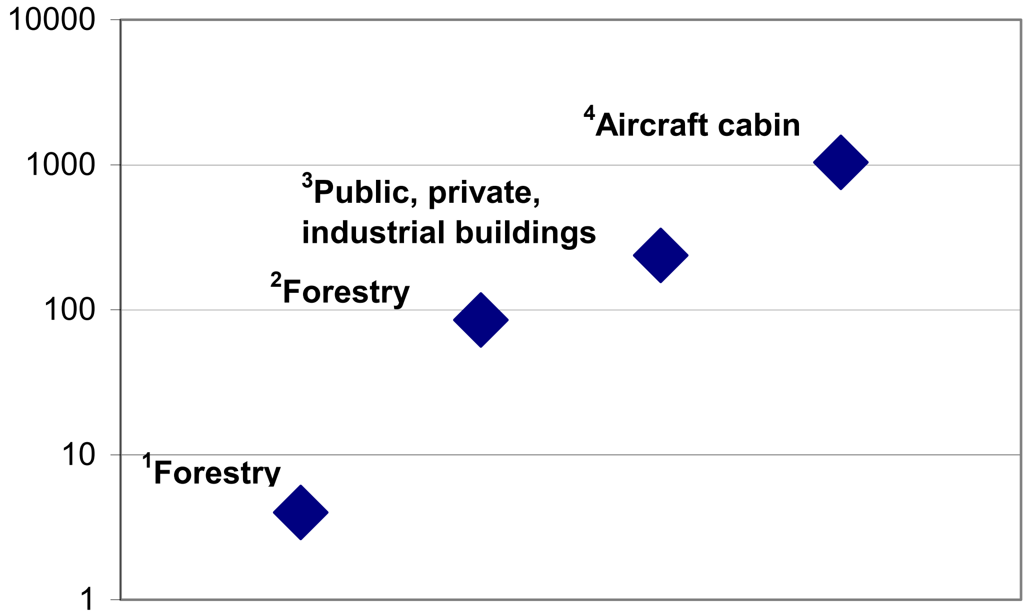
Flight attendants' skin contact with pesticides is also likely to have contributed to the illnesses documented in this report. Permethrin has a strong affinity for inert matter, a low vapor pressure, and is more photostable than other pyrethroids or the natural pyrethrins.[33,34] As a result, permethrin persists on surfaces, fabric, and in dust. [35,36] Employer data demonstrate that permethrin is present in the aircraft cabin at least 28 hours after the application. Results of case studies of indoor exposures to other low-volatility pesticides (lindane and pentachlorophenol) indicate that direct skin contact with contaminated textiles significantly contributes to total body exposure.[35] Although typically, dermal uptake of pyrethroids is relatively low,[32] most of the physical space in an aircraft is completely filled with pesticide-treated surfaces and materials, including seats, carpets, and bunks. Therefore, if residual disinsection is performed as required, pesticide residues should be widespread in the aircraft cabin, and dermal exposure will be prevalent.

Moreover, flight attendants' exposure to wet surfaces may have increased the transfer of the pesticide to their skin, and, therefore, led to increased dermal exposure. Incident-specific and general observations by flight crew and employer health and safety personnel of wet surfaces and/or puddles after disinsection (Figure 4) demonstrate the variability of pesticide residues throughout the cabin. This finding is further supported by results of surface samples which indicate that levels of permethrin in treated aircraft routinely varied by up to six orders of magnitude (Table 5). The variability among measured surface levels is partly due to the differential collection efficiencies among surface types and the lack of a standardized sampling method.[19 (p.267)] Together, the

[n] The employer tracks illnesses using Occupational Safety and Health Administration logs, workers' compensation data, and air quality reporting forms. The AFA tracks illnesses with self-reported illness reports.

direct observations and sampling data suggest that a wide range of pesticide exposure levels routinely occurred on treated aircraft. The variability in exposure levels is consistent with other work settings where pesticides are applied. A study of permethrin applications in 35 work settings concluded that, in practice, workers can incur exposures orders of magnitude above average levels.[41] From a qualitative perspective, the highest non-incident-related levels measured in aircraft air were higher than personal air monitoring exposure levels of workers in a variety of other settings where permethrin is utilized (Figure 6).

Figure 6. Maximum airborne concentration of permethrin in 4 work settings (ug/m^3)



1 Personal air monitoring of seven workers while applying permethrin to conifer seedlings.[37]
2 Personal air monitoring of six workers while applying or handling permethrin-treated conifer seedlings.[38]
3 Personal air monitoring of 44 workers while applying permethrin as a public hygiene insecticide at 35 sites.[41]
4 Ambient permethrin aircraft air levels 15 to 85 minutes post-disinsection (Employer data, Table 6).

Exposure control measures

The industrial hygiene hierarchy of controls is a recognized method to apply control measures for the primary prevention of occupational injury and disease. The accepted strategy for controlling toxic workplace exposures is to first attempt to eliminate the generation source, hazardous materials, and dangerous activities.[39] When pesticide use is not or cannot be eliminated, most techniques designed to increase safety focus on the isolation of the chemical from the worker.[40] In contrast, residual disinsection involves placing flight attendants in a pesticide-treated area with few industrial hygiene measures to minimize exposure. Assuming the pesticide is mixed according to the protocol, the total mass of permethrin applied to every treated aircraft will be the same. However, factors such as equipment leaks,[41] application equipment that is not calibrated, ambient temperature and humidity, and type and duration of ventilation (Figure 5) will impact the distribution of pesticide levels on surfaces and in the air within and among treated aircraft.

At the time of these incidents, the employer took steps to improve on the safety of the required procedure by establishing a minimum one-hour post-application ventilation period. However, the exclusive use of the ventilation system at maximum capacity was not specifically mandated in writing, and there were no quality control or other requirements to document that after every application at least one hour of such dilution ventilation had occurred. In practice, dilution ventilation procedures were inconsistently implemented, which created the potential for greater than “average” pesticide exposure levels. The results of the model illustrate the relatively large impact that dilution ventilation has on the levels of permethrin in the cabin air (Figure 5).

For one incident (ten cases), the required one hour of ventilation using the air conditioning system was implemented. The only deviation from standard procedures identified by the employer in this incident was that air was recirculated during the ventilation period. This lapse would have decreased the efficacy of the ventilation in this incident by less than one ACH,[o] and therefore did not contribute to a significant increase in flight attendant exposure. This suggests that although the standard ventilation procedures were likely to have reduced flight attendants’ exposure, the procedures were not fully effective. For the second incident, the flight attendant boarded the aircraft 45 minutes after the application, indicating that the required one hour ventilation period could not have occurred. There was insufficient information to assess what additional factors may have contributed to the flight attendant’s illness in the third incident.

Although not an exposure control measure per se, according to the disinsection procedure, the total time between completion of residual disinsection and flight crew boarding was approximately 2 hours 25 minutes to 2 hours 55 minutes.[p] In two

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[o] The filter efficiency of the aircraft ventilation system is in the range of 93-99.9% (depending on the aircraft). Therefore, the recirculation of cabin air (i.e., re-using cabin air after it is filtered, instead of using 100% fresh air) would have decreased the ventilation rate in the cabin by less than one ACH (93% of 11 ACH = 10.23 ACH).

[p] The employer audit on August 12, 1999, found there was not a full cleaning crew. According to the audit report, if a full cleaning crew had been present, the aircraft could be ready for disinsection 30 minutes sooner. Assuming all

incidents, flight attendants boarded the aircraft 45 minutes to 2 hours after disinsection was completed. The rapid turn-around time of the aircraft further reduced the time interval between disinsection and flight attendant exposure to the treated aircraft cabin.

Although assessments of wet surfaces and odors were made by the employer for a limited period for quality control purposes, these are not reliable exposure control measures. Wet surfaces may escape notice if only a cursory examination of the aircraft is made. Moreover, it is inappropriate to rely on the detection of odor as a warning of acute health hazards from permethrin because (1) the odor threshold of permethrin has not been established;[42] and (2) individuals vary in their ability to detect odors due to age, sex, previous exposure to the odor, health status, smoking, and genetics.[43, 44, 45, 46, 47,48, 49] This is illustrated by the finding that eight of 12 flight attendants who became ill did not detect odor.

Finally, flight attendants' illnesses may have been exacerbated because flight attendants were unable to remove themselves from exposure and seek medical care in a timely way. The primary intervention in the case of a toxic exposure is to remove the affected individual from the area of exposure as soon as possible, and not to return them to the area of the exposure until full decontamination is carried out.[26] Residual disinsection results in unavoidable flight attendant exposure to a pesticide in a confined space (i.e., a relatively small, enclosed area with no ready egress). Therefore, the most important treatment of any toxic syndrome, interruption of exposure,[12] is precluded by the conditions of use. Initiating basic first aid, such as removal from exposure, for flight attendants who experience pesticide-related illness is not possible during flight.

other time intervals to be constant, this would increase the time between the application and the flight crew boarding to a maximum of 2 hours 55 minutes.

3. Other Public Health Considerations Related to Residual Disinsection

The following issues, although not directly related to the acute illnesses reported by CDHS, are considerations relevant to the human health impacts of residual disinsection.

Cumulative health impacts of flight attendant pesticide exposure

Flight attendants incur other work-related pesticide exposures in addition to residual applications. Pesticides are applied to areas that are deep-cleaned or refurbished after a residual application to ensure compliance, to aircraft galleys, and/or in occupied cabins when an aircraft has not been treated with a residual application within the past eight weeks. The employer does not systematically record how frequently nonresidual pesticide applications are made in occupied aircraft cabins, but flight attendants consistently report its occurrence. Between August 1, 2000, and July 31, 2001, 13 flights involving problems with the in-flight spray were documented by the AFA.[31] The health impact of these exposures may be cumulative. The National Research Council Committee on Air Quality in Passenger Cabins of Commercial Aircraft has noted the possibility that flight attendants may have an enhanced response to successive pesticide exposures because an intermittent exposure regime is ideal for inducing sensitization or a magnified response to the same exposures.[19 (p.204)]

In addition, permethrin is considered a potential human carcinogen by the U.S. Environmental Protection Agency.[50] The International Agency for Research on Cancer states there is inadequate evidence in animals to classify the carcinogenicity of permethrin in humans.[51] Therefore, data to ensure that exposures to residues do not pose a cancer risk are lacking.

Mixed exposure environment

In addition to pesticides, flight attendants are simultaneously exposed to many other chemical, biological, and physical agents (Appendix 3). There is some evidence that the mixture of exposures incurred by flight attendants may increase the toxicity of the pyrethroid exposure in the aircraft cabin environment.[19 (pp.204, 208)] The toxicity of permethrin may be enhanced if there is simultaneous exposure to agents that increase the absorption[52,53] and/or interfere with detoxification of permethrin.[4] Conversely, a high level of pyrethroid exposure can interfere with the metabolism of other agents.[4] Exposure to organophosphate chemicals in the aircraft air as a result of oil seal failure[54] has been suggested as a possible mechanism for increased sensitivity of some crew members and passengers to disinsectants.[55] In addition, in a study of chemical interactions among compounds administered to mice at human-equivalent dose levels, permethrin pre-treatment appeared to open the blood-brain-barrier to other compounds.[56] Although there is no evidence indicating these other exposures were directly related to the acute illnesses reported by CDHS, these multiple but poorly characterized interactive factors may influence the health of the flight crew. Therefore, it is not valid to assess the potential health impacts of residual aircraft disinsection as if flight attendants are exposed to a single agent.

Population exposed is large and diverse

Residual aircraft disinsection results in the unavoidable exposure of a large population to a "small" risk. It is a basic epidemiologic principle that large numbers of people exposed to "small" risks can lead to a large public health impact.[57] The worker population at risk is not limited to flight attendants, but includes cleaners, caterers, mechanics, and others who routinely enter the aircraft cabin shortly after disinsection (Table 4). In general, vacuuming, mopping, abrasion, and walking can re-suspend dust particles in the air, and result in greatly increased levels of airborne dust.[19 (p.103)] A case report of an outbreak of permethrin-related illness in a family found symptoms to be associated with vacuuming in the home, presumably producing re-aerosolization of the settled permethrin.[12] An investigation of health complaints in connection with permethrin-protected wool carpets in homes found permethrin was detected in house dust if the wool fibers contained permethrin.[58] These data suggest that re-suspended dust may be a pathway of pesticide exposure of particular importance for cleaning crews vacuuming treated surfaces, especially in unventilated aircraft. In addition, there may be significant potential for dermal exposure among workers who clean aircraft and are responsible for wiping up puddles and wet surfaces after the application.

The passenger population at risk is also large and includes many groups of people who may be more susceptible to the health impacts of their exposure due to one or more factors such as pre-existing disease,[6] lowered immunity, age, and individual susceptibility related to the ability to detoxify the exposure.[59] Based on implementation of the procedure by one large airline, the entire fleet of aircraft flying in a region will be treated to ensure flexibility in routing, effectively maximizing the numbers of individuals exposed. Current practices for residual disinsection do not involve notification of passengers that the aircraft has been treated or when it was treated. Information about how to recognize the signs and symptoms of pesticide illness is not provided.[q] Therefore, individuals are not able to opt out of this exposure. CDHS concludes that the public health impact of residual disinsection is not limited to the risk of acute pesticide-related illness among flight attendants, but also includes the passenger population.

Efficacy of residual disinsection in preventing vector-borne diseases

Aircraft disinsection is conducted to achieve a number of crucial public health objectives, including the prevention of vector-borne diseases.[60] Since 1969, 63 cases of "airport malaria" (i.e., cases of malaria among ground workers at airports and nearby residents exposed to infected mosquitoes arriving from endemic areas) have been reported in Western Europe.[61] The potential for introducing or re-establishing disease-

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[q] Passengers' notification for in-flight spraying states, "To conform with (country destination) agriculture and health requirements, the cabin will now be sprayed prior to our arrival in _____. This procedure, **using a non-toxic spray** recommended for this purpose by the World Health Organization, is necessary to avoid introduction of harmful insects into (country destination). Please remain seated and keep the aisles clear while the aircraft is being sprayed. Thank you" (emphasis added).

carrying insect vectors in distant areas is also an important concern.[60] The increased movement of people and goods throughout the globe, changing patterns of climate, and the deterioration of the malaria control efforts in Africa and elsewhere, will likely affect transmission patterns of vector-borne pathogens.[61,62] Therefore, the prevention of vector-borne diseases will remain essential to protecting public health.

Pyrethroids are considered to be highly effective insecticides. However, the available data raise questions about the relative efficacy of aircraft disinsection in preventing vector-borne disease. For example: (1) the contribution of air transit to vector importation relative to the contribution of sea and land transport is poorly understood;[7] (2) aircraft disinsection is not considered to be efficacious in addressing “luggage malaria” (i.e., when infected vectors are transported in luggage to areas that may be a considerable distance from an airport and transmit disease upon escaping);[61] (3) vector importation is but one factor in determining disease incidence, with weather, demographic, and social factors also playing a critical role,[62] and (4) the use of pesticides is not a sustainable solution to the problem of vector-borne disease control.

Given the current understanding of the relative contribution of insect vectors on aircraft to disease transmission, and the widespread use of pyrethroids, it appears that aircraft disinsection may also violate some of the resistance management principles presented by WHO, such as: (1) limiting pesticide use to areas with high levels of disease transmission and to seasons in which peak disease transmission or pest nuisance occurs; and (2) use of nonchemical control methods either alone or as a supplementary measure in seasons or areas where they are applicable and cost effective.[63] Indeed, some resistance to pyrethroid pesticides has already been documented, and the real possibility for more widespread resistance which would render the procedure useless has led some experts to call for an urgent search for suitable alternatives.[61] CDHS’ findings show that the conditions of use (i.e., the aerosol application of a pesticide in a confined space) significantly contribute to the human health hazard of this procedure. Therefore, the replacement of permethrin with another chemical alternative would not eliminate the health hazards of disinsection.

4. Limitations

Important limitations to this investigation include:

- **Factors not identified by CDHS may have contributed to these illnesses.** CDHS did not interview the workers who applied the pesticide in Australia due to a lack of resources and legal authority. Our understanding of the residual disinsection procedure at the time of these incidents is based on information pieced together from the employer’s data (i.e., written documentation of the procedures, audits, air monitoring reports, and a video of the standard procedure), incident-specific medical records and other illness reports, and interviews with flight attendants and employer staff with in-depth, first-hand knowledge of the procedure and/or incidents. Although the employer has confirmed that CDHS’ process description is accurate, as in any workplace, only the workers who actually applied the pesticide had direct knowledge of what occurred. The lack of corroboration of these events by the workers who applied the pesticide is a critical piece of missing data. Therefore, we cannot rule out that other, unrecognized factors (e.g., the pesticide was not mixed or applied according to procedures) contributed to these illnesses. This seems unlikely to have occurred for at least one incident (ten cases). In this incident, the employer conducted a timely investigation. As previously described, the only deviation from standard procedures identified by the employer was that the air was re-circulated during the ventilation period, which would have decreased the efficacy of the ventilation by less than one ACH. There is insufficient information about the other two incidents to rule out that factors related to the application process, but not identified by CDHS, contributed to these illnesses.

- **The amount of pesticide exposure incurred by flight attendants in the incidents reported by CDHS is not known.** There were no incident-specific-personal-exposure monitoring data for flight attendants. The existing data on ambient levels of permethrin in the aircraft cabin cannot be compared to specific levels associated with adverse human health consequences because: (1) these data were not case specific, and may not reflect flight attendants' exposures at the time of the incidents documented by CDHS; (2) the collection efficiencies of the surface, materials, and fabric samples were not documented; and (3) the samples were not uniformly collected and analyzed using standardized methods. It is important to note that a standard method with documented removal efficiencies does not exist for sampling permethrin on aircraft surfaces and materials.[19 (p.267)] Despite these limitations, the existing samples are valuable in that they were all collected under real-time, representative workplace conditions, include a very large number of samples, from multiple aircraft, over time, and almost all were collected by trained industrial hygiene professionals. Given their limitations and value, the existing data do provide evidence of the magnitude of flight attendant exposure, and that exposure occurred via inhalation and through contact with treated surfaces.

- **The documented acute illnesses resulting from aircraft disinsection likely understate the health risks of this procedure.** The incidence of work-related illness associated with aircraft disinsection is not known. In general, cases of work-related pesticide illness are seldom reported and verified, because substantial barriers to reporting exist.[64] An individual must recognize they have been exposed to a pesticide, know the signs and symptoms of pesticide illness, and seek medical care. Flight attendants received minimal training regarding their pesticide exposure; and cleaners, caterers, mechanics, and other workers who routinely entered newly-pesticide treated aircraft were not recognized as being pesticide-exposed. Therefore, workers may not have made the connection between their exposure and symptoms. The treating physician must also recognize and report the illness to a local health agency. The signs and symptoms of pesticide-related illness may be nonspecific, and, therefore, may be misdiagnosed. Workers' fear of retaliation also prohibits full reporting.

- **CDHS did not assess the pesticide exposures incurred by the applicators in Sydney**. These workers may incur the highest exposures from this procedure, depending on the presence, use, and efficacy of measures implemented to control their exposures.

SUMMARY OF FINDINGS

- **Residual disinsection poses a hazard to flight attendants.**

  Residual disinsection resulted in illness among 12 flight attendants exposed to the aircraft cabin environment after disinsection. The documented acute illnesses likely understate the health risks of this procedure because many barriers to acute illness recognition and reporting exist.

- **The conditions of use (i.e., the aerosol application of a pesticide in a confined space) significantly contributed to the human health hazard of residual disinsection.**

  Residual disinsection procedures involved placing flight attendants in a pesticide-treated area with few industrial hygiene measures to limit their exposure**.** Post-disinsection aircraft ventilation procedures and administrative measures did not effectively limit flight attendants' exposure. A wide range of pesticide exposure levels routinely occurred on treated aircraft, including the potential for greater than "average" exposures. Flight attendants' illnesses may have been exacerbated because they were unable to remove themselves from exposure and seek medical care in a timely way.

- **Current assumptions about the human health impacts of residual disinsection underestimate the risks of this procedure.**

  In addition to the potential for acute illness, there may be cumulative health impacts of flight attendants' exposure to pesticides. There is also some evidence that the mixture of exposures incurred by flight attendants may increase the toxicity of the pyrethroid exposure in the aircraft cabin environment. Although there is no evidence indicating these other exposures were directly related to the acute illnesses reported by CDHS, these multiple but poorly characterized interactive factors may influence the health of flight crew. The public health impact of residual disinsection is not limited to the risk of acute pesticide-related illness among flight attendants, but also includes other workers and the passenger population.

- **The relative efficacy of aircraft disinsection in preventing vector-borne disease is not well described.**

  Although pyrethroids are considered to be highly effective insecticides, the available data raise questions about the relative efficacy of aircraft disinsection in preventing vector-borne disease.

RECOMMENDATIONS

Primary Prevention

National and international health agencies should: (1) assess the relative efficacy of disinsection in preventing vector-borne diseases; and (2) identify and recommend implementation of sustainable, nontoxic alternative methods of minimizing the importation of disease vectors in aircraft cabins.

Research is needed to determine the relative efficacy of aircraft disinsection in preventing vector-borne diseases that may pose a risk to public health and the environment. Research is also needed to identify nontoxic alternatives that will exclude viable insect vectors from aircraft cabins. Current efforts by the U.S. Department of Transportation to test the feasibility of air curtains[65] are promising and should continue to be pursued. Industries, workers, passengers, and others who are impacted by disinsection should vigorously support these measures.

Secondary Prevention

While sustainable alternatives are being identified, all airline industry employers should implement measures to control worker and passenger exposure to pesticides resulting from disinsection. It is important to note that although these interim measures are expected to *increase* protection for potentially exposed individuals, they may not be entirely effective in preventing exposure. They are recommended only as short-term measures to increase safety while primary prevention measures are instituted.

All airline industry employers should:

- **Educate all potentially exposed workers about the hazards of aircraft disinsection**. This includes maintenance workers, cleaners, caterers, and any other workers who may be exposed to the aircraft cabin during or subsequent to disinsection. All exposed workers should be trained to recognize the signs and symptoms of pesticide exposure and to seek prompt treatment from a licensed health care provider in the event of illness.

- **Restrict entry for all workers to the aircraft cabin after disinsection.** Limited measurements show the potential for airborne exposure to permethrin for up to four hours after disinsection. Therefore, all workers without protective clothing should be explicitly prohibited from entering a treated aircraft during this period. Current procedures for disinsection by the employer represent a significant improvement over the procedure performed in Sydney at the time of these incidents: the aircraft is essentially shut down for four hours after it is ventilated, and there is now approximately nine hours between the end of the application and flight crew boarding. The current procedure should be strengthened by explicitly stating in the written policy and procedures that the four-hour time interval during which the aircraft is now shut down (Appendix 1, Table A1) is not optional, but a “restricted entry requirement.” The employer should also implement effective measures to ensure and track compliance with the restricted entry requirement (e.g., signage, training, written documentation of compliance, etc.).

- **Implement and enforce maximal ventilation procedures on every treated aircraft.** Current procedures for disinsection by the employer represent a significant improvement over the procedure performed in Sydney at the time of these incidents; the aircraft is now ventilated for at least one hour using maximum dilution ventilation. However, this policy is not explicit in the written procedures. Written procedures should specify that the aircraft’s ventilation system be used at maximum capacity with no recirculation of air for at least one hour after disinsection, followed by a four-hour restricted entry requirement (described above). Although a one-hour ventilation period supplied by the air conditioning unit is expected to *increase* protection for potentially exposed individuals, it may not be entirely effective in eliminating exposure. The employer should also implement effective measures to ensure and track compliance with the ventilation procedures.

- **Institute quality control measures for every pesticide application.** All pesticide-treated aircraft should have a written record documenting: (1) when and how the pesticide was applied to the aircraft; (2) the type and duration of ventilation that occurred after the application; and (3) compliance with the restricted-entry interval. This written documentation should be presented to the flight crew prior to passenger boarding. Moreover, it should be the policy of the employer not to board aircraft that do not have written documentation of compliance with pesticide exposure control measures.

- **Cease spraying pesticides in the crew rest area (bunk room).** The bunk area is a location with minimum airflow where flight crew lie down on pesticide-treated surfaces to rest. Dermal and airborne exposures in the crew rest area are likely to be especially problematic and should be eliminated.

- **Notify in advance passengers who may be exposed to a pesticide-treated aircraft of the procedure and the potential health risks.** Currently there is no notification for residual applications. In-flight notification stating that the spray is “nontoxic” is not accurate, as shown by the data in this report. Passengers should have the choice to opt out of this otherwise unavoidable exposure prior to ticket purchase.

- **Schedule flights to countries that require disinsection so that the number of aircraft treated is minimized**. Currently, implementation of the procedure by the employer tends to increase rather than minimize the number of individuals exposed, because the treated aircraft are not limited to routes that require disinsection, but are also used on other international or U.S. domestic routes.

- **Initiate active illness surveillance among exposed workers and passengers.** The incidence of pesticide-related illness due to disinsection is not known. Active efforts to identify, document, compile, and report illnesses that may result from disinsection should be undertaken.

Appendix 1

Residual Aircraft Disinsection In Hong Kong : August 2002

Aircraft disinsection is no longer performed for the employer by the contractor in Sydney. Since August 2002, the residual disinsection process has been implemented for the employer by a different contractor in Hong Kong. The steps taken are outlined on Table A1. The current procedure is the same as it was in Sydney with the following exceptions:

(1) The same volume (34.4 L) of a two percent permethrin solution is applied, but it is mixed using a different pesticide product;

(2) The aircraft layover time in Hong Kong is 14 hours, approximately twice as long as in Sydney. As a result, the aircraft is shut down after post-disinsection ventilation for approximately four hours;

(3) The aircraft is ventilated for at least 60 minutes after disinsection by closing the aircraft doors and turning on all three air conditioning packs. The partial or exclusive use of “natural ventilation” (i.e., opening the aircraft doors without the use of the air conditioning) is not permitted unless the Auxiliary Power Units (APUs) are inoperable. The employer reports that up to September 2002, there was not any occasion in Hong Kong when the APU was not been operable. However, this policy is not explicit in the written procedures;

(4) The total time between completion of residual disinsection and flight crew boarding was approximately 9 hours and 35 minutes (10:45 pm to 8:20 am). As of Fall 2002, there has been no personal exposure monitoring or ambient air sampling for the Hong Kong procedure.

Table A1. Residual aircraft disinsection work process in Hong Kong : August 2002

	Work Process									
	Pre-disinsection cleaning	**Disinsection**	**"Waiting period"**	**Ventilation**	**Maintenance, re-stocking, security**	**Plane shut down**	**Day shift begins**	**Aircraft towed to gate**	**Aircraft positioned at gate**	**Flight crew boards**
Workers on aircraft:	Cleaners	Applicators	Maintenance	Maintenance only	Maintenance, other ground crew		Maintenance, cleaning, catering, other ground crew		Maintenance, cleaning, catering, other ground crew	Flight crew, maintenance, cleaning, catering, ground crew
Door status:	N/A	Doors closed except for entry door	Doors closed	Doors closed	Doors closed	Doors closed	Doors open	Doors closed	One or more doors open	One or more doors open
APU/AC status:	N/A	APU off; AC off	APU off; AC off	APU started; AC on	APU off; AC off	APU off; AC off	APU started; AC on	APU on; AC on	APU on; air conditioning on	APU on; air conditioning on
Time elapsed (min.):	120	45	**15**	**60***	**120**	**240**	**60**	**30**	**30**	

* 60-minute minimum. In practice, the aircraft may be ventilated with the air conditioning on for up to 3 hours.

Appendix 2

Model of Pesticide Release In Aircraft Cabin

The following model was developed by Mark Nicas, Ph.D., C.I.H, School of Public Health, University of California, Berkeley. Dr. Nicas developed this model as a consultant to the California Department of Health Services, Occupational Health Branch.

The model is an Excel spreadsheet which is available on request to CDHS. The purpose of the model is to estimate the air levels of permethrin during the 30-minute application period and during the 45-minute period after the application is completed. Using the model, two scenarios are evaluated: (1) no mechanical dilution ventilation is supplied to the aircraft; and (2) maximal dilution ventilation (11 air changes per hour) is supplied for 45 minutes following the pesticide application.

Assumptions:
(1) a solution containing 2.2% permethrin w/w is applied with a fogger in the cabin;
(2) passenger cabin volume 1000 m^3;
(3) average cabin height of 6 feet;
(4) equal permethrin mass in the different particle sizes in the diameter range 5 um to 40 um; *
(5) uniform emission during the 30-minute spray period;
(6) no ventilation whatsoever in the cabin during the application.

* CDHS requested detailed information on particle size distribution from the manufacturer but data were not provided.

To begin, the model divides the particles into small diameter bins and uses the midpoint values. For example, there was a 5 to 6 um bin (midpoint 5.5 um), a 6 to 7 um bin (midpoint 6.5 um), and so forth up to the 39 to 40 um bin (midpoint 39.5 um). For each bin, the midpoint diameter value is used to compute the terminal settling velocity (m/min) for particles in that bin by: VTS = .0018 x (D^2), where the diameter D is in um. This equation holds for a sphere of unit density (water), which is essentially what the pesticide solution is. The effective or average height H (in m) of the passenger cabin is assumed to be 1.83 m (6 ft).

Equation 1: lambda1 = VTS/H per minute for the particles in that bin.

The model assumes that each of the 35 bins contained 1/35 of the permethrin mass applied, and that the mass was applied (sprayed) in 30 minutes. So in each bin, the mass emission rate (ug/min) into air was:

Equation 2: G = (total mass/35)/(30 min).

During the spraying, it is assumed there is no exhaust ventilation. In each bin, the buildup in airborne concentration (ug/m^3) is computed by the equation:

Equation 3: C(t) = [G/(lambda1*V)] x [1 - exp(- lambda1 x t)]

where V is the passenger cabin volume (1000 m^3) and t is time in minutes. This equation holds from t = 0 to t = 30 minutes.

The total airborne concentration at any time is the sum of the concentrations for the 35 respective bins. At the end of spraying (t = 30 min), there is some total concentration. The model assumes the ventilation system was running for 45 minutes and provided Q m^3/min of effective ventilation (11 ACH). For the Q value used, compute lambda2 = Q/V per minute.

In each bin, there was some initial concentration C (zero) equal to the C(30 min) value at the end of the spraying. In each bin, the decay in concentration (ug/m^3) is computed by the equation:

Equation 4: C(t) = C zero x exp(- [lambda1 + lambda2] x (t - 30)). This equation holds from t = 30 min to t = 75 min, where t = 0 is the start of the spraying.

The total airborne concentration at any time is the sum of the concentrations for the 35 respective bins.

Note: A lower average cabin height would increase the rate of settling, and the lack of ventilation leading to relatively still air would also increase the rate of settling. Putting more of the mass in smaller particles would increase the airborne concentration, while putting more of the mass in larger particles would decrease the airborne concentration.

Table A2. Predicted air concentration of permethrin (ug/m^3) by quantity applied and by aircraft ventilation status

Quantity of pesticide applied in aircraft cabin (liters)	Permethrin concentration at the end of the application (ug/m^3)	Permethrin concentration 45 minutes after application is completed (ug/m^3)	
		No ventilation	11 Air changes per hour (ACH)
20	62,862	4,130	1.1
22.8	71,663	4,704	1.2
29	91,150	5,983	1.6

34.4 L of a 2.2% solution of permethrin is applied to the aircraft. Approximately 29 L is applied to the cabin, and 5.4L is applied to the cargo hold. It is assumed that the application to the cargo hold does not impact air quality in the cabin.

Appendix 3

Agents and physiologic stressors that flight attendants are exposed to in the aircraft cabin[19 (pp.183, 208), 54,66]

- Alcohol
- Allergens
- Bioeffluents
- Cabin pressure/partial pressure of oxygen
- Carbon dioxide
- Cosmic radiation
- Electro-magnetic fields
- Fluctuations in temperature
- Infectious or inflammatory agents
- Low relative humidity
- Noise
- Non routine exposure to carbon monoxide, and leaks of engine oils, hydraulic fluids, and deicing fluids and their combustion products
- Off-gassing from interior material and cleaning agents
- Ozone
- Personal-care products
- Pesticides
- Physiologic stressors, such as disruption of circadian rhythms and fatigue
- Turbulence
- Vibration

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