Atmospheric Effects in the Entertainment Industry

Constituents, Exposures & Health Effects

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Report to SHAPE
the Workers' Compensation Board of BC
and the BC Lung Association

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1 Introduction

1.1 History of the Project

In 1996, the Workers' Compensation Board of BC (WCB) convened two Regulation Review sub-committees representing the Live Performing Arts and the Motion Picture and Video industries. Both of these groups made independent recommendations that a study be performed on the use of theatrical smokes and fogs. SHAPE, a tripartite organization to promote Safety and Health in Arts, Production, and Entertainment, mirrors the Regulation Review committees and includes the unions, associations, guilds, and organizations that represent employers and workers in the motion picture, theatrical, and music industries in the province. In planning for the 1999 year, the members unanimously agreed that SHAPE should sponsor an application to the WCB Finding Solutions program for a study of this nature. Meetings were held with investigators from the University of British Columbia School of Occupational and Environmental Hygiene, an initiative that gave rise to successful research proposals to the WCB and the BC Lung Association and resulted in the studies described in this report.

1.2 The Issue

Personnel employed in the motion picture, theatrical, and music industries often work in fog or smoke filled environments purposely created for atmospheric effects. Whether the effect is provided for recording on film or for the benefit of a live audience, the products used and the manner of application are similar. Many industry employees, including musicians, actors, technicians, directors and other staff, are concerned about the safety of these environments.

The most common agents used to create special atmospheric effects are glycol-water mixtures and mineral oils. Other agents, less frequently used but reported in industry publications, include dry ice, petroleum distillates, zinc chloride, ammonium chloride, pressurized water, liquid nitrogen, and burning organic materials[1,2]. Anecdotal reports from industry personnel indicate that other agents may also be used, including diatomaceous earth, flour, aluminum, naphthalene, fragrances, and dyes. The extent to which each of these compounds is used in the British Columbia entertainment industry has been undocumented; thus uncertainty about the agents used has been one of the issues of concern.

The most common effect-generating techniques create suspended liquid aerosols (fogs), using heat or mechanical methods[2]. Heat-based methods involve propelling a fluid into a heat exchanger preset to the solution's boiling temperature. The vaporization produces the desired fog effect. The fog can then be gas-propelled to create a very fine droplet (0.5 to 4 microns in aerodynamic diameter) or pump propelled[2]. Mechanical methods include atomizers and ultrasound. Atomizers (called 'crackers' in the industry) work by forcing air through a dispersion system with small holes submerged in the fogging solution. The air breaks the surface of the fluid and disperses small droplets (10 - 20 microns)[2]. In ultrasonic techniques, a transducer is submerged in the solution. The extremely high vibration frequencies produce a smaller aerosol than the cracker method (1 - 10 microns)[2]. From a health perspective there is an important distinction between the heat-based and mechanical methods. Heat-based methods have the potential to generate additional airborne contaminants in the form of thermal degradation compounds of the parent solution since the temperatures of the solutions may exceed 300˚C.

Performers' and crews' exposures to the multiple components of theatrical fog will occur mainly through the inhalation route, but may also include dermal exposure and ingestion. Because of the small size of the fog droplets, once they are generated, exposures are likely to continue until the completion of work at that location on that day. The finest droplets can remain suspended in the air for hours to days,[3] although the total mass concentration will decrease over time, as the larger aerosols settle.

1.3 Literature

In order to examine the published literature on theatrical smokes and fogs, a search was conducted using medical and occupational health data bases (Medline, 1966 to the present, and Silverplatter OSH ROM, 1995, which includes NIOSHTIC, HSELINE, CISDOC and MHIDAS) using terms related to the atmospheric effects (theatrical smoke, theatrical fog, theatrical, performing arts, pyrotechnics, and special effects) and terms related to the main agents used to create the effects (mineral oil, glycol, propylene glycol, ethylene glycol, diethylene glycol, triethylene glycol, and butylene glycol). The search revealed that research on the topic of theatrical fog exposures and health effects is very limited.

1.3.1 Previous research about theatrical fogs

A recent analysis of the US National Health and Nutrition Examination Survey (NHANES III) data, which examines all industries in a cross-sectional survey of a random sample of the US population, found that the entertainment industry was one of the main industries identified with self-reported work-related asthma and work-related wheezing[30]. There have been three studies specifically examining the health effects of theatrical fogs. The US National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation in theatrical productions in 1991, with a follow up in 1993[4]. Consultech Engineering (Omaha, Nebraska) conducted a mailed survey of actors in 1993[7]. From 1997 to 1999, the Mount Sinai School of Medicine and Environ International conducted a study of exposures and irritant health effects in performers in Broadway musical productions[23]. Each of these is described in more detail below.

The NIOSH Health Hazard Evaluation quantified actors' 'smoke' exposure at four Broadway stage productions by collecting personal and area samples. The report does not explicitly identify the fog generation methods used at the time of sampling. The glycol sampling methodology used in the initial survey was inadequate (NIOSH method 5500)[5], prompting development of a new sampling and analytical method for the 1993 survey of 3 theatrical productions (NIOSH Method 5523)[6]. Ethylene glycol, propylene glycol, triethylene glycol, and butylene glycol were then detected at most but not all sampling locations. Concentrations of all glycol components combined ranged from 0.053 mg/m^3 to 7.59 mg/m^3. Two of seven samples investigating potential thermal degradation products of glycols detected low levels of acrolein, formaldehyde, acetaldehyde, acetone, C_{9-12} aliphatic hydrocarbons, and alkyl benzenes at low levels. Mineral oil was used at only one site; concentrations ranged from not detectable to 1.35 mg/m^3 (NIOSH Method 5026)[6].

The 1991 study compared symptom prevalences in four 'non-smoke' productions to those in five 'smoke' productions using a questionnaire addressing the frequency and severity of respiratory and irritant symptoms. 134 actors working in 'smoke' productions had a higher prevalence of nasal, respiratory, and mucous membrane symptoms than 90 actors working in 'non smoke' productions.

The 1993 survey[6] was designed to evaluate the relationship between occupational asthma symptoms and theatrical fog exposures among 37 actors who had reported symptoms consistent with asthma in 1991, and 68 asymptomatic controls. Participants were asked to submit peak flow measurements and complete questionnaires about medical and work histories. Only 65 subjects (62%) submitted complete or partial information. Five people met the case definition for asthma related to theatrical work, three of whom worked in 'smoke' productions at the time. Performers with asthma-like symptoms and bronchial lability were not more likely to have been exposed (OR = 1.0, 95% CI 0.1-13.1).

Consultech Engineering carried out a survey in 1993 to investigate perceived health problems reported by actors exposed to glycol fogs[7]. A questionnaire with 50 questions about health problems, exposure levels, impact of health effects on work attendance and performance quality, and confounders was published in a monthly publication distributed to approximately 14,000 people in the industry. Of these, 3,000 to 4,000 were believed to be working with glycol fogging products. 231 people returned questionnaires to Consultech. Almost all (98%) of the respondents had been exposed to fogs, and 77% reported being exposed to glycol fogs. Of those exposed to glycols, 40% reported respiratory and mucous membrane symptoms, 18% had missed a performance, and 33% had sought medical attention because of the symptom severity.

The **Mount Sinai and Environ** study[23] was conducted in three phases and examined performers in 16 Broadway musicals. The overall mean total glycol concentration was 0.73 mg/m^3, with daily subject averages ranging from non-detectable to 7.2 mg/m^3, and 15-second peaks ranging from 0.08 to 37 mg/m^3. For mineral oils, the overall mean was almost identical at 0.74 mg/m^3, but daily subject averages ranged from 0.001 to 68 mg/m^3, and 15-second peaks ranged from 0.02 to 600 mg/m^3. Among 218 actors with detailed exposure assignment, increases in respiratory, throat, and nasal symptoms were associated with higher peak, but not average, levels of exposure to glycols. Throat irritant symptoms were associated with high average exposures to mineral oil. No acute (cross-shift) changes in vocal cord or lung function were observed. In those with long-term exposures to high peak levels of glycols, increased inflammation of the vocal cords was observed, but there was no observed effect on lung function parameters. Actors with high chronic exposures to mineral oil had significant decrements in forced vital capacity, though lung volumes were still within the normal range.

Given the still limited nature of the studies conducted to date on theatrical smokes and fogs, it is reasonable to review what is known about potential health effects from the more common products used in these productions: glycols and mineral oils.

1.3.2 Glycols

The most common glycol components in theatrical fogs include ethylene glycol, diethylene glycol, triethylene glycol, propylene glycol, dipropylene glycol, butylene glycol, and glycerol[2,8,9,10].

Much of the available information about glycols is derived from toxicological experiments on animals. In general, the toxicity of glycols under normal exposure scenarios can be rated as low[9,10], that is, under normal exposure intensities encountered in common industrial environments, glycols are not expected to cause serious health outcomes. Since glycols are polyfunctional alcohols, exposure to any of these substances may cause a drying of mucous membranes, resulting in irritation and drying of the eyes and respiratory tract.

The literature search did not reveal epidemiological studies that have investigated the irritant properties of the various glycols, even though glycols are commonly reported as being responsible for respiratory, eye and skin irritation[9,10]. Table 1.1 provides a brief summary of the health effects that might be expected due to either inhalation or dermal exposure to glycols, as listed by the International Chemical Safety Cards[11]. More serious health effects due to exposure to glycols such as central nervous system depression and renal failure were observed with ingestion of diethylene glycol[12]. Spermatogenic disorders were reported in humans with a urinary metabolite indicative of ethylene glycol exposure, although the route of exposure was not specified[13]. Teratogenisis was reported in an epidemiological study looking at occupational factors and solvent exposure (parents of subjects exposed to both methyl cellosolve and ethylene glycol)[14]. Dermatitis has been documented as a result of exposure to butylene glycol[15] and propylene glycol[16].

Table 1.1 Expected health effects due to inhalation and dermal exposure to glycols

Glycol	*Types of health effects*
Ethylene glycol	Eye irritation, throat irritation, headache, respiratory irritant
Diethylene glycol	Eye irritation, skin irritation, respiratory irritant
Triethylene glycol	Headaches, eye irritation
Butylene glycol	Dermatitis, eye irritation
Propylene glycol	Eye irritation, skin irritation

1.3.3 Glycol thermal degradation products

The heating of organic compounds to high temperatures is well known to cause pyrolysis, generating decomposition products such as aldehydes (e.g., formaldehyde and acrolein), carbon monoxide, carbon dioxide, nitrogen oxides, and hydrogen cyanide. These products are generated during combustion and/or during prolonged heating of organic materials to high temperatures. Many of the products are asphyxiants and, at lower concentrations, respiratory irritants. In addition, polymerization products can be generated; these include the polycyclic aromatic hydrocarbons (PAHs) usually associated with combustion of biomass materials (wood, food, fuels). Exposure to this class of compounds was originally linked to scrotal cancer in chimney sweeps[24] and has now been linked to lung and other cancers as well[25]. Benzo[a]pyrene is regarded as the most carcinogenic in this class of compounds. The International Agency for Research on Cancer (IARC, an agency of the World Health Organization) has classified it as probably carcinogenic (group 2a)[26]. Naphthalene is the simplest of these ringed compounds with only two fused benzene rings. Its toxicity has recently been reviewed[28]; the lungs (chronic inflammation) and eyes (cataract formation) appear to the most sensitive organs. It does not appear to be carcinogenic[29].

Thermal degradation products of glycols that have been detected in field samples from heat-based fog generation or suggested in the literature include acrolein, acetaldehyde and formaldehyde, as well as other organic compounds[4,7,17]. Acrolein is a very strong irritant that can cause rapid injury to the respiratory tract, eyes, and skin[18]. It is noted more for its acute than chronic toxicity, however dermatitis and skin sensitization have been reported[17]. Acetaldehyde is a mucous membrane irritant and has been demonstrated to cause eye irritation as well as dermatitis[18]. IARC has classified acetaldehyde[19] as possibly carcinogenic (group 2b) based on animal evidence. Formaldehyde can cause irritation to the eyes, nose and respiratory tract, and asthma has also been reported[18]. It is classified as probably carcinogenic to humans (group 2a) by IARC[20].

It is important to note that the thermal decomposition products described here can also arise from other sources including off-gassing from furniture, tobacco smoke, and traffic pollution, a point raised by recent commentators on theatrical fogs[27].

1.3.4 Mineral oils

The literature does not indicate whether refined or unrefined mineral oils are used in fog generation. Unrefined mineral oils have been designated as carcinogenic to humans (group 1) by IARC[21], however most mineral oils available on the market today are refined due to improvements in the manufacturing process. Refined mineral oils have not been shown to be carcinogenic. Exposure to mineral oil mist has been found to result in an increase in respiratory symptoms such as mucous membrane irritation and dyspnea[22].

1.4 Rationale for the Study

The existing literature indicates that personnel in productions using glycol and mineral oil to produce fog effects are potentially highly exposed to the resulting aerosols[4]. The literature on the toxicity of these products indicates that they might be expected to produce mucous membrane irritation and other respiratory symptoms[9-11,18]. These symptoms have been reported in actors working in these productions[4,7], though only a few studies have been conducted to date, mostly among theatrical performers. Some have suffered from small study sizes, poor participation rates and potential volunteer biases.

Much remains unknown. No survey has been conducted to document the proportions of the two main products which are used in the industry, and there is no documentation of the use of the many other ingredients that have been anecdotally reported by industry personnel. Almost all the measurements of exposures and response to date have been done in stage productions; how representative these are of the entertainment industry as a whole, which includes a wide range of music, theatre, film, television, and other show venues, is unknown. The studies to date have focused on actors, not the many other types of personnel who work in the industry. No measurements have examined the size distribution of the aerosols. Only one health effects study to date has included lung function measurements and examined exposure-response relationships.

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2 Research Objectives

The research reported here had several parts. The core was a cross-sectional study of exposures and health effects among employees of a wide range of entertainment industry productions using special atmospheric effects (Chapters 7 and 8, respectively). In addition, we conducted a survey of special effects technicians (Chapter 3), laboratory investigations of the products used (Chapter 4), and field testing of measurement methods which might allow industry personnel to easily monitor exposures (Chapters 5 and 6).

The research had the following specific objectives:

- To enumerate the special effects technicians in BC, and interview a sample of them about the materials and equipment they use to create atmospheric effects;
- To collect bulk samples of fluids used to generate fogs and smokes, and identify their constituents by gas chromatography / mass spectrometry;
- To heat the glycol fluids, in a laboratory setting, to the temperatures used in fogging machines to identify thermal degradation products which result;
- To select a sample of sites using atmospheric effects, for monitoring of aerosol concentrations on the set and in the breathing zones of personnel, and for assessing health outcomes among personnel;
- To measure area aerosol concentrations using a variety of direct-reading aerosol monitoring devices to allow selection of a simple-to-use instrument for on-site exposure monitoring by production staff;
- To determine whether self-reporting of exposure to visible fogs by production personnel is a feasible substitute for exposure monitoring;
- To select a representative sample of productions using atmospheric effects, and measure the area exposures to aerosols, specific glycols, aldehydes, and polycyclic aromatic hydrocarbons at the site;
- To measure the size distributions of the aerosols at these sites;
- To measure the personal exposures to aerosols and polycyclic aromatic hydrocarbons among cast, crew, musicians, and special effects technicians;
- To identify factors associated with increased and decreased personal exposure levels at these sites;
- To collect information about respiratory symptoms, mucous membrane irritation, other symptoms, and lung function among the staff whose exposures are measured, and to evaluate the association between fog exposure levels and these health symptoms; and
- To make recommendations about control measures based on the results of the study.

3 Survey of Special Effects Technicians

3.1 Methods

There is no comprehensive registry of special effects technicians in the province of British Columbia, however the International Alliance of Theatrical Stage Employees (IATSE) Local 891 includes all the unionized personnel in the greater Vancouver area. IATSE provided a list of all 133 members in the special effects division for the year 2000, and from these 65 were randomly selected to take part in the survey. In the late spring and summer of 2000, each selected member was sent a letter explaining our study and asking them to participate. Those who did not respond by telephone were sent an additional letter, then individually contacted by an employee of the union.

All willing subjects were subsequently contacted by study personnel to arrange an in-person interview about the chemicals and fog-generating equipment used and the effects created (see Appendix A for data collection form). Descriptive statistics (means for continuous data; counts and percentages for categorical) were used to summarize the data.

3.2 Results

Of the 65 IATSE Local 891 members randomly selected, 51 were contacted and 30 agreed to be interviewed. Because 10 ‘yes’ respondents could not be reached subsequent to their original agreement to participate, only 20 of these members were interviewed, a participation rate of 31%. Interviews of 3 additional special effects technicians were conducted during the exposure monitoring and health study, providing a total of 23 interviews. The low rate of participation makes it possible that the sample is not representative.

Table 3.1 summarizes characteristics of the participating special effects technicians. Almost all worked primarily in the television and movie industry. They averaged about 9 years of experience in the job, and worked long work days and work weeks. About half owned their own fog machines, and about 40% on occasion formulated their own fluids.

Table 3.1 Characteristics of the special effects technicians interviewed, all subjects combined and stratified by specific job subcategory (results from all interviewees combined in bold)

	All interviewees	*Special effects technician / assistant*	*Special effects coordinator*	*Other classifications**
n (%)	**23**	11 (48%)	9 (39%)	3 (13%)
Years of experience	**8.9**	5.8	11.7	12.3
Primary industry: TV / movie (%)	**96**	100	100	66
Primary industry: theatre (%)	**4**	0	0	33
Average shift length (hrs)	**12.2**	12.4	12.4	10.7
Average hours worked per week	**62.0**	60.0	65.0	60.0
% technicians owning fog machines	**48**	18	100	0
% technicians formulating fog fluid	**39**	27	67	0

* rigging coordinator, puppeteer, and electrician

Table 3.2 describes the machines owned and used by the interviewees. The most commonly used machines were LeMaitre and Rosco for glycol-based fluids, Hessy and IGEBA for either glycol- or mineral oil-based fluids, and bee-smokers. Although many of the technicians owned fog machines, they also used equipment that they did not own, providing a diversity of machines for their repertoire of effects.

Table 3.2 Percent of technicians who had used and/or owned the various fog machines and special effects devices, all subjects combined and stratified by specific job subcategory (results from all interviewees combined in bold)

	All interviewees		*Special effects technician/ assistant*		*Special effects coordinator*		*Other classifications**	
	Used	*Own*	*Used*	*Own*	*Used*	*Own*	*Used*	*Own*
Glycol based fog machines								
Corona Integrated Technology®	**17**	**4**	27	0	11	11	0	0
LeMaitre®	**87**	**39**	100	9	100	89	33	0
Lightwave & High End System®	**17**	**4**	9	0	22	11	33	0
Mole fogger/Madewill fogger	**48**	**4**	46	0	56	11	33	0
Radioshack® fogger	**44**	**26**	46	9	56	56	33	0
Rosco®	**70**	**13**	73	0	100	33	33	0
Mineral oil based fog machines								
Curtis fogger	**9**	**0**	9	0	11	0	0	0
Diffusion™ fogger	**35**	**4**	46	9	22	0	0	0
Navy fogger	**13**	**0**	18	0	11	0	0	0
Glycol and mineral oil fog machines								
Burgess® fogger	**35**	**4**	18	0	56	11	33	0
Crackers	**30**	**4**	27	0	44	11	0	0
Hessy	**87**	**43**	100	18	89	89	33	0
IGEBA®	**87**	**4**	100	0	89	11	33	0
MDG®	**52**	**4**	46	0	56	11	67	0
Other								
Bee-Smoker	**83**	**22**	82	0	100	56	33	0
Chill chamber	**18**	**13**	82	0	100	33	0	0
Dry ice barrel (chugger, rumble pot)	**20**	**17**	82	0	100	44	67	0
Nitrogen fogger	**8**	**4**	36	0	44	11	0	0
Smoke cookie	**17**	**17**	73	0	89	44	33	0
Steamers	**13**	**9**	64	0	67	22	0	0

Table 3.3 indicates the fluids or materials used and the types of effects created with each machine type, and the typical location of use. The glycol-using machines were typically used with the fluid supplied by the manufacturer, but this was rarely the case for any other type of machine or special effects device. Most machines were used in either indoor or outdoor locations, and many could be used to create diverse effects, including source smoke, large volume smoke, smoldering, atmospheric haze, low lying fog, and steam effects. Only smoke cookies were used to create coloured smoke. Mineral oil-based machines were limited to a more circumscribed set of effects, as were crackers, bee-smokers, and steamers.

Table 3.3 Fluids and materials used, location of use, and effect created for each fog machine type

	Manufacturer supplied fluid used	*Other fluids or materials used**	*Used in indoor or outdoor environments*	*Effect created***
Glycol based fog machines				
Corona Integrated Technology®	yes	no	in & out	1, 4
LeMaitre®	yes	no	in & out	1, 2, 3, 4, 5, 6
Lightwave & High End System®	yes	no	in & out	1, 2, 3, 4, 5, 6
Mole fogger / Madewill fogger	yes	2	in & out	1, 2, 3, 4, 5
Radioshack® fogger	yes	2	in & out	1, 2, 3, 4, 5, 6
Rosco®	yes	no	in & out	1, 2, 3, 4, 5, 6
Mineral oil based fog machines				
Curtis fogger	no	1	out	2, 5
Diffusion™ fogger	yes	no	in	4, 6
Navy fogger	no	1	out	2, 6
Glycol and mineral oil fog machines				
Burgess® fogger	no	1, 2, 3	out	1, 3, 4, 5
Crackers	no	1,2	in & out	1, 4
Hessy	no	1, 2, 3	in & out	1, 2, 3, 4, 5, 6
IGEBA®	no	1, 2	out	2, 4, 6
MDG®	yes	2	in & out	1, 2, 3, 4, 5, 6
Other				
Bee-Smoker	no	4	in & out	1, 3
Chill chamber	no	5, 7	in & out	1, 2, 6
Dry ice barrel (chugger, rumble pot)	no	5, 7	in & out	1, 2, 3, 4, 5
Nitrogen fogger	no	2, 6, 7	in & out	2, 5, 6
Smoke cookie	no	8	in & out	1, 3, 7
Steamers	no	2, 7	in & out	1, 6

* 1. mineral / white oil
2. 'poly G' (glycol)
3. glycerin
4. bee gum burned
5. dry ice
6. nitrogen
7. water
8. cookie burned

** 1. source smoke
2. large volume smoke
3. smoldering effect
4. atmospheric haze
5. low lying fog
6. steam effect
7. coloured smoke

4 Constituents and Thermal Products of Glycol Fluids

4.1 Introduction

There were two issues which inspired a series of laboratory-based tests investigating the constituents and products of the fluids. The first was the concern expressed by industry personnel that it was not clear which fluids were being used on a regular basis and to what extent the constituents of the fluids were accurately reflected in their Material Safety Data Sheets (MSDS). The latter concern arose because there were anecdotal reports that special effects technicians on occasion used additives with base fluids to create 'home brews' which produced unique effects.

The second concern arose because glycol-based fluids are heated to produce fogs, leading to the question of whether the temperatures are high enough to produce pyrolysis products. To address the issue in a better controlled environment than possible in field studies, an experimental procedure was developed to determine whether formaldehyde and other pyrolysis products might arise when commercially available or home-brewed glycol-based fluids are heated to produce fogs.

4.2 Methods

4.2.1 Sample acquisition

During field work, bulk samples of fifteen glycol-based fluids were collected from the special effects technicians. The samples were taken either from the fog machine itself or from opened bottles of fog fluid, to ensure that samples of actual fog fluids as typically used were obtained. The fluids obtained are listed below:

- Antari™
- Atmospheres™
- CITI FCF100A™
- CITI FCF200B™
- home-brewed #1
- home-brewed #2
- LeMaitre Extra Quick Dissipating™
- LeMaitre Long Lasting™
- LeMaitre Maxi Fog™
- LeMaitre Molecular™
- LeMaitre Regular Haze™
- MBT®
- MDG Dense Fog™
- Rosco Scented-Pina Colada™
- Rosco Stage & Studio™ Unscented

4.2.2 Constituents of the fluids

A drop (25 µg) of each bulk sample was diluted with 25 mL of ethanol. The glycols in the sample were then quantified using a Varian 3400 gas chromatograph (Varian Inc., Palo Alta, CA, USA) equipped with Supelco SPB™-1000 column (Sigma-Aldrich, St. Louis, MO, USA) and a Varian Saturn II mass spectrometer, based on a revised version of NIOSH Method 5523[4]. The following 7 glycols from Acros® Organics (99% purity) were used as standards: propylene glycol; 1,3-butanediol; dipropylene glycol; diethylene glycol (2-hydroxyethyl ether); triethylene glycol; glycerin/glycerol; and tetraethylene glycol.

The measured constituents of the bulk samples were compared with the ingredients listed on the material safety data sheet (MSDS) to confirm the presence of a particular glycol and, if applicable, the percent of the glycol in the bulk fluid.

4.2.3 Thermal products of the glycol fluids

In order to identify whether heating of these fluids in fog-generating machines resulted in unknown and/or unwanted degradation products, these fluids were investigated in a pyrolysis experiment as outlined below. The method is identical to that used previously for the pyrolysis of aircraft jet engine oils and hydraulic fluids[1-3].

The experiment entailed heating the fluids in an environmentally controlled stainless steel chamber 54 cm wide x 64 cm long x 71 cm high (245.4 liters). A ceramic top hotplate was put at the bottom of this chamber and allowed to reach 343 ºC while the top lid was open. A surface thermometer (Model 573C, Pacific Transducer Corporation) was placed on top of the hotplate to monitor the temperature. The selected temperature of 343 ºC was based on the published literature and consultation with the fog machine manufacturers, who identified this as the upper operating range of the machines.

Air sampling instrumentation and sampling trains were then mounted to take air samples within the environmental chamber. A direct-reading data-logging multi-gas monitor (TMX-412, Industrial Scientific Corporation, Oakdale, PA) with sensors for NO_2, O_2, CO, and lower explosive limit (LEL; based on methane) and an indoor air quality meter (YES-204A, Young Environmental Systems, Richmond, BC) with sensors for temperature, humidity and CO_2 were suspended at the top inside of the chamber. Other sampling devices, each with its own calibrated constant-flow air sampling pump (SKC, Eighty-Four, PA, USA), were attached to the chamber sampling ports prior to each trial. These included:

- for measuring aerosol mass and PAHs, a 7-hole inhalable aerosol sampler (JS Holdings Ltd., Stevanage, UK) mounted with a 25-mm diameter, 0.45-micron pore size Teflon filter (Gelman Sciences, Ann Arbor, MI, USA) and Supelpak™ 20U Orbo43 XAD-2 tubes (Sigma-Aldrich, St. Louis, MO, USA), with air sampled at a rate of 2 L/min;
- for measuring glycols, XAD-7 OVS tubes (SKC) and midget impingers with 10 mL of ethanol; with air sampled at a rate of 2 L/min; and
- for measuring aldehydes, silica gel tubes impregnated with 2,4 DNPH (SKC), with sampled at a rate of 1 L/min.

When all instrumentation was in place and the direct reading instruments were turned on, a 0.5 mL sample of the fluid to be investigated was introduced onto a 5 cm x 5 cm piece of aluminum foil with the edges slightly curled up. This sample was put directly on top of the hot plate at

343 ºC. The chamber lid was closed and, in order to prevent the direct reading instruments from thermal damage, the hot plate was kept at this temperature for 5 additional minutes, at which time it was allowed to cool off. Air sampling continued for a further 10 minutes, for a total of 15 minutes. In order to lower the limit of detection for PAHs and aldehydes, the process was repeated with a 1 mL sample of the fluid and using only the XAD-2 and silica gel tube sampling trains. After the lid of the chamber was closed, the hot plate was kept at 343 ºC for a 5-minute period and sampling continued for another 40 minutes, for a total of 45 minutes. Prior to each experiment, a control sample was taken with the same procedure except no fog fluid was placed in the weighing boats. After each experiment, including the control samples, the insides of the chamber and hotplate were thoroughly cleaned with ethanol, then the chamber was aerated.

All filter air samples were quantified gravimetrically on a micro-balance (M3P, Sartorius, Germany). Prior to triplicate pre-sampling weighing, filters were equilibrated for at least 24 hours to a stable temperature and relative humidity (22 ºC ± 0.3 ºC and 45% ± 5% relative humidity). Prior to triplicate post-sampling weighing, filters were desiccated for 24 hours, then equilibrated for at least 24 hours to the same stable temperature and relative humidity.

Glycols were extracted from the sorbent tubes using ethanol and quantified using the method described in section 4.2.2.

Aldehydes were extracted with acetonitrile and quantified using a Varian 9010 high performance liquid chromatograph using WCB Method 5270[5]. The following 14 aldehydes from Supelco® T1011/IP6A Carbonyl-DNPH Mix were used as standards: formaldehyde; acetaldehyde; acrolein (note that acrolein and acetone have the same retention time); propionaldehyde; crotonaldehyde; butylaldehyde; benzaldehyde; isovaleraldehyde; valeraldehyde; o-tolualdehyde; m-tolualdehyde; p-tolualdehyde; hexaldehyde; and 2,5-dimethylbenzaldehyde.

PAHs were extracted from both the Teflon filter (after weighing) and the XAD2 tubes with toluene and quantified using a Varian 3400 gas chromatograph with a flame ionization detector using NIOSH Method 5515[6]. This protocol was altered to decrease the detection limits by concentrating the filter and sorbent tube extracts four-fold to 1 mL using nitrogen gas and increasing the injection volume from 2 μL to 5 μL. The following 16 PAHs from Supelco® EPA 610 Polynuclear Aromatic Hydrocarbons Mix were used as standards: naphthalene; acenaphthylene; acenaphthene; fluorine; phenanthrene; anthracene; fluoranthene; pyrene; chrysene; benzo(a) anthracene; benzo(k)fluoranthene; benzo(b)fluoranthene; benzo(a)pyrene; indeno(1,2,3-cd)pyrene; dibenzo(a,h)anthracene; and benzo(ghi)perylene.

4.3 Results

4.3.1 Constituents of the glycol fluids

The results from the GC-MS analysis of bulk samples of various theatrical fog producing fluids that were collected at the time of aerosol sampling are summarized in Table 4.1. This table also provides a comparison to the ingredients reported on the MSDS for each product. While most fluids were found to have the same composition as reported on the MSDS, there were a number of inconsistencies between the reported ingredients and those actually present in the following fluids: LeMaitre Long Lasting; MDG Dense Fog; and the two Rosco fluids (highlighted in bold in Table 4.1). These differences may indicate that some fluids may have been contaminated with other fluids in the fog machines.

Table 4.1 Presence and composition (%) of bulk glycol-based fluid samples, based on Material Safety Data Sheets (MSDS) and gas chromatography-mass spectrometry (GC-MS) analysis (in bold where GC-MS results differed from MSDS)

	Propylene glycol		*1,3-butandiol*		*Dipropylene glycol*		*Diethylene glycol*		*Triethylene glycol*		*Glycerin/glycerol*		*Tetraethylene glycol*	
	MSDS	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*
Antari™	√ *	√ (13)	X	ND	X	ND	√ *	ND	√ *	√ (21)	X	ND	X	ND
Atmospheres™	√	√ (28)	X	ND	X	ND	X	ND	√	√ (20)	X	ND	X	ND
CITI FCF100A™	n/a	√ (60)	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	ND
CITI FCF200B™	n/a	√ (28)	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	√ (34)	n/a	ND
home-brewed #1	n/a	√ (39)	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	√ (55)	n/a	ND
home-brewed #2	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	√ (21)	n/a	ND	n/a	√ (19)
LeMaitre Extra Quick Dissipating™	√ (<40)	√ (34)	X	ND	X	ND	X	ND	X	ND	X	ND	X	ND
LeMaitre Long Lasting™	**X**	**√ (27)**	X	ND	**√ (<35)**	**ND**	X	ND	√ (<35)	√ (18)	X	ND	X	ND
LeMaitre Maxi Fog™	X	ND	X	ND	√ (<25)	√ (19)	X	ND	√ (<25)	√ (17)	X	ND	X	ND
LeMaitre Molecular™	√ (<90)	√ (75)	X	ND	X	ND	X	ND	X	ND	X	ND	X	ND
LeMaitre Regular Haze™	X	ND	X	ND	X	ND	X	ND	X	ND	√ (<10)	ND	X	ND
MBT®	X	ND	X	ND	X	ND	X	√ (21)	X	ND	X	ND	X	ND
MDG Dense Fog™	**X**	**√ (54)**	X	ND	X	ND	X	ND	X	√ (7)	X	ND	X	ND
Rosco Scented Pina Colada™	**X**	**√ (13)**	**X**	**√ (14)**	X	ND	X	ND	**X**	**√ (22)**	X	ND	X	ND
Rosco Stage & Studio™ Unscented	**X**	**√ (20)**	**X**	**√ (25)**	X	ND	X	ND	**X**	**√ (23)**	X	ND	X	ND

√ = indicated on MSDS and/or detected on GC-MS (%)
* = MSDS indicates propylene glycol, glycerol or di- or tri- ethylene glycol
X = not indicated on MSDS
ND = not detected on GC-MS
n/a = MSDS not available

4.3.2 Thermal products of the glycol fluids

Table 4.2 reports simple gaseous constituents of the air and physical conditions inside the environmental chambers, during heating of 15 glycol-based fluids (listed in section 4.2.1) to 343 °C, and under control conditions with no fluid present. There is little difference between the results in control and fluid heating conditions for any of these parameters, indicating that the temperature to which the fluids were raised inside the chamber was not high enough to result in the generation of gases usually associated with the combustion of organic compounds. This is consistent with the normal oxygen concentration measured; it would have changed considerably had breakdown occurred. Only 'home brewed #2' appeared to generate some carbon monoxide indicating the degradation of one (or more) of its constituents at this temperature.

Table 4.2 Physical conditions and gaseous constituents of the air in glycol heating and control conditions, for 15 different glycol-based fluids

	No fluid, control conditions	*Heating of glycol-based fog fluids*
Temperature (°C)[A]	24-37	25-37
% Relative humidity[A]	52-68	52-67
CO_2 (ppm)[B]	431-490	314-569
Temperature (°C)[B]	24-36	25-35
% Relative humidity[B]	25-48	25-44
CO (ppm)[C]	0.0	0.0-2.0*
O_2 (%)[C]	20.8-21.5	20.7-21.2
LEL (%)[C]	0.0	0.0

[A] From the top of the chamber at the location of the recording instrument
[B] From YES-204A monitor
[C] From TMX-412 monitor
* For only 1 of 15 glycol-based fog fluids (home-brewed #2)

Table 4.3 lists the mass concentrations of the aerosols generated during heating of the fluids in the environmental chamber. The clearly increased concentrations during fluid heating indicate that the fluid was being aerosolized.

Table 4.3 Mass concentration of aerosols in the chamber air during glycol heating and control conditions, from 15 different glycol-based fluids

	No fluid, control conditions	*Heating of glycol-based fog fluids*	*Heating of glycol-based fog fluids, blank corrected*
Minimum [mg/m^3]	0.011	0.052	0.04
Maximum [mg/m^3]	0.149	213	213
Arithmetic mean [mg/m^3]	0.075	56.9	56.9
Arithmetic SD [mg/m^3]	0.049	57.6	57.6

Table 4.4 summarizes the GC-MS analysis of the glycol air concentrations generated within the stainless steel chambers during heating. The glycol aerosols produced agreed well with the glycols reported in Table 4.1, i.e., the % composition of the bulk samples based on the GC-MS analyses. This result suggests no gross changes in composition on heating.

Table 4.4 GC-MS analysis of concentrations of glycols (in mg/m³) in the chamber air during glycol heating and comparison to MSDS data, from 15 different glycol-based fluids

	Propylene glycol		*1,3-butandiol*		*Dipropylene glycol*		*Diethylene glycol*		*Triethylene glycol*		*Glycerin/glycerol*		*Tetraethylene glycol*	
	MSDS	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*	*MSDS*	*GC-MS*
Antari™	√ *	√ (8.2)	X	ND	X	ND	√ *	ND	√ *	√ (4.7)	X	ND	X	ND
Atmospheres™	√	√ (46.4)	X	ND	X	ND	X	ND	√	√ (11.2)	X	ND	X	ND
CITI FCF100A™	n/a	√ (45.5)	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	ND
CITI FCF200B™	n/a	√ (32.7)	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	√ (26.1)	n/a	ND
home-brewed #1	n/a	√ (26.8)	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	√ (21.0)	n/a	ND
home-brewed #2	n/a	ND	n/a	ND	n/a	ND	n/a	ND	n/a	√ (8.7)	n/a	ND	n/a	√ (8.0)
LeMaitre Extra Quick Dissipating™	√	√ (57.7)	X	ND	X	ND	X	ND	X	ND	X	ND	X	ND
LeMaitre Long Lasting™	X	√ (45.0)	X	ND	√	ND	X	ND	√	√ (11.4)	X	ND	X	ND
LeMaitre Maxi Fog™	X	ND	X	ND	√	√ (9.0)	X	ND	√	√ (5.9)	X	ND	X	ND
LeMaitre Molecular™	√	√ (53.0)	X	ND	X	ND	X	ND	X	ND	X	ND	X	ND
LeMaitre Regular Haze™	X	ND	X	ND	X	ND	X	ND	X	ND	√	ND	X	ND
MBT®	X	ND	X	ND	X	ND	X	√ (5.8)	X	ND	X	ND	X	ND
MDG Dense Fog™	X	√ (32.6)	X	ND	X	ND	X	ND	X	ND	X	ND	X	ND
Rosco Scented Pina Colada™	X	√ (10.6)	X	√ (6.0)	X	ND	X	ND	X	√ (8.3)	X	ND	X	ND
Rosco Stage & Studio™ Unscented	X	√ (16.0)	X	√ (11.2)	X	ND	X	ND	X	√ (9.6)	X	ND	X	ND

√ = indicated on MSDS and/or detected on GC-MS (mg/m³)
* = MSDS indicates propylene glycol, glycerol or di- or tri- ethylene glycol
X = not indicated on MSDS
ND = not detected on GC-MS
n/a = MSDS not available

Table 4.5 reports the air concentrations of aldehydes detected in the chamber when the glycol-based fluids were heated. All fluids investigated released acetaldehyde and formaldehyde into the air. Propionaldehyde was released from 13 fluids and hexaldehyde from 8. Whether the heating of these fluids to 343ºC resulted in the generation of these aldehydes or whether they were already present in the bulk fluids cannot be determined from these results. The former is likely the case, but would need to be verified with an aldehyde analysis of the bulk samples.

Table 4.5 Concentrations of aldehydes in the chamber air during glycol heating, from 15 different glycol-based fluids

	Number of samples > LOD	*Minimum > LOD [mg/m³]*	*Maximum [mg/m³]*	*Arithmetic mean [mg/m³]*	*Arithmetic SD [mg/m³]*
Acetaldehyde	15	0.022	0.878	0.367	0.313
Acrolein	0	-	-	-	-
Benzaldehyde	0	-	-	-	-
Butylaldehyde	0	-	-	-	-
Crotonaldehyde	0	-	-	-	-
2,5-Dimethylbenzaldehyde	0	-	-	-	-
Formaldehyde	15	0.079	1.436	0.391	0.373
Hexaldehyde	8	0.0005	0.0022	0.0012	0.0006
Isovaleraldehyde	0	-	-	-	-
Propionaldehyde	13	0.026	0.269	0.126	0.071
m-Tolualdehyde	0	-	-	-	-
o-Tolualdehyde	0	-	-	-	-
p-Tolualdehyde	0	-	-	-	-
Valeraldehyde	0	-	-	-	-

LOD = limit of detection
- = not detected

Table 4.6 reports the air concentrations of PAHs detected in the chamber when the glycol-based fluids were heated. One sample (Rosco, unscented) indicated the presence of naphthalene in the aerosol. (F-100 Atmospheres and LeMaitre Regular Haze) indicated acenaphthylene as an aerosol constituent. As before, whether these were already present in the bulk fluids or were generated upon heating needs to be verified.

Table 4.6 Concentrations of PAHs in the chamber air during glycol heating, from 15 different glycol-based fog fluids

	Number of samples > LOD	*Minimum > LOD [μg/m³]*	*Maximum [μg/m³]*	*Arithmetic mean [μg/m³]*	*Arithmetic SD [μg/m³]*
Acenaphthene	0	-	-	-	-
Acenaphthylene	2	0.057	0.072	0.063	0.008
Anthracene	0	-	-	-	-
Benzo(a)anthracene	0	-	-	-	-
Benzo(a)pyrene	0	-	-	-	-
Benzo(b)fluoranthene	0	-	-	-	-
Benzo(ghi)perylene	0	-	-	-	-
Benzo(k)fluoranthene	0	-	-	-	-
Chrysene	0	-	-	-	-
Dibenzo(a,h)anthracene	0	-	-	-	-
Fluoranthene	0	-	-	-	-
Fluorine	0	-	-	-	-
Indeno(1,2,3-cd)pyrene	0	-	-	-	-
Naphthalene	1	0.098	0.098	0.098	-
Phenanthrene	0	-	-	-	-
Pyrene	0	-	-	-	-

LOD = limit of detection
- = not detected

4.4 Conclusions

The constituents of the glycol based fluids was found in most cases to conform well with the ingredients listed on the Material Safety Data Sheets.

Heating of the glycol-based theatrical fog fluids to 343 ºC, i.e., the maximum temperature to which these agents should be exposed under normal use conditions, could not be classified as causing pyrolysis since very little breakdown of these agents could be demonstrated. The presence of typical combustion gases such as CO_2 and CO along with a decline in O_2 concentration would have indicated pyrolysis, but changes in the levels of these gases were not observed in our experiments, except from one ‘home-brew’ sample which generated carbon monoxide. In addition, little or no polymerization, i.e., PAHs, could be clearly identified as being generated because of heating.

It was demonstrated, however, that certain unwanted agents were released into the air and could be measured using standard techniques. These agents include formaldehyde from all 15 glycol-based fluids, and propionaldehyde and hexaldehyde from most (13/15 and 8/15, respectively). Napthalene was released by 1 of 15 and acenaphthylene from 2 of 15.

References, Chapter 4

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5 Evaluation of Direct-reading Aerosol Monitors

5.1 Methods

One of the objectives of this project was to evaluate techniques for the measurement of theatrical fogs that could be used by industry personnel to rapidly assess levels of exposure. Accordingly, three real-time direct-reading monitors were evaluated for ease of use, feasibility for use to assess theatrical fogs and smokes, and cost:

1. an integrating nephelometer (M903, Radiance Research, Seattle, WA, USA);
2. a personal aerosol monitor (DataRAM 1000, MIE Inc., Bedford, MA, USA); and
3. a laser single-particle counter (APC-100, Biotest Diagnostics Corporation, Denville, NJ, USA).

To compare them, area air concentrations were measured for approximately 4 hours in 32 production sites at locations near to fogging machines, where personnel would reasonably be expected to spend time (details of area measurements are provided in Chapter 7). All three direct-reading monitors were placed beside two standard filter-based monitoring devices used to assess air concentrations in units of mass per volume of air, i.e., gravimetric monitors (7-hole sampler and Marple cascade impactor), and were turned on and off at the same time as the gravimetric monitors.

The principle of operation is similar for the nephelometer and the DataRAM, as both instruments estimate the mass concentration of particles as a function of the amount of scattered light of a specific wavelength. The nephelometer records light scattering coefficients which can then be converted externally to particle mass concentrations based on calibration with gravimetric monitors measuring the same specific particle mixtures. Here, all nephelometer measurements reported in the results are calculated particle mass concentrations based upon regression of nephelometer light-scattering measurements against the 7-hole sampler mass concentrations. The coefficients for these regressions are presented in Table 5.1. The DataRAM records calculated particle mass concentrations directly; these are based upon a factory calibration with a standard test aerosol. Modifications to the DataRAM calibration and calibration of the APC particle counter can also be done, specific to the particle mixtures being measured; regressions against the 7-hole sampler for these instruments are also presented in Table 5.1.

Table 5.1 Regression slopes for calibration of direct-reading monitors against filter-based (7-hole sampler) concentrations, for all samples combined and stratified by type of fog fluid (results for all fluids in bold)

	All fog fluids		*Glycol*		*Mineral oil*	
	Slope	R^2	*Slope*	R^2	*Slope*	R^2
Nephelometer	**609**	**0.83**	759	0.79	564	0.89
DataRAM-1000	**0.399**	**0.78**	0.438	0.67	0.384	0.88
APC-100 Particle Counter	**4.65E-06**	**0.63**	5.81E-06	0.63	4.24E-06	0.64

* when calibrating the nephelometer and DataRAM for sites which used both glycol and mineral oil or dry ice, the 'all fog fluids' equation was used

While the laser single-particle counter is also a light-scattering instrument, it measures individual particles in the sample air stream and classifies them into 4 particle diameter size ranges: 0.3-0.5 µm, 0.5-1.0 µm 1.0-5.0 µm and >5.0 µm. The instrument records the total number of measured particles in each of these size ranges during a specified sampling period, enabling the calculation of particle *number* concentrations (rather than particle *mass* concentrations, as for the other monitors). Unless the specific size and density of the individual particles are known, it is not possible to convert these particle number concentrations into particle mass concentrations. The particle counter was factory calibrated at annual intervals prior to and during the September 2000 to December 2001 study period (March 2000, 2001, 2002).

Regular clean-air calibration of the all three instruments was conducted prior to each sampling session by blowing particle-free air (passed through two HEPA filters [Bacterial Air Vent Filters, Gelman Sciences] in series) into the sensing chamber and adjusting the instrument response to 0 mg/m^3, 0 particle count, or $0 \pm 0.05 \times 10^{-5}$ m^{-1}, for the DataRAM, APC, and nephelometer, respectively.

Descriptive statistics were used to summarize characteristics of the direct-reading monitors. To compare the instruments' performances when monitoring identical atmospheres, correlations (Pearson r) and simple linear regression models were calculated to determine how well *area* air measurements by the direct-reading monitors predicted *area* measurements by the gravimetric filter-based devices.

To determine whether the direct-reading instruments could reasonably predict the *personal* breathing zone concentrations of production personnel, linear regression models were also developed for each of the area monitors with personal aerosol exposures as the dependent variable. Since the direct-reading instruments' measurements may be affected by the particle size and chemical composition of the theatrical smoke, the type of fog fluid being used was also offered in these models.

Costs for each direct-reading instrument were assessed by contacting local sales representatives, and use characteristics were recorded by study personnel during the field sampling.

5.2 Results

5.2.1 Comparisons of area measurements using direct-reading monitors to area measurements using standard methods

Table 5.2 presents summary statistics for the area aerosol concentrations measured by the standard filter-based 7-hole sampler and the three direct-reading monitors, the nephelometer, DataRAM, and APC-100 particle counter. The measurements using the nephelometer, show a narrower range and a lower arithmetic mean than the 7-hole sampler. For the DataRAM the opposite is the case, i.e., the data show a wider range and higher means than the 7-hole sampler. The APC-100 has the lowest geometric standard deviation of all instruments; other summary statistics are difficult to compare because of the differing scales of measurement.

Table 5.2 Area aerosol concentrations measured using the standard 7-hole sampler, and the direct-reading instruments: Nephelometer, DataRAM-1000, and APC-100 Particle Counter (results for 7-hole sampler in bold)

	7-hole sampler [mg/m³]	*Nephelometer* [mg/m³]	*DataRAM-1000* [mg/m³]	*APC-100* [particles per minute]
n	**32**	28	32	29
Minimum	**0.05**	0.02	0.01	21,915
Maximum	**17.1**	2.41	29.3	288,191
Arithmetic mean	**1.36**	0.78	2.64	169,431
Arithmetic standard deviation	**3.16**	0.66	4.59	75,896
Geometric mean	**0.41**	0.45	0.77	142,921
Geometric standard deviation	**4.21**	3.67	7.31	1.98

Figures 5.1 to 5.4 are scatter plots and regression lines showing the relationships between the air concentrations measured by the three direct-reading monitors, the cascade impactor and the 7-hole sampler, considered here as the reference or 'gold' standard. Figure 5.1 is a plot of the two filter-based measurement methods illustrating the ideal of both a high correlation (Table 5.3) and no bias (slope near 1.0), as would be expected given the similarities between these two methods. As is evident in Figure 5.3, although the DataRAM and 7-hole sampler are highly correlated, there is a clear overestimation of the measured concentration by the DataRAM. This is a result of the instrument's factory calibration against a 'standard' particle material, not the fogging fluids. The instrument software allows an adjustment to be made to correct the measurements to account for differences in particle light scattering due to differences in particle size distribution and composition. The regression equations reported in Table 5.1 can be used for this adjustment. Figures 5.2 and 5.4 show the rather strong correlation between the 7-hole sampler and the nephelometer and the weaker correlation with the APC particle counter.

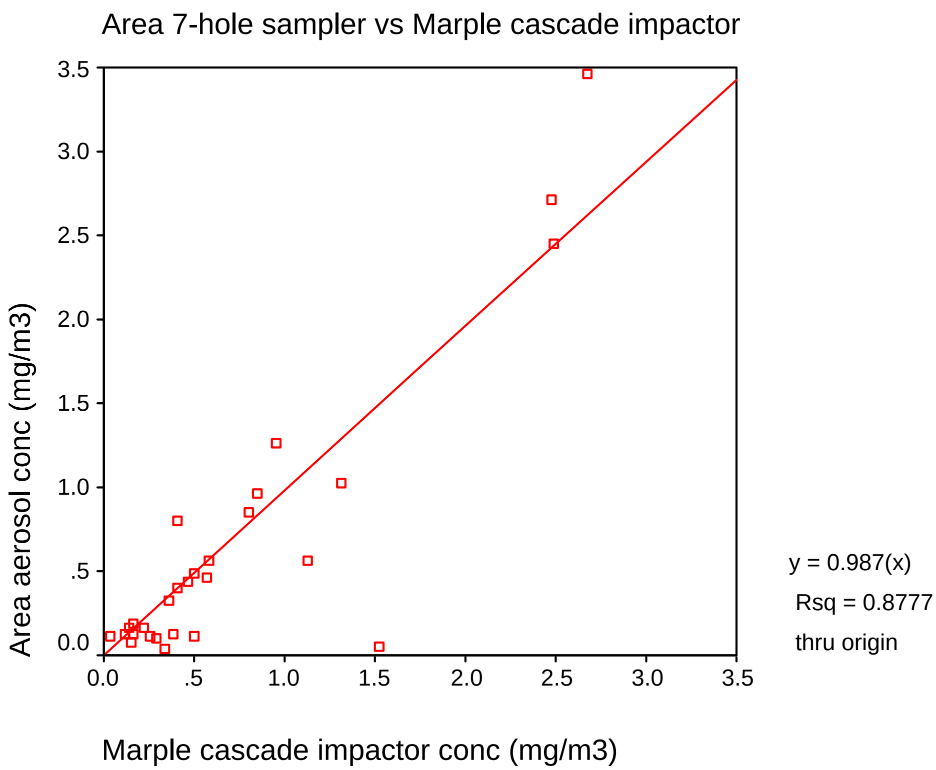

Figure 5.1 Relationship between measurements made using the two filter-based gravimetric methods: the 7-hole sampler and the Marple cascade impactor

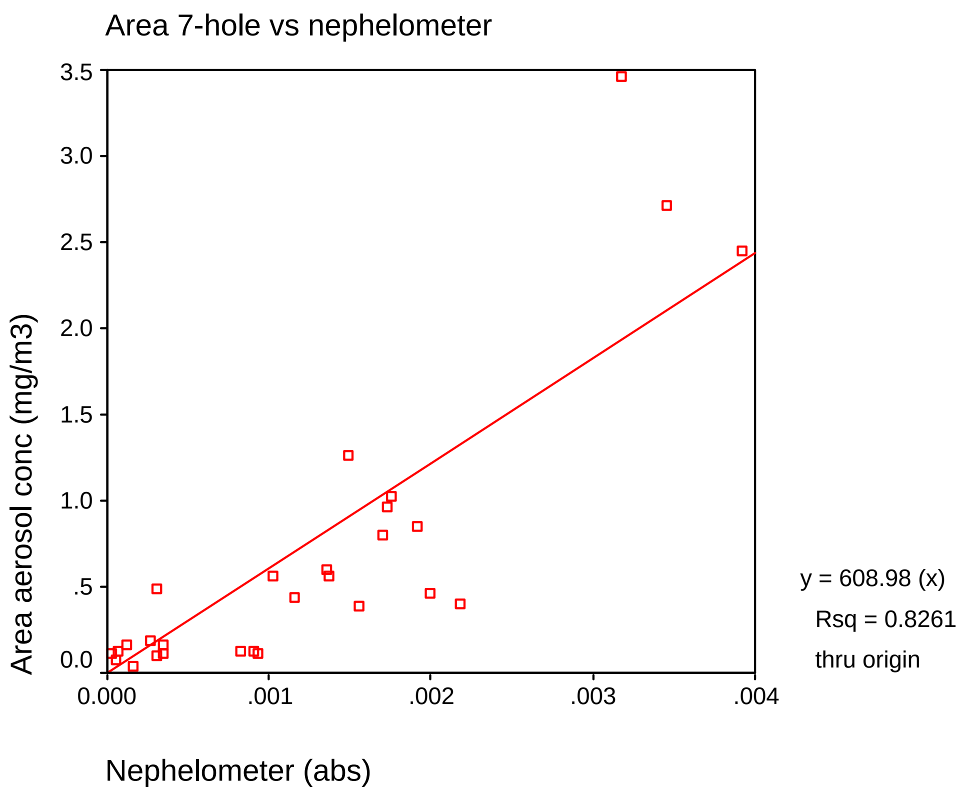

Figure 5.2 Relationship between measurements made using the 7-hole sampler and the nephelometer

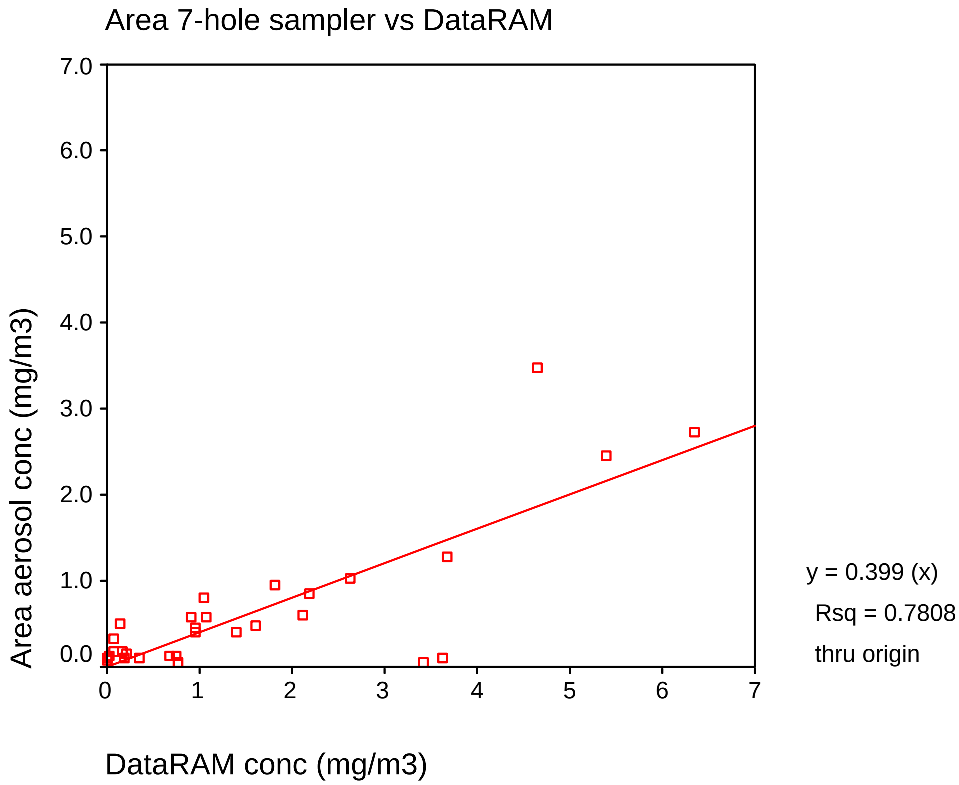

Figure 5.3 Relationship between measurements made using the 7-hole sampler and the DataRAM

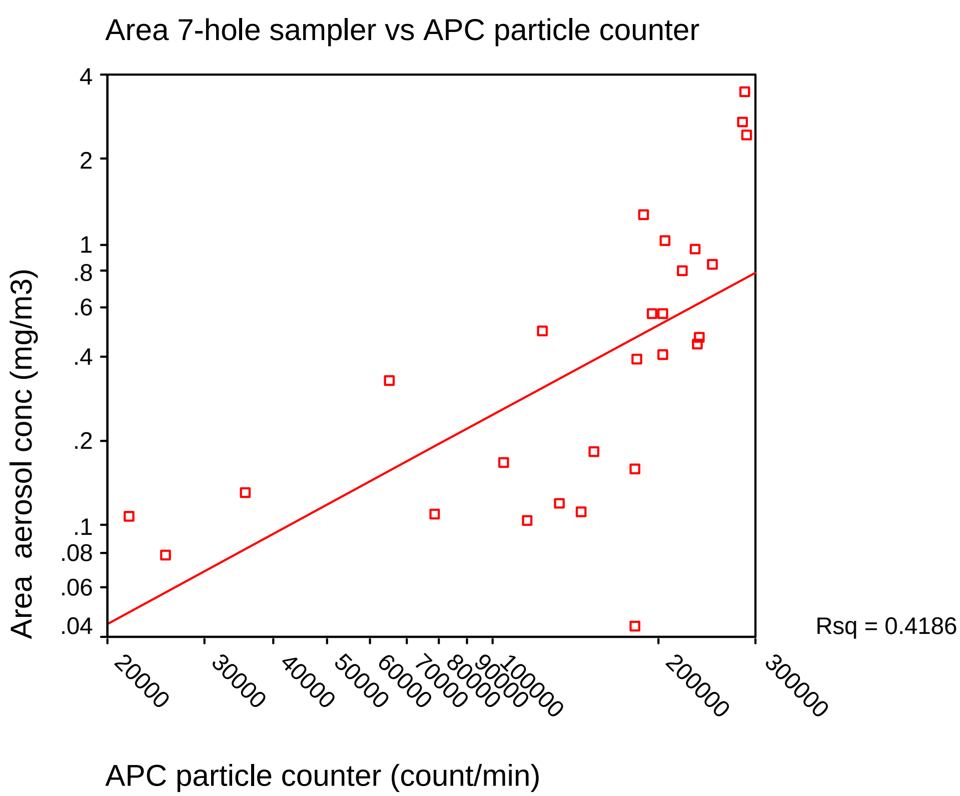

Figure 5.4 Relationship between measurements made using the 7-hole sampler and the APC particle counter

Table 5.3 presents a summary of the correlations between the different direct-reading monitors and the filter-based measurement methods. For both filter-based samplers, correlations were highest for the nephelometer and only slightly lower for the DataRAM. The correlations for these two instruments were similar, as was expected given the similarities in their operating characteristics. Somewhat lower correlations were measured for the laser particle counter. As is evident from the results presented Table 5.1, however, all the direct-reading instruments had lower correlations with the gravimetric methods for measurements of glycol-based fluids relative to those made during sessions in which mineral oil was used. This may result from the higher concentrations present when mineral oil was used, heterogeneity in the particle size of glycol-based fogs resulting in different instrument response, or a combination of these two factors.

Table 5.3 Correlations (Pearson r) between area air concentrations as measured using gravimetric methods vs. direct-reading monitors (all $p<0.01$)

	Filter-based gravimetric methods	
	7-hole sampler	*Cascade impactor*
Nephelometer	0.86	0.87
DataRAM 1000	0.81	0.85
APC-100	0.69	0.69

Figures 5.5 to 5.10 provide examples of the types of data recorded by each of the three instruments for two separate sampling sessions, one (Figures 5.5-5.7) in which a glycol-based fluid was used and another (Figures 5.8-5.10) in which a mineral oil fluid was used. In all cases, the instruments responded to increases in airborne particle concentrations although there do appear to be differences in the sensitivity and speed of the response. Figures 5.5 and 5.8 present data from the nephelometer measurements. These figures present mass concentration measurements directly calculated by the nephelometer and calculated using the relationship between the nephelometer and the 7-hole sampler (Table 5.1). Figures 5.6 and 5.9 present DataRAM measurements for both the raw data as recorded by the instrument as well as the 'calibrated' data based on adjusting the instrument response according to the relationship with the 7-hole samples (Table 5.1). This calibration has the effect of decreasing the measured concentration. Figures 5.7 and 5.10 present data from the APC particle counter, in which different size ranges of particles are counted. From these graphs, the predominance of particles larger than 0.5 μm is evident, although the particle size distribution appears to be complex, with different size ranges showing increased concentrations at different times. There is general agreement between the calculated results for the nephelometer and the DataRAM.

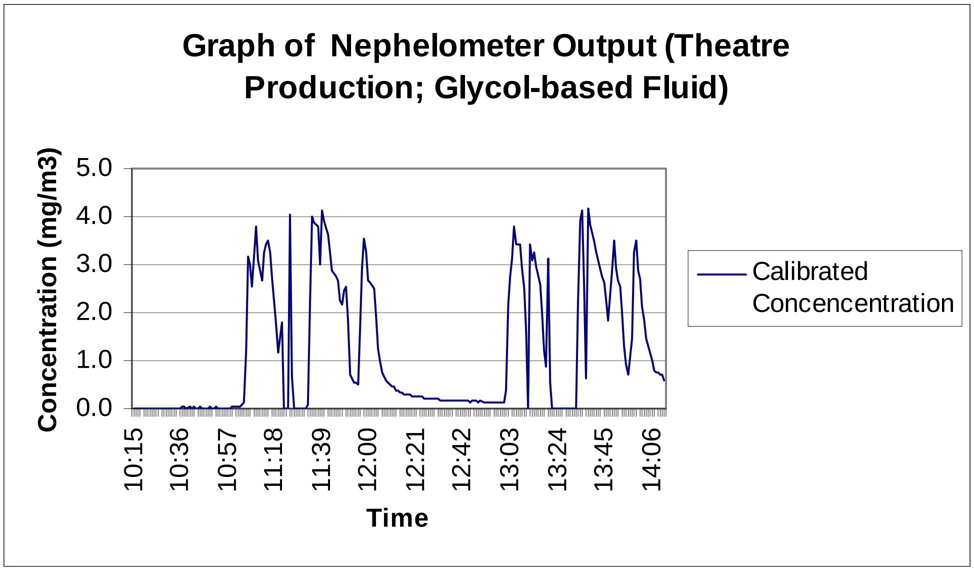

Figure 5.5 Output of nephelometer during a theatre production using glycol-based fluids, data after calibration against 7-hole sampler (relationship shown in Table 5.1)

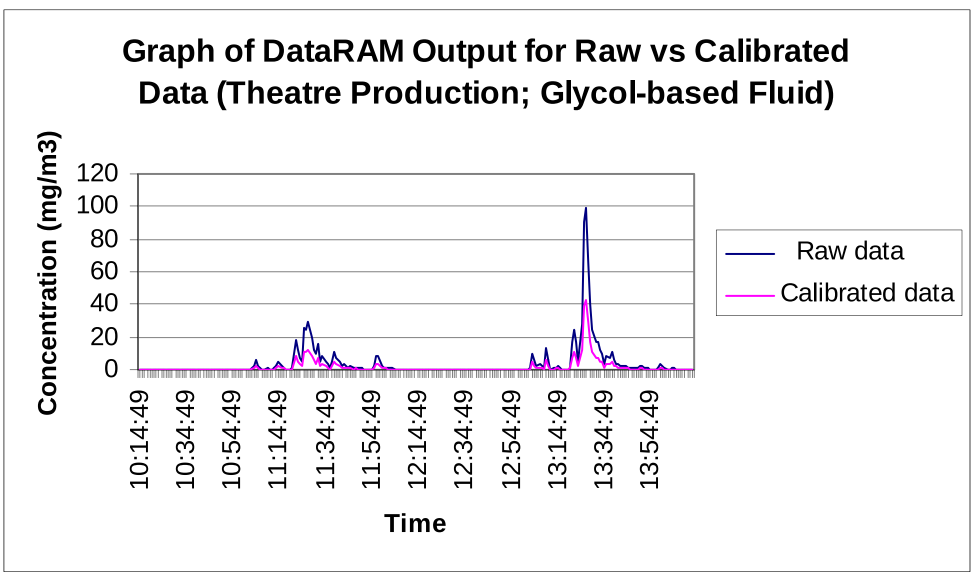

Figure 5.6 Output of DataRAM during a theatre production using glycol-based fluids, raw data and data after calibration against 7-hole sampler (relationship shown in Table 5.1)

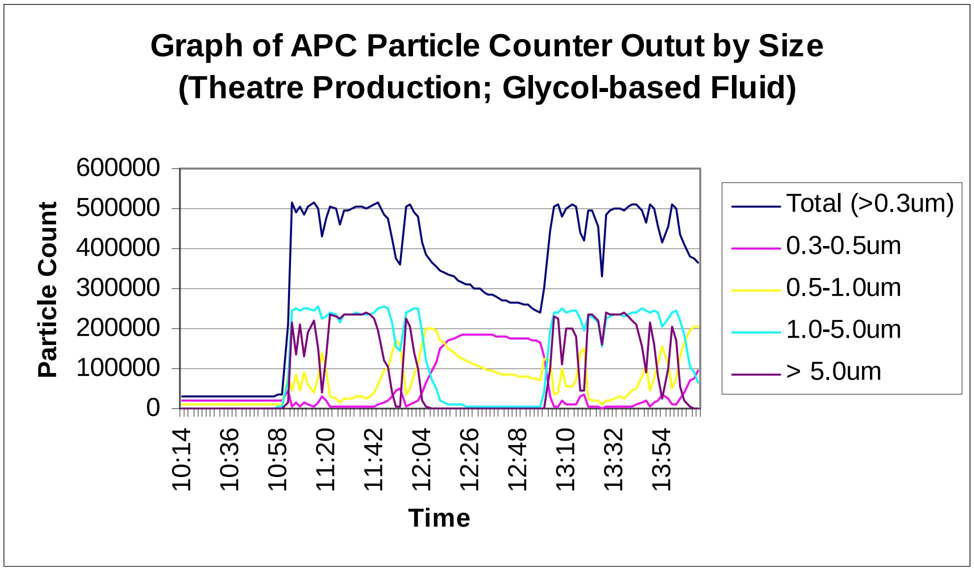

Figure 5.7 Output of APC particle counter during a theatre production using glycol-based fluids, total concentration and concentration stratified by particle size

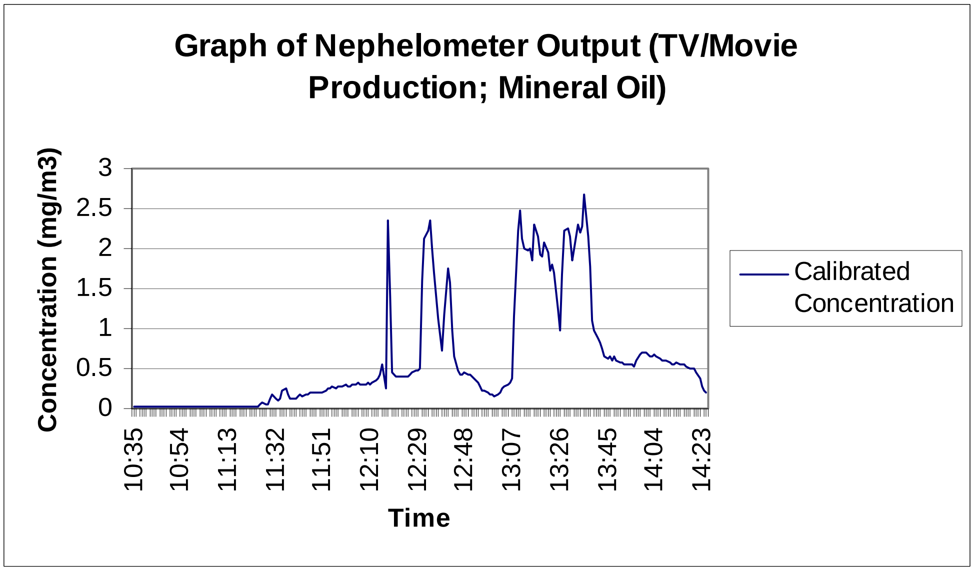

Figure 5.8 Output of nephelometer during a TV/movie production using mineal oil-based fluids, data after calibration against 7-hole sampler (relationship shown in Table 5.1)

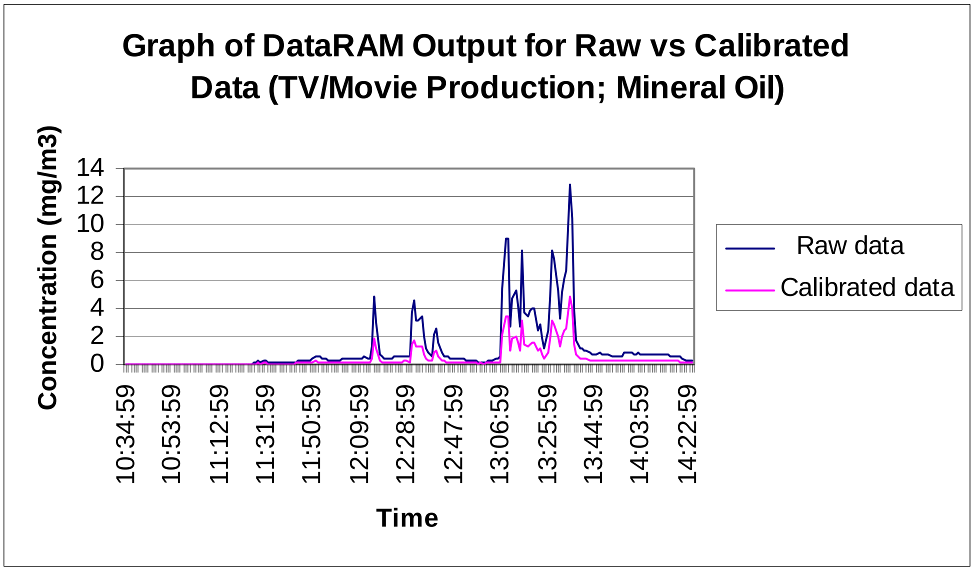

Figure 5.9 Output of DataRAM during a TV / movie production using mineral oil-based fluids, raw data and data after calibration against 7-hole sampler (relationship shown in Table 5.1)

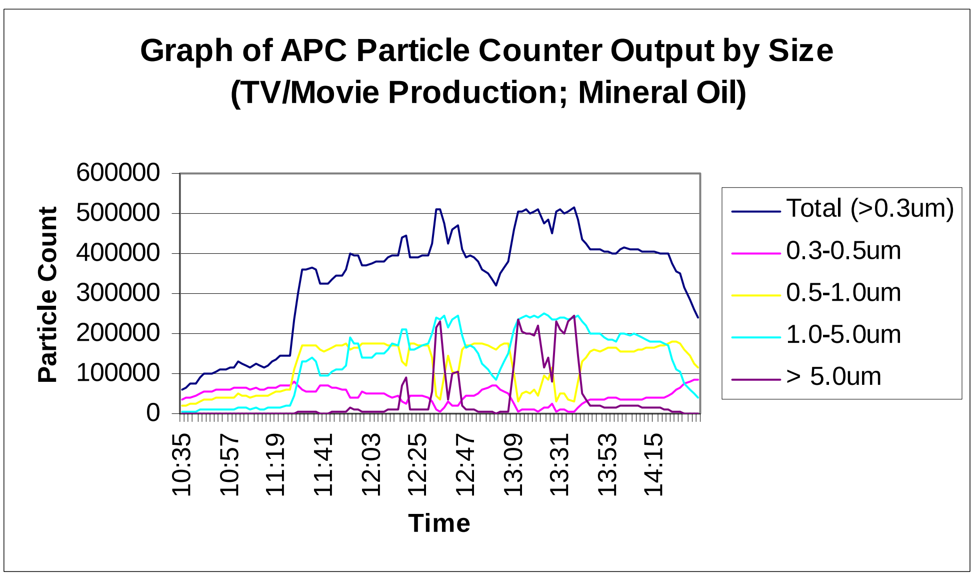

Figure 5.10 Output of APC particle counter during a TV / movie production using mineral oil-based fluids, total concentration and concentration stratified by particle size

5.2.2 Comparisons of area measurements using direct-reading monitors to personal measurements using standard methods

While the previous comparisons were between the various *area* samples, another consideration in assessing the usefulness of the direct-reading monitors is their relationship with measured *personal* exposures, taken in the breathing zones of industry personnel. Differences may result from the differences in measured area vs. personal concentrations (Figure 5.11) as well as differences in measurement techniques (direct-reading monitors vs. the 7-hole sampler; Figures 5.12 to 5.14). Table 5.6 presents the results of regression models that also considered the potential impact of different fluid mixtures.

From the scatter plots of the measurement data presented in the figures, it is evident that for equivalent samplers (7-hole samplers, Figure 5.11) only 45% of the variability (R^2) in measured personal exposures can be explained by an area sample. After adjusting for the different types of fluids (Table 5.6) only a slightly higher amount of variability in personal exposures is explained by the area measurements (R^2=49%). The variability predicted by the other area sampler (Marple cascade impactor) is very similar, though slightly higher. Given that all of the direct-reading monitors use different measurement principles, it is unreasonable to expect that their area measurements would explain a greater proportion of the variability in filter-based *personal* exposure measures than either of the two filter-based *area* samplers. While this is clearly the case, the DataRAM and nephelometer perform only moderately worse in predicting the personal sample concentrations (see model R^2 in Table 5.6).

Table 5.6 Linear regressions of concentrations measured using the *area* monitors as predictors of *personal* concentrations measured using gravimetric methods, adjusting for type of fog fluid used

Area Sampler		*Fog fluid adjusted for in model*		*n*	*Intercept*	*Model R^2*	*Model p-value*
Type	*coefficient*	*Type of fluid*	*coefficient*				
7-hole sampler	0.72	Mineral oil	0.34	104	0.08	0.49	<0.001
Marple cascade	0.91	-	-	101	0.07	0.50	<0.001
Nephelometer	560	Glycol and mineral oil	0.63	98	0.08	0.40	<0.001
DataRAM-1000	0.31	Mineral oil	0.77	104	697	0.43	<0.001
APC-100	5.9E-06	Glycol and mineral oil	0.71	97	0.21	0.25	<0.001

- = no fluid adjusted for in Maple cascade impactor model

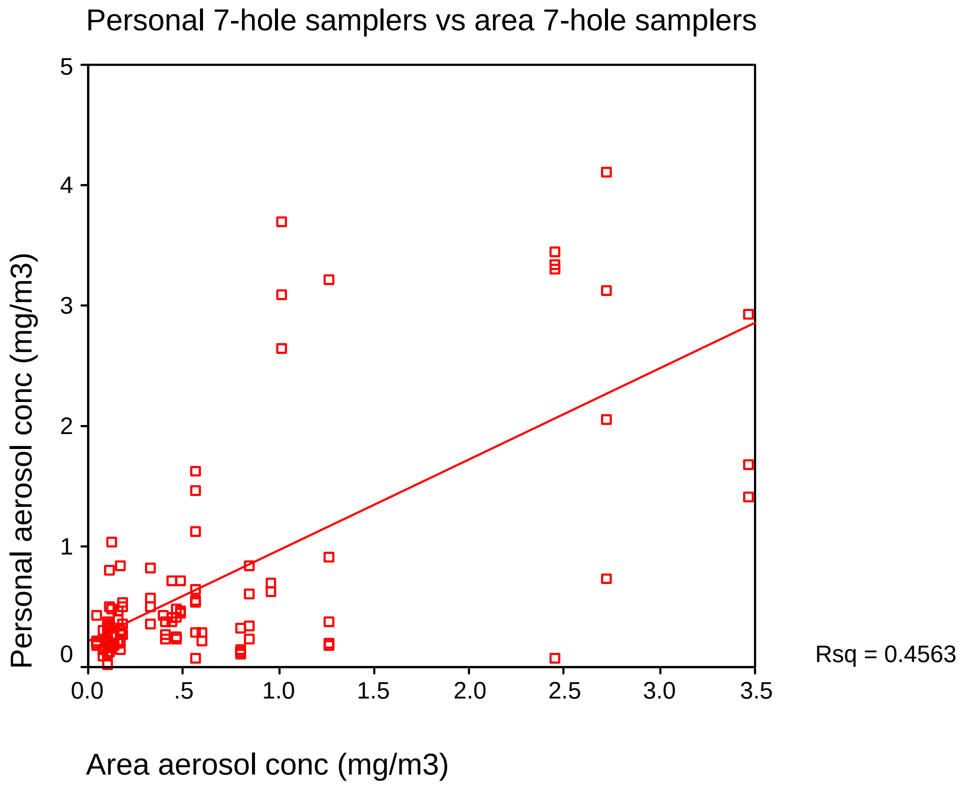

Figure 5.11 Comparison of area and personal measurements using the 7-hole sampler

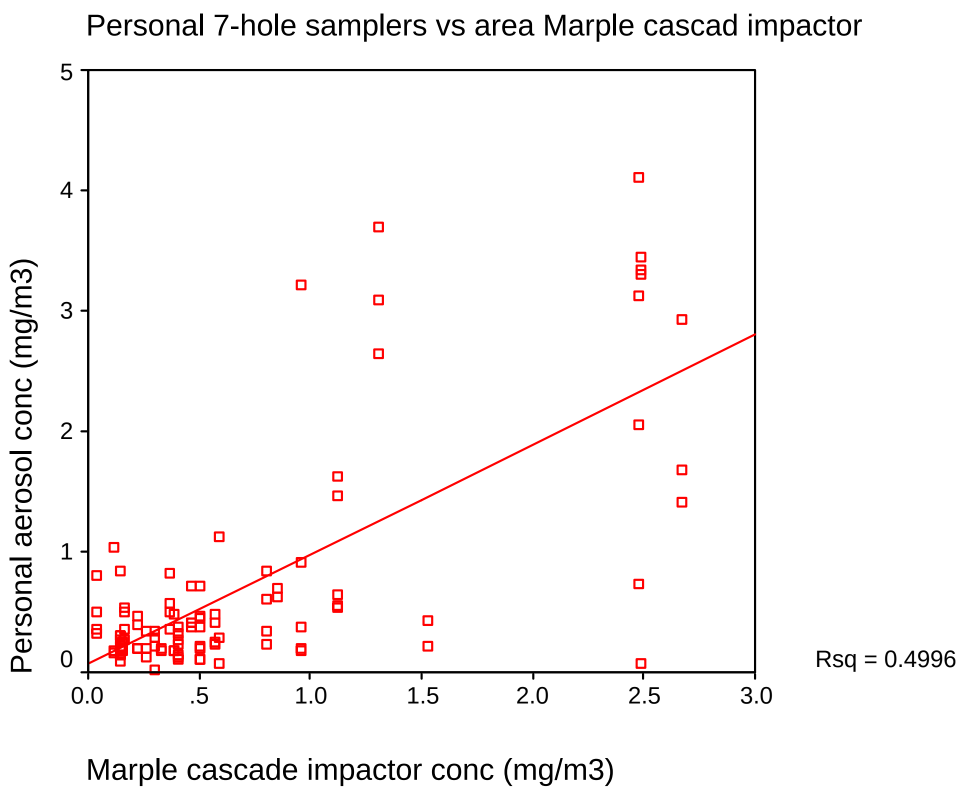

Figure 5.12 Comparison of area (Marple cascade impactor) to personal measurements (7-hole sampler)

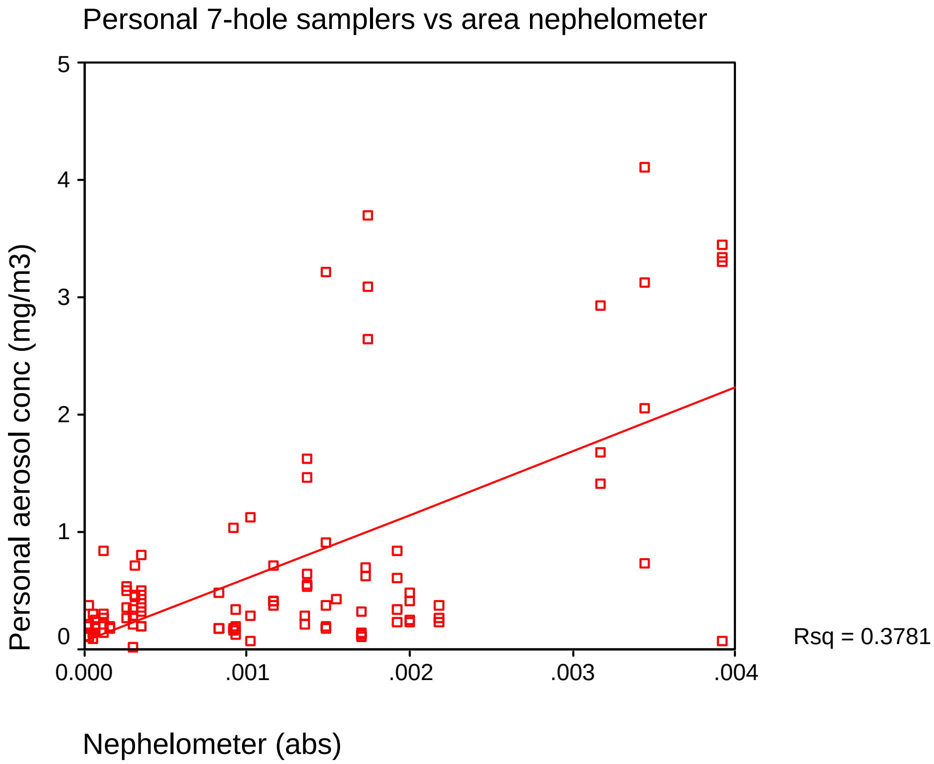

Figure 5.13 Comparison of area (nephelometer) to personal measurements (7-hole sampler)

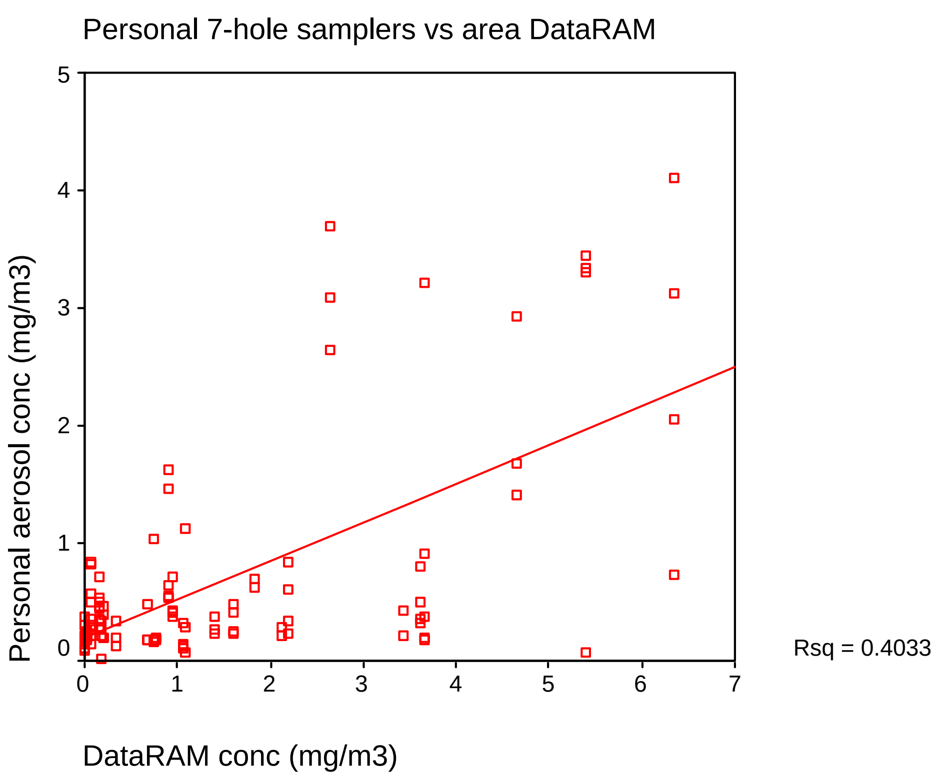

Figure 5.14 Comparison of area (DataRAM) to personal measurements (7-hole sampler)

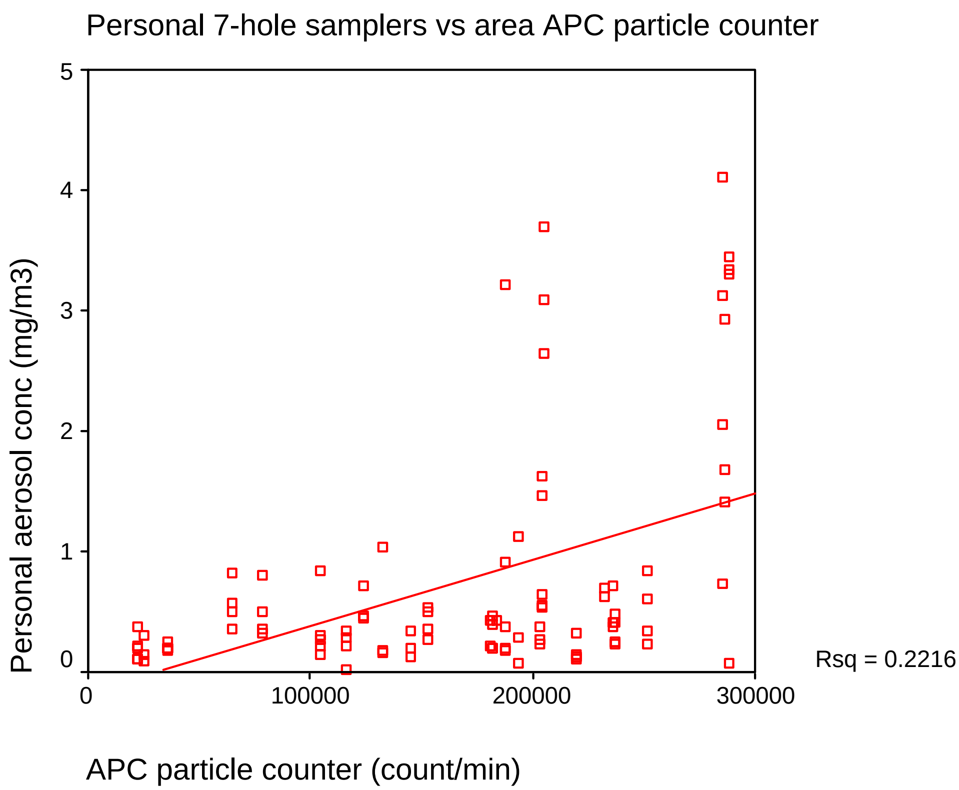

Figure 5.15 Comparison of area (APC particle counter) to personal measurements (7-hole sampler)

5.2.3 Cost and ease of use of the direct-reading monitors

Comparisons between the instruments also were based upon purchase cost and ease of use as assessed by the study technicians.

1. Nephelometer: $6,200 CAD
   - Bulky
   - Silent
   - Requires external measurements for concentration measurement calibration
2. DataRAM: $8,000 CAD
   - Most user-friendly (easiest to interpret)
   - Both area and personal samples possible
   - Lightest when using a 9V battery
   - Silent
3. APC: $6,500 CAD
   - Provides some particle size distribution information
   - Both area and personal samples possible
   - Does not provide particle mass concentration data
   - Memory is limited to only 200 data points so must collect data with longer averaging times or download data frequently

- Not too bulky or loud

In the comparisons between the filter-based samplers and the three direct-reading monitors, the nephelometer and the DataRAM performed equally well. In all cases, the APC showed less agreement with the filter-based samplers. The nephelometer was somewhat superior to the DataRAM in comparisons to the filter-based *area* samples, but both instruments performed similarly in predicting *personal* exposure measurements, the ultimate goal of measurement. Although the DataRAM is somewhat more expensive, its superior ease of use, size and noise characteristics make it the preferred instrument of those tested for the assessment of theatrical smokes and fogs by production personnel. It should be noted that several instruments using similar measurement technology are available and might also be good choices, although they were not specifically tested in this project.

6 Observed vs. Self-reported Time Spent in Visible Fog

6.1 Methods

Perhaps the simplest way for personnel working in special effects atmospheres to gauge their exposures is to estimate the time they spend in visible fog atmospheres. Such 'self-reports' of exposure duration can be used as an exposure estimate in epidemiological studies of health effects. It was one method of estimating exposure in our health effects study (Chapter 8).

To determine how well exposure durations can be self-reported, all study subjects who participated in the cross-sectional study (reported in detail in Chapters 7 and 8) were asked at the end of their exposure measurement period (approximately 4 hours), "How many hours or minutes have you spent in an environment in which visible smoke was present?" Research personnel conducting the air monitoring observed and recorded, every 10 minutes, the location of each study subject and whether visible atmospheric effects were present at the time.

Both observed and self-reported times were measured in minutes and also converted to the percent of the total monitoring period spent in visible fog. The monitoring period differed between the self-reported and observed time records: the *self-reported* period was based on when the subjects were interviewed pre- and post-shift, whereas the *observed* period was based on times when the air sampling pumps were turned on and off. To examine the agreement between the observed and self-reported times, paired sample t-tests and correlations (Pearson r) were conducted. Scatter plots were used to visualize the relationship between the observed and self-reported times and percent times.

The abilities of the observed and self-reported times in the fog environment as predictors of personal exposure concentrations (as measured using the 7-hole sampler) of each subject on that day were tested using simple linear regression.

6.2 Results

Table 6.1 summarizes the times spent in a visible fog atmosphere, as observed by research personnel throughout the measurement period, and as reported by study participants at the end of the period. Self-reported and observed times were positively correlated with each other; the correlations would be considered moderate. Self-reported times and % times were significantly higher on average than the observed times, by about 50% and 30% respectively. Over-reporting of exposure times is a common phenomenon, observed in other studies[1]; examination of Figure 6.1 indicates one reason why this occurs. The vertical lines of data points indicate that study subjects, because they are reporting at the end of their measurement period, have the reasonable tendency to round their times to the hour or half-hour. Figure 6.2 shows slightly better agreement when % of the measurement period is used as the basis for comparison.

Table 6.1 Comparison of observed (by research personnel during exposure measurement) and self-reported (by health study subjects at the end of the exposure measurement period) times spent in visible fog

	n	*Minimum*	*Maximum*	*Arithmetic mean*	*Arithmetic SD*	*Paired t-test*	*Pearson correlation*
Observed time (min)	101	0	250	85.9	73.0	p<0.001	0.66 (p<0.001)
Self-reported time (min)	101	0	390	132.6	100.8		
Observed time (% of measurement period)	101	0	100	38.5	31.2	p<0.001	0.68 (p<0.001)
Self-reported time (% of measurement period)	101	0	121	50.4	36.7		

SD = standard deviation

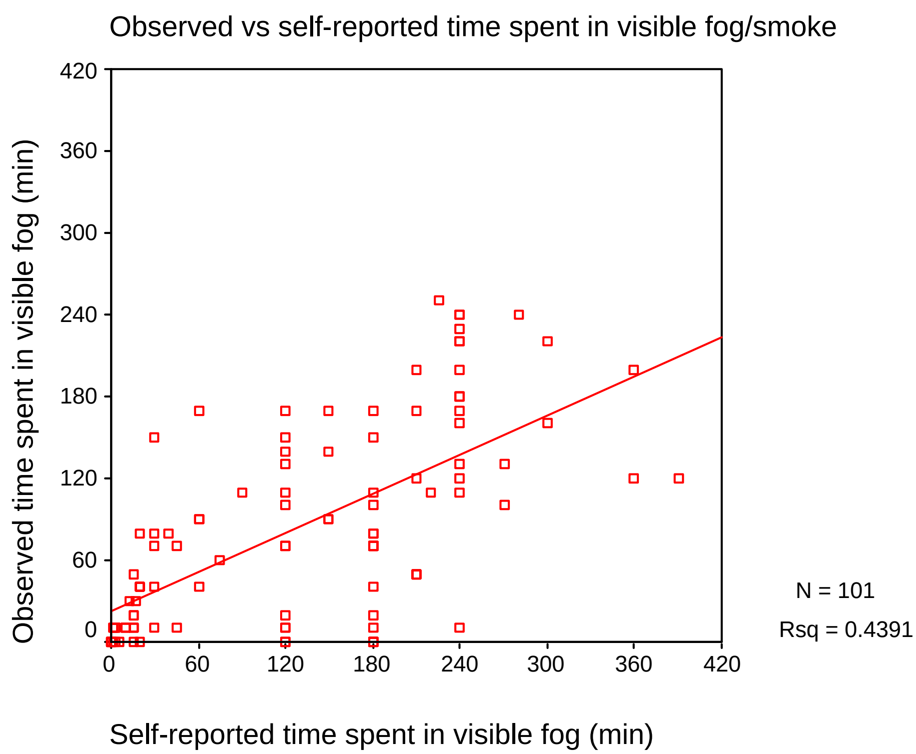

Figure 6.1 Scatterplot of observed and self-reported times spent by study subjects in visible fog

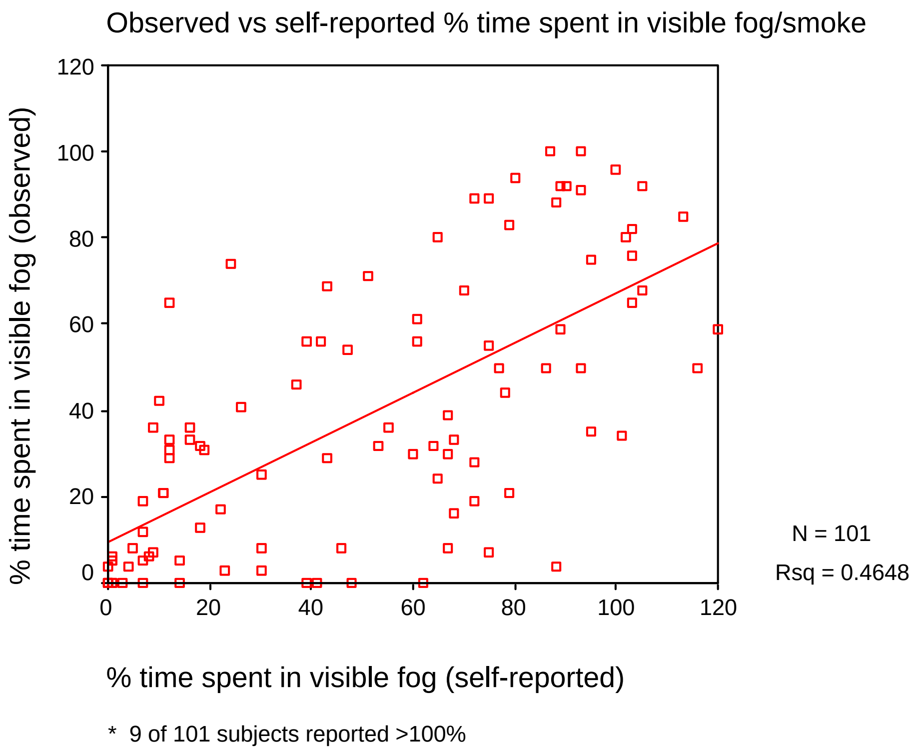

Figure 6.2 Scatterplot of percent of measurement period observed by research personnel and self-reported by study subjects, as spent in visible fog

Table 6.2 summarizes the results of simple linear regressions testing how well the observed and self-reported measures of time spent in visible fog serve as predictors of subjects' personal breathing zone exposure to smokes and fogs. All four models indicated that there were statistically significant positive relationships between the time variable and personal aerosol concentration. The observed time models predicted more of the variability in personal exposures than the self-reported, and the percent of measurement period models were better predictors than the absolute time models. The best model (% observed time) predicted about 25% (R^2) of the personal exposure variability.

Table 6.2 Simple linear regressions testing observed and self-reported time spent in visible fog as predictors of personal 7-hole aerosol concentrations (log-transformed, base e)

	n	*Intercept*	*Coefficient*	*Model R^2*	*Model p-value*
Observed time (minutes)	111	-1.43	0.00589	0.176	<0.001
Self-reported time (minutes)	101	-1.22	0.00245	0.056	0.017
% observed time	111	-1.56	0.01655	0.247	<0.001
% self-reported time	101	-1.37	0.00925	0.105	0.001

References, Chapter 6

1. Teschke K, Kennedy SM, Olshan AF. Effect of different questionnaire formats on reporting of occupational exposures. *American Journal of Industrial Medicine.* 1994;26:327-337

7 Levels of Exposure

7.1 Methods

7.1.1 Site identification

A number of strategies were used to identify entertainment industry sites and productions in the Vancouver area for inclusion in the cross-sectional study of exposures and health effects. Special effects technicians who participated in the survey reported in Chapter 3 were asked for names of current or future fog-using productions. The International Photographers Guild, IATSE Local 669, maintains a list of movie and television productions in western Canada on its website (http://www.ia669.com/productions.html); this list is updated weekly and was consulted for new productions. Rob Jackes, then General Manager of SHAPE, Linda Kinney, then Labour Advisor of the Canadian Film and Television Production Association, Beth Hanham, Manager of Occupational Health and Safety of IATSE 891, and Don Cott, Vice President of the Canadian affiliates of the US-based Alliance of Motion Picture and Television Producers were asked to identify TV and movie productions that were using fogs and that would be willing to participate. Ian Pratt, Associate Professor of Theatre at UBC provided a list of theatre contacts. Lists of concerts and theatrical performances were obtained by contacting concert venues and speaking with the technical directors and concert promoters. In addition, the entertainment trade and other local newspapers, and yellow pages were consulted to identify live theatre productions, live music productions, other live shows, and arcades which might use theatrical fogs.

The production managers or technical directors of every site so identified between July 1, 2000 and December 1, 2001 were sent an information package asking for participation. The package included a summary of the study purpose and methods, and letters of support from the Directors Guild of Canada, IATSE 891, Canadian Film and Television Production Association, Alliance of Motion Picture and Television Producers, and Vancouver Musicians' Association. One week later, the letters were followed with telephone calls to determine whether the production/site would be using special atmospheric effects and if so, whether the manager would be willing to have the site included in the study.

All eligible and willing sites were included in the study for as many days as the production was using fogs and during which new subjects could be recruited to the study. No more than 5 subjects were recruited on each measurement day. Subjects recruited for sampling included all non-performance personnel who might come into contact with the fogs, e.g., special effects technicians, production managers, sound technicians, and makeup artists. Performers were not recruited to the study because of the difficulties presented by the noise of the air sampling pumps.

7.1.2 Area air concentration measurements

To measure a range of possible components of the fogging aerosols, on each day of sampling one location within the atmospheric effect zone was selected for 'area' sampling using a variety of monitoring devices. The agents monitored, sampling devices, and analytical methods are summarized in Table 7.1 and described in more detail below. The measurement devices were placed near to the fog-generating machines in an area expected to reasonably represent potential exposures of some study subjects. The duration of sampling was 4 hours (except where the production was shorter than 4 hours) and included at least one period when visible fog was present.

Table 7.1 Summary of area air monitoring sampling trains and analytical methods

Agent	*Sampling train*	*Laboratory analytical method*
Inhalable aerosol mass	7-hole sampler with Teflon filter*	gravimetric
Size-selective aerosol mass	Marple 290 cascade impactor with polyvinyl chloride filter	gravimetric
Aerosol mass	integrating nephelometer M903	none (direct-reading)
Aerosol mass	personal aerosol monitor DataRAM 1000	none (direct-reading)
Aerosol count	laser single-particle counter APC-100	none (direct-reading)
Glycols	200/100 mg XAD-7 OVS tube preceded by a 13-mm glass fibre filter	gas chromatography mass spectrometry
Aldehydes	100/50 mg silica gel tube impregnated with 2,4 DNPH	high performance liquid chromatography
Polycyclic aromatic hydrocarbons	7-hole sampler with Teflon filter*; and 100/50 mg Orbo43 washed XAD-2 tubes	gas chromatography with flame ionization detection

*same filter used for aerosol mass and polycyclic aromatic hydrocarbon measurements

The purpose, operation, and results of the three direct-reading aerosol monitors are described in detail in Chapter 5, and are not described further in this chapter.

Two types of filter-based gravimetric sampling trains were used to monitor mass concentrations of aerosols:

- a 7-hole inhalable aerosol sampler (JS Holdings Ltd., Stevanage, UK) mounted with a 25-mm diameter, 0.45-micron pore size Teflon filter (Gelman Sciences, Ann Arbor, MI, USA); and
- a Marple 290 personal cascade impactor (Thermo Andersen, Smyrna, GA, USA) mounted with five 34-mm diameter 5-micron pore size polyvinyl chloride filters (PVC; Thermo Andersen, Smyrna, GA, USA). The impactor has five 'stages' which cause the aerosol to be separated into five size fractions: ≥ 21 microns; ≥ 15 to < 21; ≥ 10 to < 15; ≥ 3.5 to 10; and < 3.5 microns. These allow calculation of the proportions of the particulate masses reaching the nasopharyngeal (≥ 10 microns), tracheobronchial (≥ 3.5 to 10 microns), and alveolar (< 3.5 microns) regions of the respiratory tract.

Air was drawn through these two filter systems with portable constant-flow sampling pumps (SKC, Eighty-Four, PA, USA) set to a flow rate of 2.0 L/min ± 5%. The pumps were calibrated before and after sampling using a rotameter (Matheson Tri-Gas, Montgomeryville, PA, USA). A calibration curve for the rotameter was established at the UBC School of Occupational and Environmental Hygiene Laboratory using an automated soap-film flow meter (Gillibrator, Gilian, USA) as the primary standard.

Sorbent tubes were used to capture various volatile components of the fogs:

- XAD-7 OVS tubes (SKC) were used to monitor glycols; air was drawn using constant-flow sampling pumps (as described above) at a calibrated flow rate of 2.0 L/min ± 5%;
- silica gel tubes (SKC) were used to monitor aldehydes; air was drawn at a calibrated flow rate of 1.0 L/min ± 5%; and

- Supelpak™ 20U Orbo43 XAD-2 tubes (Sigma-Aldrich, St. Louis, MO, USA) were used to monitor polycyclic aromatic hydrocarbons (PAHs); they were attached to the same sampling train as the 7-hole sampler, between the filter and the pump, and therefore had the same air flow rate.

At every site, one field blank was collected for each type of collection medium. All samples were quantified at the School of Occupational and Environmental Hygiene Laboratory.

All filter air samples were quantified gravimetrically on a micro-balance (M3P, Sartorius, Germany). Prior to triplicate pre-sampling weighing, filters were equilibrated for at least 24 hours to a stable temperature and relative humidity (22 ºC ± 0.3 ºC and 45% ± 5% relative humidity). Prior to triplicate post-sampling weighing, filters were desiccated for 24 hours, then equilibrated for at least 24 hours to the same stable temperature and relative humidity. The average concentration detection limits for the Teflon filters and PVC filters based on 4 hours of sampling at 2.0 L/min were 0.022 mg/m^3 and 0.042 mg/m^3, respectively.

Glycols were extracted using ethanol and quantified using a Varian 3400 gas chromatograph (Varian Inc., Palo Alta, CA, USA) equipped with Supelco SPB™-1000 column (Sigma-Aldrich, St. Louis, MO, USA) and a Varian Saturn II mass spectrometer, based on a revised version of NIOSH Method 5523[1]. The following 7 glycols from Acros® Organics (99% purity) were used as standards: propylene glycol; 1,3-butanediol; dipropylene glycol; diethylene glycol (2-hydroxyethyl ether); triethylene glycol; glycerin/glycerol; and tetraethylene glycol. The concentration detection limits for the glycols were about 0.1 mg/m^3 for triethylene glycol, glycerin/glycerol, and tetraethylene glycol; about 0.2 mg/m^3 for dipropylene glycol; and about 0.3 mg/m^3 for propylene glycol, 1,3-butanediol, and diethylene glycol (2-hydroxyethyl ether).

Aldehydes were extracted with acetonitrile and quantified using a Varian 9010 high performance liquid chromatograph using WCB Method 5270[2]. The following 14 aldehydes from Supelco® T1011/IP6A Carbonyl-DNPH Mix were used as standards: formaldehyde; acetaldehyde; acrolein (note that acrolein and acetone have the same retention time); propionaldehyde; crotonaldehyde; butylaldehyde; benzaldehyde; isovaleraldehyde; valeraldehyde; o-tolualdehyde; m-tolualdehyde; p-tolualdehyde; hexaldehyde; and 2,5-dimethylbenzaldehyde. The concentration detection limits for the aldehydes were ≤ 0.0005 mg/m^3 for all aldehydes except formaldehyde (0.0015 mg/m^3) and acrolein (same retention time as for acetone) (0.011 mg/m^3).

PAHs were extracted from both the Teflon filter (after weighing) and the XAD2 tubes with toluene and quantified using a Varian 3400 gas chromatograph with a flame ionization detector using NIOSH Method 5515[3]. The following 16 PAHs from Supelco® EPA 610 Polynuclear Aromatic Hydrocarbons Mix were used as standards: naphthalene; acenaphthylene; acenaphthene; fluorine; phenanthrene; anthracene; fluoranthene; pyrene; chrysene; benzo(a) anthracene; benzo(k)fluoranthene; benzo(b)fluoranthene; benzo(a)pyrene; indeno(1,2,3-cd)pyrene; dibenzo(a,h)anthracene; and benzo(ghi)perylene. The concentration detection limits for the PAHs was 0.0006 mg/m^3 for phenanthrene and in the range of 0.0015 to 0.005 mg/m^3 for all other PAHs.

7.1.3 Personal exposure measurements

On each day of monitoring, up to 5 individuals were asked to wear personal samplers to measure aerosol mass concentrations and PAHs in their breathing zones. Only two agents were sampled during personal sampling because of the difficulties inherent in wearing the sampling instrumentation. Wherever possible the subjects recruited included one member of the special effects crew and one member of the hair and make-up crew. Subjects were given an explanation of the sampling apparatus and asked whether they would consent to participate.

Table 7.2 lists the collection apparatus and analytical methods for the two agents collected during personal sampling. Sampling, calibration and analysis were identical to the methods described for these sampling trains in section 7.1.2, describing the area measurements.

Table 7.2 Summary of personal air monitoring sampling trains and analytical methods

Agent	*Sampling train*	*Laboratory analytical method*
Aerosol mass	7-hole sampler mounted with Teflon filters*	gravimetric
Polycyclic aromatic hydrocarbons	7-hole sampler with Teflon filter*; and 100/50 mg Orbo43 washed XAD-2 tubes	gas chromatography flame ionization detector

*same filter used or aerosol mass and polycyclic aromatic hydrocarbon measurements

For personal sampling of television and movie productions only, the pumps were turned off by the subjects during filming when silence on the set was required, from the time the assistant director called "Rolling" to when the assistant director called "Cut." Calculations of the air volumes sampled were based on the actual sampling time displayed on the pump clock (Table 7.3). Note that the fog machines were also always turned off during filming.

Table 7.3 Summary of actual sampling times vs. total sampling period length for personal air samples taken in television and movie productions, where pumps were shut off during filming

	n	*Minimum*	*Maximum*	*Mean*	*Standard deviation*
Actual sampling time (min)	55	61	305	192	48.5
Total sampling period (min)	55	140	389	241	44.9

7.1.4 Determinants of exposure to fog aerosols

During the sampling period, factors considered potentially associated with levels of exposure were recorded, both at the level of the production day, and at the level of the subject (see Appendix B for data collection form).

On each production day, the following factors were recorded:

- temperature (at the beginning, middle and end of the sampling period);
- relative humidity (at the beginning, middle and end of the sampling period);
- atmospheric pressure (at the beginning, middle and end of the sampling period);
- distance of the area samplers from the primary fog machine;
- stage dimensions (length, width, and height);
- type of production (TV/movie; theatre, music, other);
- location (indoors or outdoors);
- number of fog machines used;
- manufacturer and model of each fog machine;
- type of fog fluid used in each machine; and

- the atmospheric effect created by each machine (source smoke, large volume smoke, smoldering effect, atmospheric haze, low lying fog, coloured smoke, and steam).

The job title of each subject, the number of people similarly exposed (i.e., with the same job title), and whether the subject used personal protective equipment were recorded. The work tasks/locations of each subject were recorded by research personnel every 10 minutes using the following task categories:

- refilling fluids or maintenance of the fog machine;
- operating fog machine;
- working within 10 feet of fog machine while it was on;
- working inside the stage or studio within ≤ 20 feet of the main production set;
- working inside the stage or studio more than 20 feet from main production set; and
- working outside the smoke/fog area (i.e., outside the studio/stage).

The estimated distance to the fog machine and the production set, as well as whether visible fog effect was present around the subject were recorded by research staff in parallel with the task/location data, every 10 minutes.

7.1.5 Data analysis

All statistical analyses were conducted using SPSS version 10.0.5 (SPSS Inc., Chicago, IL, USA) or SAS version 8.01 (SAS Institute Inc., Cary, NC, USA).

Descriptive statistics (minima, maxima, means, standard deviations) were tabulated for all area and personal air monitoring data. Because examination of the frequency histograms of the exposure variables suggested that the data were approximately log-normally distributed, all aerosol exposure data were log-transformed (base e) and geometric means and geometric standard deviations were calculated.

> *A short note on log-normal distributions.* Many environmental and occupational distributions are approximately log-normally distributed, i.e., they are bounded by zero on the left, tend to have a single mode close to the lower bound, but long tails to the right. These 'skewed' distributions become approximately bell-shaped (normally distributed) when the exposure data are log-transformed, thus the name. In addition to the usual arithmetic mean, another measure of central tendency used to describe such data is the geometric mean: the antilog of the mean of the log-transformed values. This is the same as the median when the data are exactly log-normal. Note that the arithmetic mean will be higher than the geometric mean, and this difference will increase the more skewed the data. Similarly the geometric standard deviation is the antilog of the standard deviation of the log-transformed values. It is unitless. Low geometric standard deviations (< ~ 2) indicate less skewed data, whereas higher geometric standard deviations (> ~ 3.5) indicate very skewed data.

All data were also summarized after stratification by production type (TV/movie; theatre, music, and other), and fluid type used to generate the effect (glycol; mineral oil; both glycol and mineral oil; dry ice).

Descriptive statistics were used to summarize characteristics of the crew members who participated in the exposure monitoring, including job title, tasks, percent time spent in environment where visible fog was present, distance away from the primary fog machine, distance away from the primary set, and personal protective equipment used.

Descriptive statistics were used to summarize characteristics of the sites and fog machines used to generate the effect. Characteristics of the sites included the number of fog machines used, the duration that the fog machine was on, the distance between fog machine and subjects or area samplers, the number of indoor versus the number of outdoor sites, temperature, relative humidity, pressure, and the stage dimensions. Characteristics of the fog machines included the name brand, the type and name brand of fog fluid used, and the effect created using the fog machine.

To determine which factors which were associated with increased or reduced personal aerosol exposure levels, a multiple regression analysis was conducted. All aerosol exposure data were log-transformed (base e). Prior to developing the model, variables for offering to the models were selected in several steps. First, we considered whether there was reasonable support for the hypothesis that there could be a relationship between the factor and the exposure. Second, correlations between independent variables were examined, and where Pearson $r \geq 0.6$, only one variable was chosen for inclusion in the analysis, the variable considered likely to be most directly related to exposure, or where this reasoning did not provide a clear choice, the variable more strongly associated with exposure in univariate analyses. Third, we examined whether the variables were associated with exposure in univariate analyses ($p < 0.25$) and, if so, whether the direction of association could be logically interpreted. To create the multiple regression model, initially general linear least squares fixed effects model fitting was conducted using manual backwards stepwise regression; all variables with $p \leq 0.10$ were retained. Because the number of variables available for inclusion in the model was too great for the number of measurements, the modeling was first conducted in three steps, one for each of three groups of variables:
1. continuous variables only; 2. job titles only; and 3. all other categorical variables only. Variables selected from these three groups were then offered to an overall model. To control for correlation within site, beyond that explained by factors in the model, we entered the variables retained in the fixed effects regression model into a mixed model (ProcMixed, SAS) with site as a random variable. The final model was checked for influential values using Cook's D and residuals were plotted to look for patterns in the unexplained variance.

7.2 Results

7.2.1 Sites and participation

In total, 19 sites using theatrical fogs were included in the study; 9 of these were visited on more than one occasion for a total of 32 days of sampling. Eight were television or movie productions (16 days of sampling), 6 were live theatre productions (8 days of sampling), 3 were live music productions (4 days of sampling), and 2 were other types of site – a dog show and a video arcade (3 days of sampling).

Participation rates by sites were not high; of 59 sites where fog was identified as being used during the study period, only 19 agreed to participate (32%). This problem was mainly due to poor participation from television and movie productions, where only 8 of 46 sites (17%) agreed to participate. Other production types (including music, theatre, and other productions) were more receptive to participation; 11 of 13 (85%) agreed.

Participation rates by subjects of the air monitoring study were good: 111 of the 144 individuals asked to participate agreed to do so (77.1%). Once again there was a difference in participation by type of production. In television and movie production, 56 of 83 individuals agreed (67.5%), whereas 55 of the 61 individuals in music, theatre, and other productions agreed (90.2%). The most common reason for refusal to participate was concern about the noise and size of the personal sampling pumps.

7.2.2 Area air concentrations

The average distance between the primary fog machine and the area samplers was 26 feet (standard deviation = 18 ft). Inhalable aerosol mass concentrations of area samples taken in these locations are summarized in Table 7.4. The arithmetic mean concentration over all productions was 1.36 mg/m^3. The concentrations varied a great deal from site/day to site/day as indicated by the high geometric standard deviation of 4.21 and the range of measurements, from 0.05 to 17 mg/m^3. Stratification by fluid type indicates that mineral oil appeared to produce higher aerosol concentrations than glycol, and that sites using both fog types had the highest concentrations. Stratification by type of production suggested that movie and television productions usually but not always had higher aerosol concentrations than other types of production.

Table 7.4 Summary of area aerosol concentrations using 7-hole samplers, stratified by production type and fog fluid type (results for all productions and all fluid types in bold)

	All fog fluids	*Glycol only*	*Mineral oil only*	*Glycol & mineral oil*	*Dry ice*
All productions (n)	**(32)**	(14)	(14)	(3)	(1)
Minimum [mg/m^3]	**0.05**	0.05	0.05	0.60	n/a
Maximum [mg/m^3]	**17.1**	3.47	6.56	17.1	n/a
Arithmetic mean [mg/m^3]	**1.36**	0.57	1.21	6.18	0.08
Arithmetic SD [mg/m^3]	**3.16**	0.91	1.74	9.45	n/a
Geometric mean [mg/m^3]	**0.41**	0.24	0.55	2.05	0.08
Geometric standard deviation	**4.21**	3.37	3.71	6.32	n/a
Movie & TV productions (n)	(16)	(6)	(9)	(1)	(0)
Minimum [mg/m^3]	0.05	0.11	0.05	n/a	n/a
Maximum [mg/m^3]	17.07	3.47	2.71	n/a	n/a
Arithmetic mean [mg/m^3]	1.86	0.76	0.90	17.09	n/a
Arithmetic SD [mg/m^3]	4.20	1.33	1.00	n/a	n/a
Geometric mean [mg/m^3]	0.47	0.30	0.43	17.09	n/a
Geometric standard deviation	4.90	3.71	3.96	n/a	n/a
Theatre, music, & other productions (n)	(16)	(8)	(5)	(2)	(1)
Minimum [mg/m^3]	0.05	0.05	0.41	0.60	n/a
Maximum [mg/m^3]	6.56	1.49	6.56	0.85	n/a
Arithmetic mean [mg/m^3]	0.86	0.42	1.77	0.72	0.08
Arithmetic SD [mg/m^3]	1.57	0.47	2.69	0.18	n/a
Geometric mean [mg/m^3]	0.35	0.20	0.88	0.71	0.08
Geometric standard deviation	3.68	3.32	3.24	1.28	n/a

SD = standard deviation
n/a = not applicable

Table 7.5 summarizes the 'size fractionated' aerosol concentrations. As expected, the overall mass concentrations are very similar to those measured using the 7-hole sampler, reported above. The additional information provided by the Marple sampler is the size distribution of the aerosol. On average, the largest proportion of the aerosol (61%) was small enough to reach the alveolar region of the lungs. These fine aerosols (< 3.5 microns) are not visible and can stay suspended in air for long periods (hours to days), whereas larger aerosols (> 10 microns) stay suspended for only seconds to minutes. Glycol fogs tended to have higher proportions of aerosol in the larger nasopharyngeal size ranges, whereas mineral oil and combined fog types had more in the alveolar size range. These trends appeared similar across production types.

Table 7.5 Summary of area aerosol concentrations using Marple™ Cascade Impactor for size-selective sampling, stratified by production type and fog fluid type (results for all productions and all fluid types in bold)

	All Fog Fluids	*Glycol*	*Mineral oil*	*Glycol & mineral oil*	*Dry ice*
All productions (n)	**(30)**	(13)	(14)	(2)	(1)
Minimum [mg/m³]	**0.04**	0.04	0.15	0.80	n/a
Maximum [mg/m³]	**11.14**	2.68	6.12	11.14	n/a
Arithmetic mean [mg/m³]	**1.25**	0.54	1.32	5.97	0.15
Arithmetic SD [mg/m³]	**2.23**	0.68	1.58	7.31	n/a
Geometric mean [mg/m³]	**0.55**	0.33	0.77	2.99	0.15
Geometric standard deviation	**3.41**	2.77	2.97	6.42	n/a
% nasopharyngeal (≥10 μm)	**23.8**	37.9	12.3	5.8	38.8
% tracheobronchial (3.5-10 μm)	**14.7**	14.3	15.2	8.0	27.1
% alveolar (<3.5 μm)	**61.4**	47.8	72.5	86.3	34.1
Movie & TV productions (n)	(15)	(5)	(9)	(1)	(0)
Minimum [mg/m³]	0.11	0.11	0.15	n/a	n/a
Maximum [mg/m³]	11.14	2.68	2.49	n/a	n/a
Arithmetic mean [mg/m³]	1.65	0.71	1.12	11.14	n/a
Arithmetic SD [mg/m³]	2.79	1.10	0.93	n/a	n/a
Geometric mean [mg/m³]	0.67	0.34	0.71	11.14	n/a
Geometric standard deviation	3.98	3.45	3.11	n/a	n/a
% nasopharyngeal (≥10 μm)	20.7	36.0	14.5	0.0	n/a
% tracheobronchial (3.5-10 μm)	19.7	20.7	20.8	5.3	n/a
% alveolar (<3.5 μm)	59.6	43.3	64.7	94.7	n/a
Theatre, music, & other productions (n)	(15)	(8)	(5)	(1)	(1)
Minimum [mg/m³]	0.04	0.04	0.40	n/a	n/a
Maximum [mg/m³]	6.12	0.96	6.12	n/a	n/a
Arithmetic mean [mg/m³]	0.85	0.43	1.68	0.80	0.15
Arithmetic SD [mg/m³]	1.48	0.26	2.49	n/a	n/a
Geometric mean [mg/m³]	0.46	0.33	0.89	0.80	0.15
Geometric standard deviation	2.91	2.59	3.05	n/a	n/a
% nasopharyngeal (≥10 μm)	27.0	39.0	8.4	11.5	38.8
% tracheobronchial (3.5-10 μm)	9.8	10.4	5.1	10.7	27.1
% alveolar (<3.5 μm)	63.3	50.6	86.5	77.8	34.1

SD = standard deviation

Table 7.6 indicates results from the direct-reading DataRAM aerosol monitors, which provide information about aerosol concentrations not only averaged over a working day (see Chapter 5), but also on a minute-to-minute basis. This data was summarized for each monitoring site to indicate the proportion of the sampling period during which the concentrations exceeded 0.2, 1, 5, and 10 mg/m^3. Most sites (n= 28) had concentrations exceeding 0.2 mg/m^3 at least part of the time, 25 sites had concentrations exceeding 1 mg/m^3, 17 sites had concentrations exceeding 5 mg/m^3, and 14 sites had concentrations exceeding 10 mg/m^3. A number of sites had substantial proportions of their measurement periods at these high levels.

Table 7.6 Proportion of monitoring period (%) at each site when concentrations were greater than 1, 5, and 10 mg/m³, data recorded at one-minute intervals by DataRAM 1000 direct-reading aerosol monitor

	% of monitoring period during which aerosol concentrations exceeded the following levels:			
Site number	*0.2 mg/m³*	*1 mg/m³*	*5 mg/m³*	*10 mg/m³*
1	90.6	36.6	11.4	6.5
2	58.2	32.4	1.6	0.5
3	4.9	4.9	2.2	1.6
4	13.1	4.5	0	0
5	15.5	11.4	8.2	6.8
6	61.5	40.2	28.2	3.8
7	67.4	19.4	5.4	0.8
8	31.8	15.2	10.5	8.8
9	44.9	42.9	40.4	39.1
10	14.4	0	0	0
11	100	94.4	67.5	5.6
12	99.6	94.4	70.5	2.6
13	0	0	0	0
14	37.5	20.7	5.3	1.4
15	75.6	71.1	64.3	58.3
16	61.5	53.5	4.8	0
17	75.6	53.7	0	0
18	100	33.3	0	0
19	29.9	19.6	2.8	0
20	28.7	1.5	0	0
21	45.8	20.8	3.3	0
22	29.4	11.4	0	0
23	94.5	11.4	0	0
24	66.8	0	0	0
25	37.0	0	0	0
26	73.6	43.0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	80.6	67.5	0	0
31	53.4	35.9	16.3	9.6
32	100	95.2	39.8	2.8

Glycol monitoring was initiated midway through the field study (March 2001), therefore only 13 area samples were taken for glycols, and of these only 6 were taken at sites where glycol fluids were used (Table 7.7). The following glycols were below the limits of detection in all samples: 1,3-butanediol; diethylene glycol; dipropylene glycol; glycerin/glycerol; and tetraethylene glycol.

Table 7.7 Summary of area glycol concentrations using sorbent tubes, glycol fluid types only

	All productions using glycol-based fluids n=6
Propylene glycol	
# samples > LOD	2
Minimum > LOD [mg/m³]	0.217
Maximum [mg/m³]	0.709
Arithmetic mean [mg/m³]	0.463
Arithmetic SD [mg/m³]	0.348
Triethylene glycol	
# samples > LOD	2
Minimum > LOD [mg/m³]	0.136
Maximum [mg/m³]	0.369
Arithmetic mean [mg/m³]	0.253
Arithmetic SD [mg/m³]	0.165

LOD = limit of detection
n/a = not applicable

Table 7.8 summarizes the area concentrations of aldehydes, considered to be potential thermal decomposition products of glycols, which are heated during fog production. In all samples, the following aldehydes were below the limit of detection: crotonaldehyde; 2,5-dimethyelbenzaldehyde; isovaleradehyde; *m*-tolualdehyde; *o*-tolualdehyde; and *p*-tolualdehyde. In most of the samples, acrolein was below detection limits, as was butylaldehyde in almost half the samples. Of the aldehydes consistently measured, formaldehyde and acetaldehyde had the highest mean concentrations, 0.039 and 0.025 mg/m^3, respectively. When considering the potential source of these agents, it is useful to compare the levels between the productions using fogs and those using mineral oils. If the main source of the aldehydes were heating of the glycol fluids, one would expect the levels to be consistently higher in productions using these fluids. This appears to be the case for acetaldehyde, but not for the other aldehydes. This evidence suggests there were other sources of these chemicals, e.g., ambient air contamination from traffic, fabrics, composition board products and other materials. These trends appeared similar across production types (data not shown).

Table 7.8 Summary of area aldehyde concentrations in all production types, stratified by fog fluid type (results for all fluid types in bold)

	All fog fluids n= 29	*Glycol* n=13	*Mineral oil* n=12	*Glycol & mineral oil* n=3	*Dry ice* n=1
Acetaldehyde					
% < LOD	**0**	0	0	0	0
Minimum > LOD [mg/m³]	**0.004**	0.014	0.004	0.005	n/a
Maximum [mg/m³]	**0.144**	0.144	0.030	0.035	n/a
Arithmetic mean [mg/m³]	**0.025**	0.034	0.018	0.018	0.021
Arithmetic SD [mg/m³]	**0.025**	0.034	0.007	0.016	n/a
Acrolein (2-propenaldehyde)*					
% < LOD	**83**	85	75	100	100
Minimum > LOD [mg/m³]	**0.011**	0.011	0.017	n/a	n/a
Maximum [mg/m³]	**0.043**	0.021	0.043	n/a	n/a
Arithmetic mean [g/m³]	**0.023**	0.016	0.027	n/a	n/a
Arithmetic SD [mg/m³]	**0.012**	0.007	0.014	n/a	n/a
Benzaldehyde					
% < LOD	**10**	8	0	67	0
Minimum > LOD [mg/m³]	**0.001**	0.001	0.001	n/a	n/a
Maximum [mg/m³]	**0.003**	0.003	0.003	n/a	n/a
Arithmetic mean [mg/m³]	**0.002**	0.002	0.002	0.001	0.001
Arithmetic SD [mg/m³]	**0.001**	0.001	0.001	n/a	n/a
Butylaldehyde					
% < LOD	**45**	53	33	67	0
Minimum > LOD [mg/m³]	**0.001**	0.001	0.001	n/a	n/a
Maximum [mg/m³]	**0.009**	0.006	0.009	n/a	n/a
Arithmetic mean [mg/m³]	**0.002**	0.003	0.002	0.001	0.001
Arithmetic SD [mg/m³]	**0.002**	0.002	0.003	n/a	n/a
Formaldehyde					
% < LOD	**0**	0	0	0	0
Minimum > LOD [mg/m³]	**0.006**	0.006	0.010	0.006	n/a
Maximum [mg/m³]	**0.140**	0.122	0.140	0.100	n/a
Arithmetic mean [mg/m³]	**0.039**	0.034	0.055	0.009	0.015
Arithmetic SD [mg/m³]	**0.042**	0.040	0.047	0.002	n/a
Hexaldehyde					
% < LOD	**7**	0	0	67	0
Minimum > LOD [mg/m³]	**0.001**	0.001	0.001	n/a	n/a
Maximum [mg/m³]	**0.064**	0.065	0.029	n/a	n/a
Arithmetic mean [mg/m³]	**0.010**	0.010	0.010	0.009	0.002
Arithmetic SD [mg/m³]	**0.013**	0.017	0.009	n/a	n/a
Propionaldehyde					
% < LOD	**0**	0	0	0	0
Minimum > LOD [mg/m³]	**0.001**	0.001	0.001	0.001	n/a
Maximum [mg/m³]	**0.010**	0.010	0.003	0.005	n/a
Arithmetic mean [mg/m³]	**0.002**	0.003	0.002	0.002	0.001

Valeraldehyde					
% < LOD	**7**	15	33	67	0
Minimum > LOD [mg/m³]	**0.001**	0.001	0.001	n/a	n/a
Maximum [mg/m³]	**0.006**	0.005	0.006	n/a	n/a
Arithmetic mean [mg/m³]	**0.003**	0.002	0.004	0.003	0.001
Arithmetic SD [mg/m³]	**0.002**	0.002	0.002	n/a	n/a

* Acetone has the same retention time as acrolein
LOD = limit of detection
n/a = not applicable

Naphthalene was the only polycyclic aromatic hydrocarbon detected in a large proportion of samples. Table 7.9 summarizes the area concentrations of naphthalene, stratified by production and fluid types. Note that the measurements are reported in *micrograms* per cubic meter of air, and that these samples were only analyzed for 20 of the 32 measurement days. The average concentration was 3.2 $\mu g/m^3$ and there was relatively little variation in the measurements. A higher proportion of measurements were above detection limits in movie and television production than other production types. In all samples the following PAHs were below the limits of detection: acenaphthylene; anthracene; benzo(a)pyrene; benzo(b)fluoranthene; benzo(ghi)perylene; benzo(k)fluoranthene; chrysene; dibenzo(a,h)anthracene; fluorine; indeno(1,2,3-cd)pyrene; and phenanthrene. Only one sample was greater than the limit of detection for each of the following PAHs: acenaphthene (2.1 $\mu g/m^3$ in a movie/TV production using glycols); benzo(a)anthracene (5.2 $\mu g/m^3$ in a movie/TV production using mineral oil); fluoranthene (2.1 $\mu g/m^3$ in another production type using glycols and mineral oil); and pyrene (5.4 $\mu g/m^3$ in another production type using glycols and mineral oil).

Table 7.9 Summary of area naphthalene concentrations, stratified by production type* and fog fluid type (results for all productions and all fluid types in bold)

	All fog fluids	*Glycol*	*Mineral oil*	*Glycol & mineral oil*
All productions (n)	**20**	9	9	2
% < LOD	**65**	78	44	100
Minimum > LOD [μg/m³]	**1.94**	1.94	2.58	n/a
Maximum [μg/m³]	**5.62**	2.69	5.62	n/a
Arithmetic mean [μg/m³]	**3.18**	2.31	3.53	n/a
Arithmetic SD [μg/m³]	**1.20**	0.53	1.25	n/a
Movie & TV productions (n)	8	2	5	1
% < LOD	25	50	0	100
Minimum > LOD [μg/m³]	2.58	n/a	2.53	n/a
Maximum [μg/m³]	5.62	n/a	5.62	n/a
Arithmetic mean [μg/m³]	3.39	2.69	3.53	n/a
Arithmetic SD [μg/m³]	1.17	n/a	1.25	n/a
Theatre, music & other productions (n)	12	7	4	1
% < LOD	92	86	100	100
Minimum > LOD [μg/m³]	n/a	n/a	n/a	n/a
Maximum [μg/m³]	n/a	n/a	n/a	n/a
Arithmetic mean [μg/m³]	1.94	4.85	n/a	n/a
Arithmetic SD [μg/m³]	n/a	n/a	n/a	n/a

LOD = limit of detection
n/a = not applicable
* No samples analyzed with dry ice as the fog fluid

When analytical results are so low, it is useful to compare them to 'control' samples taken in an area not subject to the theatrical fogs, to determine if the levels measured might correspond to background levels in the environment. Control samples were taken outdoors at four sites. At one site, all polycyclic aromatic hydrocarbons were below detection limits. At the remaining three sites, only one PAH was measurable at levels above detection limits: naphthalene at 0.2 µg/m^3 at one site; and acenaphthene at 0.36 and 0.18 µg/m^3 at two sites. The proportion of the outdoor control samples with measurable levels was very similar to that in the areas where the fogs were being used, though the levels measured were somewhat lower. This suggests that sources other than the theatrical fogs may be producing the PAHs measured at the production sites, but is not definitive evidence in this regard.

So many of results of the first 20 area samples (and the first 65 personal samples) were below the limits of detection that we altered the protocol to decrease the detection limits by concentrating the filter and sorbent tube extracts four-fold to 1 mL and increasing the injection volume from 2 uL to 5 uL. With this altered method, 6 additional area samples analyzed and all the laboratory pyrolysis samples (Chapter 4) were still found to be below the limit of detection, therefore no further air samples were analyzed for PAHs.

7.2.3 Personal exposure levels

Inhalable aerosol mass concentrations in the breathing zones of study subjects are summarized in Table 7.10. The arithmetic mean concentration over all productions was 0.70 mg/m^3; not surprisingly, this is lower than the average measured by the area samplers stationed near the fog machines. The concentrations varied considerably from person to person with a geometric standard deviation of 2.75 and a range of measurements from 0.02 to 4 mg/m^3. Once again, exposures were higher on average in productions using mineral oil than those using glycols. Personnel in movie and television productions had aerosol exposures 2.5 times higher, on average, than those in other types of production.

As reported in section 7.2.2 above, only the first 65 personal samples were analyzed for PAHs because so few of the samples had results above detection limits, and reductions in the detection limits did not alter the proportion of samples with detectable levels. As for the area samples, naphthalene was the only polycyclic aromatic hydrocarbon detected in a large proportion of samples. Table 7.11 summarizes the personal concentrations of naphthalene, stratified by production and fluid types. Note that the measurements are reported in *micrograms*/m^3, and that these samples were only analyzed for 65 of the 111 subjects. The average concentration, 4.2 µg/m^3, was higher than for the area samples. There was also more variability in the measurements from subject to subject. There was no pattern by fluid or production type. In all samples the following PAHs were below the limits of detection: acenaphthylene; anthracene; benzo(a)pyrene; benzo(b)fluoranthene; benzo(ghi)perylene; benzo(k)fluoranthene; chrysene; dibenzo(a,h)anthracene; fluoranthene; fluorine; indeno(1,2,3-cd)pyrene; and pyrene. Only one sample was greater than the limit of detection for each of the following PAHs: acenaphthene (1.7 µg/m^3 in a movie/TV production using glycols); benzo(a)anthracene (9.8 µg/m^3 in a movie/TV production using mineral oil); and phenanthrene (0.9 µg/m^3 in another production type using glycols).

Table 7.10 Summary of inhalable aerosol concentrations in the breathing zones of subjects, stratified by production type and fog fluid type (results for all productions and all fluid types in bold)

	All fog fluids	*Glycol*	*Mineral oil*	*Glycol & mineral oil*	*Dry ice*
All productions (n)	**(111)**	(49)	(51)	(8)	(3)
Minimum [mg/m^3]	**0.02**	0.02	0.06	0.13	0.09
Maximum [mg/m^3]	**4.11**	3.22	4.11	2.77	0.31
Arithmetic mean [mg/m^3]	**0.70**	0.49	0.94	0.68	0.18
Arithmetic SD [mg/m^3]	**0.92**	0.63	1.12	0.88	0.11
Geometric mean [mg/m^3]	**0.40**	0.31	0.54	0.42	0.16
Geometric standard deviation	**2.75**	2.52	2.83	2.64	1.85
Movie & TV productions (n)	(55)	(19)	(34)	(2)	(0)
Minimum [mg/m^3]	0.06	0.12	0.06	0.13	n/a
Maximum [mg/m^3]	4.11	2.93	4.11	2.77	n/a
Arithmetic mean [mg/m^3]	1.01	0.62	1.21	1.45	n/a
Arithmetic SD [mg/m^3]	1.16	0.72	1.29	2.77	n/a
Geometric mean [mg/m^3]	0.55	0.39	0.65	0.59	n/a
Geometric standard deviation	3.11	2.50	3.29	8.83	n/a
Theatre, music & other productions (n)	(56)	(30)	(17)	(6)	(3)
Minimum [mg/m^3]	0.02	0.02	0.10	0.22	0.09
Maximum [mg/m^3]	3.22	3.22	0.72	0.84	0.31
Arithmetic mean [mg/m^3]	0.40	0.41	0.41	0.42	0.18
Arithmetic SD [mg/m^3]	0.43	0.57	0.17	0.25	0.11
Geometric mean [mg/m^3]	0.30	0.27	0.37	0.37	0.16
Geometric standard deviation	2.17	2.49	1.63	1.73	1.85

SD = standard deviation
n/a = not applicable

Table 7.11 Summary of naphthalene concentrations in the breathing zones of subjects, stratified by production type* and fog fluid type

	All fog fluids	*Glycol*	*Mineral oil*	*Glycol & mineral oil*
All productions (n)	**65**	30	31	4
% < LOD	**75**	77	71	100
Minimum > LOD [µg/m^3]	**1.95**	2.57	1.95	n/a
Maximum [µg/m^3]	**11.90**	7.78	11.90	n/a
Arithmetic mean [µg/m^3]	**4.28**	4.26	4.30	n/a
Arithmetic SD [µg/m^3]	**2.47**	1.81	3.00	n/a
Movie & TV productions (n)	23	5	16	2
% < LOD	52	60	44	100
Minimum > LOD [µg/m^3]	1.95	2.57	1.95	n/a
Maximum [µg/m^3]	11.90	3.04	11.90	n/a
Arithmetic mean [µg/m^3]	4.02	2.80	4.30	n/a
Arithmetic SD [µg/m^3]	2.75	0.33	3.00	n/a
Theatre, music & other productions (n)	42	25	15	2
% < LOD	88	80	100	100
Minimum > LOD [µg/m^3]	2.87	2.87	n/a	n/a
Maximum [µg/m^3]	7.78	7.78	n/a	n/a
Arithmetic mean [µg/m^3]	4.85	4.85	n/a	n/a
Arithmetic SD [µg/m^3]	1.85	1.85	n/a	n/a

LOD = limit of detection
n/a = not applicable
* No samples analyzed with dry ice as the fog fluid

7.2.4 Characteristics of sites, days, and subjects

Table 7.12 summarizes the characteristics of the sites on the 32 sampling days. On all but one day, sampling was conducted indoors and, because of this, temperatures were fairly stable averaging about room temperature. Relative humidity was more variable with a mean of 56%. Most sites used only one fog machine. The machine running times were extremely variable, though the average was only about 35 minutes. As expected, the production stages were very large, averaging about three stories in height, and 110 feet by 75 feet in length and width.

Table 7.13 summarizes the characteristics of the primary fog machines used on the sampling days. About half used glycols and half mineral oil; only one used any other method, dry ice. Although there were 8 different machines and 13 different fluids used, the most frequently used brand was Diffusion™. One of the 32 fluids used was a 'home brew'. By far the most common effect created was atmospheric haze, particularly in film and movie productions. In theatre, music and other production types, source smoke was also a common effect.

Table 7.14 summarizes the characteristics of the subjects whose exposures were measured. The subjects were about equally distributed between the TV/movie industry and theatre, music and other productions. Eighteen different jobs were represented, the most common being stage hand, production assistant, playmaster (at a video arcade), and make-up, hair and prosthetics. Only 7 of the 111 subjects were special effects technicians. It is therefore not surprising that the mean percent time (over all subjects) spent operating the fog machines was less than 1%, and within 10 feet of the machine when it was on, less than 5%. On average, sampled personnel spent almost half their time within 20 feet of the production set, but almost 30% of their time outside the studio or stage area. The average proportion of the measurement period spent by subjects in areas where visible fog was present was about 40%, with the average distance from the primary fog machine being about 40 feet. Personnel in movie and television productions worked somewhat longer on average within visible fog and about 18 feet closer to the fog machine than those in other types of production. Only one subject ever wore a respirator as protection from the aerosol.

Table 7.12 Characteristics of the 32 site/days when exposures were measured (results for all productions in bold)

	All productions *n=32*	*Movie & TV productions* n=16	*Theatre, music, & other productions* n=16
Number of indoor samples	**31**	15	16
Number outdoor samples	**1**	1	0
Mean temperature on sampling day, in °C (SD)	**20.1 (3.1)**	19.2 (4.1)	21.1 (0.8)
Mean relative humidity on sampling day, in % (SD)	**56.2 (10.6)**	59.5 (11.0)	52.7 (9.4)
Mean pressure on sampling day, in inches Hg (SD)	**30.5 (0.20)**	30.6 (0.19)	30.5 (0.21)
Mean no. of machines used (SD)	**1.19 (0.40)**	1.19 (0.40)	1.19 (0.40)
Mean on-time of primary machine, in minutes (SD)	**34.8 (47.7)**	26.5 (30.5)	43.2 (60.3)
Mean stage length, in ft (SD)	**109 (49)**	107 (43)	112 (56)
Mean stage width, in ft (SD)	**76 (39)**	86 (31)	66 (43)
Mean stage height, in ft (SD)	**34 (23)**	29 (17)	39 (30)
Mean stage volume, in ft^3 (SD)	**$4.5E^{+5}$ ($7.6E^{+5}$)**	$3.6E^{+5}$ ($2.9E^{+5}$)	$5.4E^{+5}$ ($1.0E^{+6}$)

SD = standard deviation

Table 7.13 Characteristics of primary fog machines used to generate fog or smoke effects on 32 sampling days (results for all productions in bold)

	All productions *n=32*	*Movie & TV productions* *n=16*	*Theatre, music, & other productions* *n=16*
Number of fog machines using glycols	**16**	7	9
Number of fog machines using mineral oil	**15**	9	6
Number of fog machines using dry ice	**1**	0	1
Brand of machine (type of fluid used)			
Antari ® (glycol)	**2**	2	0
Diffusion ™ (mineral oil)	**12**	9	3
Hessy (home brew)	**1**	1	0
LeMaitre ® (glycol)	**6**	3	3
Lightwave ® (glycol)	**3**	0	3
MDG ® (mineral oil, n=3; glycol n=1)	**4**	1	3
Radioshack ® (glycol)	**1**	0	1
Rosco ® (glycol)	**3**	0	3
Brand of fog fluid used (type)			
Antari ™ (glycol)	**1**	0	1
Atmospheres ™ (glycol)	**2**	0	2
Diffusion ™ (mineral oil)	**12**	9	3
Dry ice	**1**	0	1
Home brew (glycol)	**1**	1	0
LeMaitre Extra Long Lasting ™ (glycol)	**1**	1	0
LeMaitre Long Lasting ™ (glycol)	**1**	1	0
LeMaitre Maxi Fog ™ (glycol)	**2**	2	0
LeMaitre Regular Haze ™ (glycol)	**3**	1	2
MDG Dense Fog ™(glycol)	**1**	1	0
MDG Neutral ™ (mineral oil)	**3**	0	3
Rosco Scented, Pina Colada ™ (glycol)	**2**	0	2
Rosco Stage & Studio (unscented) ™ (glycol)	**2**	0	2
Effect created (type of fluid used)			
Source smoke (glycol)	**7**	1	6
Large volume smoke (glycol)	**1**	0	1
Smoldering (glycol)	**3**	1	2
Atmospheric haze (mineral oil, n=15; glycol, n=5)	**20**	14	6
Low lying fog (dry ice)	**1**	0	1
Coloured smoke	**0**	0	0
Steam	**0**	0	0

Table 7.14 Characteristics of 111 subjects whose exposures where measured on the sampling day (results for all productions in bold)

	All productions n=111	*Movie & TV productions* n=55	*Theatre, music, & other productions* n=56
Job title			
Assistant director	**5**	5	0
Camera person	**3**	3	0
Costumes	**5**	2	3
Electronics technician	**1**	0	1
Grip	**6**	6	0
Lighting technician	**6**	2	4
Make-up, hair & prosthetics	**9**	8	1
Musician	**1**	0	1
Play master	**10**	0	10
Production assistant	**13**	13	0
Production manager	**7**	0	7
Props technician	**3**	1	2
Set decorator	**2**	2	0
Sound technician	**7**	2	5
Special effects technician	**7**	5	2
Stage hand*	**20**	0	20
Stand-in	**3**	3	0
Video/computer technician	**3**	3	0
Mean % time during sampling period			
Operating fog machine (SD)	**0.7 (4.1)**	1.1 (5.6)	0.4 (1.6)
Working within 10' of fog machine on (SD)	**4.5 (9.3)**	5.4 (8.5)	3.6 (9.9)
Working within ≤20' of production set (SD)	**48.5 (29.4)**	41.6 (23.2)	55.2 (33.2)
Working outside >20' of production set (SD)	**17.8 (23.8)**	27.9 (24.8)	7.9 (17.9)
Working outside stage/studio area (SD)	**28.6 (25.9)**	24.1 (21.8)	33.0 (28.9)
Mean % time working in visible fog (SD)	**39.2 (30.4)**	41.7 (32.5)	36.8 (28.3)
Mean distance from primary fog machine, in ft (SD)	**39.4 (32.2)**	30.7 (16.7)	48.3 (40.9)
Mean distance from primary/active set, in ft (SD)	**12.1 (17.7)**	14.2 (14.7)	9.9 (20.2)
Number of subjects wearing respirator**	**1**	1	0

* includes trap crew
** 1/2 mask respirator with NIOSH P100 cartridges

7.2.5 Determinants of personal aerosol exposure levels

In order to determine which site, machine, and subject characteristics were related to exposure levels, after adjusting for other associated factors, we conducted multiple regression analyses with personal aerosol exposure levels (as measured by the 7-hole sampler) as the dependent variable (i.e., the variable being predicted). The following variables were *not* offered to the models because either they were not related to exposure in the initial simple linear regressions, or they were strongly correlated with variables which were considered to have a more direct relationship with exposure: refilling/maintenance of the fog machines; working more than 20 feet away from the production set, distance from the set, stage dimensions, relative humidity, atmospheric pressure, time the secondary fog machine was on, certain jobs (assistant director, camera person, costumes, make-up, production assistant, production manager, stage hand, trap crew, video/computer technician), the makes of the fog machines and the fog fluids, and the effect created.

Table 7.15 lists the factors which were significantly related to exposure. Two were related to characteristics of the production site: exposures increased as the number of fog machines increased; and exposures decreased as ambient temperatures increased (temperature may have been a surrogate for ventilation if ventilation of the set was increased as temperatures rose). The remaining factors associated with personal breathing zone exposure were related to characteristics of the subjects. The more time the subject was observed in visible fog and the closer the subject was, on average, to the primary fog machine, the higher the exposure. Subjects with the job ‘grip’ had exposures higher than predicted based on the other factors in the model, and those with the job ‘sound technician’ had exposures lower than otherwise predicted. The model explained about 50% of the variance in personal breathing zone exposure levels.

Table 7.15 Multiple regression model, coefficients (and p-values) for personal aerosol concentrations (log-transformed, base e)

	Coefficient	*(p-value)*
Background exposure (intercept)	0.177	
Ambient temperature (°C)	-0.095	(0.001)
Number of machines used	0.48	(0.014)
% time observed in visible fog	0.019	(<0.001)
Distance away from primary fog machine (ft)	-0.011	(<0.001)
Job title: grip	0.69	(0.025)
Job title: sound technician	-1.06	(0.001)
Number of observations	106	
Model p-value	<0.001	
Model R^2	0.50	

R^2 = the proportion of variance explained

The model outlined in Table 7.16 is based on the *self-reported* time the subject spent in visible fog (see Chapter 6 for more details), rather than the *observed* time. The other variables that were included in the model are nearly identical to the original model reported in Table 7.15. The only difference is that instead of the number of machines used, it was the time the primary fog machine was on that entered the model. The directions of the effects of the variables are the same as in the original model, but the model based on *self-reported* time explains somewhat less of the variance in personal exposures, 39%. The analysis in Chapter 6 illustrated that it is difficult to accurately self-report exposures at the end of a shift, and this results in less predictive power from this variable.

Table 7.16 Multiple regression model, coefficients (and p-values), for personal aerosol concentrations offering percent of *self-reported time* spent in visible fog (log-transformed, base e)

	Coefficient	*(p-value)*
Background exposure (intercept)	1.35	
Ambient temperature (°C)	-0.11	(0.001)
Time primary fog machine is on (minutes)	0.00014	(<0.001)
% time *self-reported* in visible fog	0.0076	(0.002)
Distance away from primary fog machine (ft)	-0.019	(<0.001)
Job title: grip	0.87	(0.014)
Job title: sound technician	-0.99	(0.007)
Number of observations	97	
Model p-value	<0.001	
Model R^2	0.39	

R^2 = the proportion of variance explained

The value of such 'determinants of exposure' models is that they indicate the factors which can be altered in order to decrease exposure levels. Here there are few surprises; fewer fog machines, less machine 'on' time, greater distance from the fog, and less time in the visible fog will all help reduce exposures. What is perhaps more interesting is the factors that were not included in the final models. For example, most jobs (including even the special effects technician classification) and tasks did not increase or decrease exposure beyond that predicted by the distance from the fog machine and the time spent in visible fog. In addition, neither the type of fog fluid nor the type of production contributed independently to exposure beyond their relationship to the factors which stayed in the models. For example, movie and television production personnel had higher exposures on average, and this can be attributed to the fact that they worked closer to the fog machines and spent a greater proportion of time in visible fog.

Another use for models of this type is that the relationships can be used to predict exposures for situations where they cannot be measured, e.g., exposures in the past. We used certain aspects of these predictive models to help estimate cumulative exposures of the study subjects, for examining exposure-response relationships in Chapter 8.

7.3 Summary and Conclusions

Of the 19 productions and 32 sampling days included in this study, about half used mineral oils to produce fogs (always to produce atmospheric haze effects) and about half used glycols (to produce many different types of effects, including haze). Dry ice was used only once. The average aerosol concentration measured in the area samples taken near the fogging machines was 1.36 mg/m^3 and the average personal concentration taken in the breathing zones of the study subjects was somewhat lower, at 0.70 mg/m^3. These exposures were achieved with subjects averaging about 40% of their sampling time in visible fog. Exposures to mineral oils tended to be higher than exposures to glycols (0.94 vs. 0.49 mg/m^3 average personal exposure). The mineral oil aerosols were on average smaller than the glycols, though both included substantial fractions that could reach the smallest airways and air sacs of the lungs, with about 73% and 48%, respectively, less than 3.5 microns in aerodynamic diameter. These small aerosols can stay suspended in air for periods of hours to days, a feature that is useful to sustain the effect, but one that prolongs exposures.

To provide a basis for comparison, it is useful to consider occupational exposure limits for these aerosols. The WCB 8-hour Exposure Limit (EL)[4] for mists of mildly refined oils is 0.2 mg/m^3 and of severely refined oils is 1 mg/m^3, based on a *total* aerosol sampling method (a method that usually captures somewhat less aerosol than the *inhalable* aerosol sampler we used). The American Conference of Governmental Industrial Hygienists (ACGIH) 8-hour time weighted average Threshold Limit Value (TLV)[5] for mineral oil mist is 5 mg/m^3. It is worth noting that changes to the TLVs have been under discussion since 1992-3. Earlier proposed changes suggested a TLV of 0.005 mg/m^3 for total PAHs in unrefined oils. However, since 2001, the Notice of Intended Changes has not distinguished the type of mineral oil and has proposed a standard of 0.2 mg/m^3, as *inhalable* aerosol. The arithmetic mean of the personal mineral oil mist exposures exceeded the current standard for mildly refined mineral oils set by the WCB (0.2 mg/m^3; also the proposed ACGIH TLV for all mineral oils), and was very close to the EL for severely refined oils (1 mg/m^3). In movie and television productions, the average mineral oil exposure exceeded the latter standard, and is well above the level (0.5 mg/m^3, one-half the Exposure Limit) requiring an exposure control plan according to the WCB regulation.

The WCB 8-hour Exposure Limit (EL)[4] and the ACGIH 8-hour time weighted average TLV[5] for glycerin mists, as *total* aerosol, is the same as the 'particulate not otherwise classified' standard: 10 mg/m^3. None of the glycol samples exceeded the current glycerin mist standard of 10 mg/m^3.

When comparing measurements to occupational exposure standards, it is important to remember that the standards must be reduced for personnel whose shifts are longer than 8 hours. For example, since special effects technicians reported working average shift lengths longer than 12 hours (Chapter 3), WCB 8-hour Exposure Limits would be multiplied by a factor of 0.25.

As with the evidence from the experimental heating of glycols (Chapter 4), there was no evidence of high levels of aldehydes or PAHs, suggesting little or no thermal degradation of the fog materials. All of the personal samples had PAH levels more than 1000 times lower than the current WCB Exposure Limit[4] and ACGIH TLV[5] for naphthalene: both are 8-hour limits of 10 ppm (52 mg/m^3). Average measurements for aldehydes in the area of the fog machines were also low: 0.025 mg/m^3 for acetaldehyde; 0.023 mg/m^3 for acrolein; 0.039 mg/m^3 for formaldehyde; and 0.003 mg/m^3 for valeraldehyde,. The WCB ELs[4] and ACGIH TLVs[5] for acetaldehyde (ceiling limit of 25 ppm or 45 mg/m^3) and valeraldehyde (8-hour limit of 50 ppm or 176 mg/m^3) are the same for both standard-setting bodies. For acrolein (0.1 ppm or 0.2 mg/m^3) and formaldehyde (0.3 ppm or 0.4 mg/m^3), the standards appear the same for both agencies, but the WCB lists these ELs as 8-hour standards and the ACGIH lists these TLVs as ‘ceiling’ standards. Since our sampling durations were several hours long, the results cannot easily be compared to ceiling standards. No other aldehydes have standards set by these agencies.

It is important to remember that both PAHs and aldehydes may have other sources at production sites. Both of these types of compounds are common products of combustion of organic materials. Because the levels observed in this study were low and had no discernable pattern with the type of production, fluid type, or indoor vs. outdoor location, the observed contamination could result from cigarette smoke or engine exhaust, even from outdoor sources. Formaldehyde may also arise from building products, since it is a common component of glues and stabilizers. No conclusions about the sources of these agents can be made on the basis of this study.

An examination of the characteristics of the fogs on the sampling days yields some interesting information. All productions but one were indoors. The predominant effect created was atmospheric haze (62.5% of production days sampled). Congruent with the frequency of haze effects, Diffusion™ machines and fluids were the most commonly used (37.5%). A ‘home-brewed’ fluid was used on only one of the production days.

A model to predict exposures was built; it was able to account for 50% of the variability in exposures. The most important factors determining exposures to the fluids were distance from the fog machine (the closer, the higher the exposure), the number of fog machines used, and the percent time spent in the visible fog. Grips had higher than expected exposures based on these factors, and sound technicians lower exposures. The model was used to help estimate cumulative exposures in the health effects analysis. It can also be used to guide exposure controls.

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8 Health Effects

8.1 Methods

8.1.1 Participation, study design

As initially proposed, a pilot survey of potential health effects of exposure to theatrical fogs was conducted on the same individuals who participated in the exposure monitoring survey. Each individual who participated in the exposure monitoring was invited to participate in the health effects component of the study. Recruitment of productions and sites was thus identical to that described in section 7.1.1 above, namely a convenience sample of those productions willing to participate. Once a site/production agreed to participate in the study, up to 5 individuals on site on the test day were invited to participate in the health and exposure monitoring survey. Three recruitment strategies were attempted: 1) asking the production manager to identify 5 suitable participants in advance; 2) use of a special production assistant provided by SHAPE to recruit participants; and 3) UBC team being on site 30 minutes to 1 hour before the start of work and approaching potential participants directly during breakfast and on set. The majority of recruiting was accomplished using the third approach. Because 'pre-shift' lung function testing and symptom interviews took approximately 10 minutes for each participant and because it was necessary to complete these prior to the use of fog on set, the team was required to move quickly around the set asking as many people as possible until 5 individuals were identified or time was unavailable for further testing. At each site, we attempted to obtain at least one participant from the hair/makeup department and one from the special effects department in addition to other participants.

The general design of the health study involved pre-shift and post-shift evaluation of symptoms and pulmonary function and a comprehensive assessment of current health status, prior health and employment history. The 'pre-shift' evaluation was conducted prior to any significant exposure to theatrical fog on the test day. The 'shift' period was expected to involve a minimum of 4 hours work, during which theatrical fog would be present at the site for a definable period of time.

Because of the difficulties encountered in recruitment of productions, the number of participants in the health survey was about half that planned. This reduces the ability of the study to detect statistically significant relationships between measures of exposure and their potential health effects, even where such relationships may exist.

8.1.2 Ethics, informed consent

Prior to carrying out the health survey, each participant was informed that he or she may decline to participate or may stop participation at any time without prejudice. The procedures were explained in detail (orally and with a written consent form) and informed written consent was obtained from each individual.

Personal results remain stored securely and confidentially in the research team's offices and will be released only with the written consent of the individual.

8.1.3 Questionnaires

Two standardized questionnaires were administered to each participant by a trained interviewer: one focusing on general health status and 'chronic' or ongoing symptoms (referred to here as the 'General Health Questionnaire') and the other focusing on symptoms experienced on the testing day (referred to here as the 'Acute Symptoms Questionnaire').

General Health Questionnaire

An expanded version of the American Thoracic Society standard questionnaire recommended for use in epidemiologic surveys was used.[1] Additional questions from the European Respiratory Health Survey standardized questionnaire for asthma were included,[2] as were questions regarding mucous membrane irritation, skin and voice symptoms. Symptoms were only reported as being present if the participant provided an unequivocal 'yes' response. Any uncertainty or hesitation in response to questions regarding symptoms was treated as a negative response. The questionnaire was similar to that used by our research team for previous studies at worksites throughout BC, with modifications specific to this study.

Also included were questions to evaluate demographic and other health and exposure factors that may influence symptoms (e.g., age, history of asthma, smoking, history of other irritant or allergenic exposures, and a detailed past and current employment history).

Acute Symptoms Questionnaire

A brief questionnaire was also completed by each participant before and after the exposure monitoring period. This questionnaire was similar to the one used by our research team in a recent study of acute and chronic symptoms in the lumber industry. The questionnaire includes a list of upper and lower respiratory, eye, mucous membrane, and systemic symptoms (including some not expected to be influenced by the exposures present). The participants were asked to identify if the symptom was present in the past 8 hours (pre-exposure questionnaire) or during the exposure period (post-exposure questionnaire), and if so, to choose from statements regarding severity.

Sample questionnaires are included in Appendix C.

8.1.4 Physiologic testing

Physiologic testing of pulmonary function was carried out by a trained technician, before and after the exposure monitoring period, using a volume sensitive dry rolling seal spirometer (Pulmonary Data Services Inc., Louisville CO), following American Thoracic Society standard procedures.[3] Subjects were seated and wearing nose-clips. A minimum of 3 acceptable forced vital capacity manoeuvres were obtained on each occasion.

To allow us to control for the atopic (or 'allergic') status of the study subjects, allergy skin testing was conducted using three common environmental antigens (mixed Pacific grasses, cat epidermal antigen, house dust mite antigen) and negative (normal saline) controls. Atopy was defined as having one or more positive tests. A test was positive if the mean wheal diameter was 3 mm or more greater than that of the negative control. A total of 19 participants did not have allergy skin testing completed. For these participants, atopic status was inferred from their responses to questions regarding hayfever. Seven persons with current hayfever were categorized as atopic, the other 12 were categorized as non-atopic.

8.1.5 Comparison data

Comparison data for general health characteristics, general (or ongoing) respiratory symptoms, and pre-shift pulmonary function were obtained from another study carried out by our research team. The comparison population was a sample of 'on-ship' employees of the BC Ferry Corporation, including deck crew, kitchen staff, and stewards. This group was studied by us in 1999 using a similar 'general health' questionnaire and the same pulmonary function testing equipment. The BC Ferries survey was carried out in response to employee concern about past exposure to asbestos on ships. The study found that only a subset of BC Ferry Corporation employees had been affected by past asbestos exposure (those in maintenance and engine room crew). The maintenance and engine room employees were excluded from the comparison group identified for the current project. Although not exposed to asbestos, employees in the BC Ferries 'control' subgroup used for this project may have been exposed to respiratory irritants in the course of their work (e.g., vehicle exhaust, kitchen smoke, cleaning and disinfecting chemicals). Thus, the BC Ferry subgroup provides comparison data about 'expected' symptom rates and respiratory function among a group of actively employed BC residents who are concerned about workplace hazards, and may be exposed to non-specific respiratory irritants at work.

Because the unexposed BC Ferry comparison population was considerably older, on average, than the theatrical population studied here, an age-matched sub-sample of the BC Ferry group was selected. The age matching was not completely successful; therefore, it was necessary to control for (or consider) age differences in all comparisons of the BC Ferry and entertainment industry groups.

8.1.6 Data management and analysis, definitions

Questionnaires were coded and data entered into computer files by double entry keypunching. Coding and computer files were checked for accuracy and consistency prior to analysis.

Health outcomes investigated: symptoms

The health outcomes analyzed included acute symptoms (i.e., symptoms appearing or worsening on the sampling day), general ongoing symptoms, and physiologic tests of lung function.

An acute symptom was defined as being present if it was reported on the post-shift questionnaire, but not reported on the pre-shift questionnaire; *or* it was reported as increased post-shift compared to the pre-shift questionnaire. These symptoms included irritated eyes, red eyes, watery eyes, itchy eyes, runny/stuffy nose, nose bleeding, congestion, sneezing, sinus problems, sore throat, irritated throat, dry throat, dry cough, cough with phlegm, chest tightness, wheezing, breathlessness, nausea, stomach aches, drowsiness, dizziness, headache, tiredness, fever, skin irritation, voice problems, joint pains, or any other symptoms (in this case, subject was asked to specify). These individual symptoms were subsequently grouped into categories according to their effects on specific body systems as described in Tables 8.1 and 8.2.

Table 8.1 Acute symptom variables

Variable Name	*Explanation of variable*
	new appearance or worsening of the following *during the testing period*:
Upper airway / voice symptoms	2 or more of: runny stuffy nose, nosebleeding, congestion, sneezing, sinus problems, sore throat, irritated throat, dry throat, voice problems
Cough	either dry cough or cough with phlegm or both
Dryness symptoms	dry cough and/or dry throat
Chest symptoms	any of: chest tightness, wheezing, breathlessness
Systemic symptoms	any of: nausea, stomach ache, drowsiness, dizziness, headache, tiredness
Eye symptoms	any of: irritated eyes, red eyes, watery eyes, itchy eyes

Table 8.2 General, ongoing symptom variables

Variable Name	*Explanation of variable*
Cough	Subject reported yes to any of the following questions: Do you usually have a cough?/Do you usually cough at all on getting up or first thing in the morning?/Do you usually cough at all during the rest of the day or night?
Phlegm	Subject reported yes to any of the following: Do you usually bring up phlegm from your chest (exclude phlegm with first smoke or fist going out of doors. Count swallowed phlegm. Exclude phlegm from the nose)?/Do you usually bring up phlegm at all on getting up or first thing in the morning/Do you usually bring up phlegm at all during the rest of the day or night.
Wheeze	Subject reported: chest sounding wheezy or whistling occasionally apart from colds or most days and nights
Chest tightness	Subject reported: episodes of chest tightness associated in difficulty in breathing
Breathlessness	Subject reported: being troubled by shortness of breath when hurrying on the level or walking up a slight hill
Eye symptoms	Subject reported: usually having burning, itching, watering eyes
Nasal symptoms	Subject reported: sneezing or an itchy runny nose when they did not have a cold, and/or usually having a stuffy or blocked nose
Voice symptoms	Subject reported: usually having problems with voice (not asked of controls)
Skin rash	Subject reported: often having skin rashes (not asked of controls)
Current asthma symptoms	Subject responded 'yes' to 3 or more of the following in the past 12 months: wheezing or whistling in the chest without having a cold, woken by chest tightness, woken by attach of coughing, woken by attach of shortness of breath, attack of shortness of breath when not doing anything strenuous, attack of shortness of breath coming on after stopping exercise.
Work-related symptoms (cough, phlegm, wheezing, chest tightness, nasal symptoms, eye symptoms, voice symptoms, skin rash)	Each of these symptoms were identified as being 'work-related' if the symptom was reported as being present AND: there was improvement on days off AND/OR long holidays AND/OR the symptom was triggered or worsened by work-related situations or environments. However, if the symptoms started before the age of 16 it was not considered to be work-related.

Pulmonary function outcomes investigated

Table 8.3 outlines the tests of pulmonary function that were considered.

Table 8.3 Definitions: pulmonary function tests

Test name	*Abbreviation*	*Interpretation*
Forced expired volume in 1 second	FEV_1	This test measures air flow rates; if reduced it is an indication of airflow obstruction in large (or central) airways.
Forced vital capacity	FVC	This test measures lung capacity. It is reduced by exposure to agents that cause lung scarring. It can also be reduced in asthma due to air trapping during forced expiration.

Baseline (or 'pre-exposure') lung function status was determined using the 'pre-shift' pulmonary function testing. Following standard procedures, the maximum values for FVC and FEV_1 were used. For some analyses, results are expressed as a percentage of predicted values (based on age, height, gender, and race) for healthy non-smokers[6].

Acute changes in pulmonary function were considered by examining the percentage change in $FEV_1$and FVC, over the 'shift', calculated as:

100 *x* (post-shift value – pre-shift value) / pre-shift value

We also examined the proportion of persons having a 4% or greater decline in either FEV_1 or FVC as an indicator of the prevalence of 'clinically relevant' cross-shift decline in lung function. Although it is more typical to consider a 5% decline in FEV_1 or FVC as being 'clinically relevant', the use of a 4% cut-off has been used in other occupational studies where the study population size was small[4,5].

Non-work risk factors considered

In all analyses to investigate the potential health effects of exposures to the fog aerosols, the following demographic and other 'non-work' exposure factors were taken into consideration: age, gender, race, history of childhood asthma, atopy (i.e., positive skin prick test to at least one common environmental antigen), cigarette smoking status (never smoked, former smoker, current smoker), and cumulative amount smoked (cigarette packs/day *x* years smoked, separately for former and current smokers), and for internal analyses only, marijuana smoking status.

In addition, for analyses of acute outcomes, indicator variables to identify whether or not the participant smoked cigarette(s) in the hour prior to the 'pre' and 'post' test, and an indicator variable to identify work shifts commencing in the afternoon were also included.

Work-related risk factors considered

Work-related factors examined in analyses of acute (sampling day) outcomes (i.e., acute symptoms and cross-shift changes in FEV_1 and FVC) are listed in Table 8.4; those examined for analyses of general, ongoing outcomes (i.e., chronic symptoms and baseline FEV_1 and FVC) are shown in Table 8.5.

Table 8.4 Exposure variables used in analyses of acute health outcomes

Variable Name	*Explanation of variable*
Personal exposure (mg/m^3)	Personal 7-hole inhalable Teflon concentration (mg/m^3) on sampling day
Personal exposure (categorized)	Personal exposure as above, categorized as: <0.2/0.2–0.4 /0.4–0.7/> 0.7 mg/m^3
Alveolar fraction (mg/m^3)	Aerosol concentration < 3.5 (% in this fraction in area samples X personal concentration, in mg/m^3)
Tracheo-bronchal fraction (mg/m^3)	Aerosol concentration, 3.5-10 , (% in this fraction in area samples X personal concentration, in mg/m^3)
Nasopharyngeal fraction (mg/m^3)	Aerosol concentration ≥ 10 , (% in this fraction in area samples X personal concentration, in mg/m^3)
Observed time exposed to fog	Technician-reported minutes that subject spent in fog
Reported time exposed to fog	Self-reported minutes that subject spent in fog
Glycol	Glycol fog fluid used on sampling day
Mineral oil	Mineral oil fog fluid used on sampling day
Acrolein	Acrolein detected on sampling day in area samples 1 = acrolein detected 0 = < LOD for acrolein
Formaldehyde	Formaldehyde levels in area samples (mg/m^3)
Atmospheric fog	Type of effect being created on the sampling day was atmospheric (*v.* specific source) (note: highly correlated with mineral oil use, therefore both variables were not put in models together)
Makeup	Job title: hair/makeup/prosthetics department
Special effects	Job title: special effects department
Costume	Job title: costumes department
Grip	Job title: grip
Type of production	TV or film / live theatre / concert / arcade

Table 8.5 Exposure variables used in analysis of general, ongoing, health outcomes

Variable Name	*Explanation of variable*
Factors associated with the current production:	
% of days exposed to fog, current production	Reported percentage of days exposed to fog, for the current job
Average h/day exposed to fog, current production	Reported average hours/day exposed to fog, current job
Usual location on set, current production	1. working 10 ft or less from fog machine 2. working inside studio/stage within 20 ft of production set but not within 10ft of fog machine 3. working inside studio/stage, but more than 20 ft from production set; or working outside production set
Location, current production	1. mostly indoors 2. mostly outdoors 3. both, about the same
Days/week worked	Days/week worked on average in current production
Hours/day worked	Hours/day worked on average in current production
Makeup	Job title, current production: hair/makeup department (note: correlated with cumulative exposure)
Special effects technician	Job title, current production: special effects department (note: correlated with cumulative exposure)
Costume	Job title, current production: costumes department
Grip	Job title, current production: grip
Factors calculated from all jobs over the past 2 years:	
Days worked, past 2 years	Reported total number of days worked in the industry over the past 2 years
Exposure duration over past 2 years (in hrs*1000)	Sum (over all jobs in the past 2 years) of: Total # days worked *x* % of days exposed to fog *x* average hours/day exposed to fog on the fog days)/1000
Cumulative exposure over past 2 years (in mg/m^3 *hrs*1000)	Sum (over all jobs in the past 2 years) of: [(Total # days worked *x* % of days exposed to fog *x* average hours/day exposed to fog on the fog days) *x* weighting factor[1]]/1000 [1] the weighting factor for exposure concentration was related to usual location on set and was based on the results from exposure modeling; the following values were used: 1.5: working 10 ft or less from the fog machine 0.4: working inside studio/stage within 20 ft of production set but not within 10 ft of fog machine 0.08: working inside studio/stage but more than 20 ft from the production set or working outside the production set
Cumulative exposure over past 2 years (in 4 categories)	Cumulative exposure, as described above, categorized as follows: 1. < 20 mg-hrs/m^3 2. 20-200 mg-hrs/m^3 3. 200-800 mg-hrs/m^3 4. > 800 mg-hrs/m^3

Data analyses

All analyses were performed using SAS V8.01 statistical analysis software (SAS Institute Inc, Cary NC).

Demographic characteristics and prevalence rates for chronic and 'work-related' symptoms and mean values for lung function parameters were compared to those from the external comparison population. No external comparison data were available for acute symptoms or cross-shift changes in pulmonary function.

To examine whether work and other factors were associated with the various health outcomes, regression analyses were carried out. Non-work risk factors were fit to all models first, after which work-related risk factors were offered to the models, first one by one, followed by multivariable modeling. Generalized linear models were used for continuous outcomes (lung function values, acute change in lung function) and logistic regression models for dichotomous outcomes (symptoms, prevalence of 4% cross-shift drop in lung function). Prior to modeling, correlations among all potential risk factors were examined. Where predictor variables were highly correlated, choices were made as to which one to include in the model, based on *a priori* expectations.

8.2 Results

8.2.1 Participation

Participation rates for the health effects component of the study are shown below (Table 8.6). Although the same 111 persons (77%) who wore air sampling equipment also participated in some aspects of the health testing, complete health test results were available for only 101 persons.

Table 8.6 Participation of entertainment industry subjects in the health study

Subjects	*n (%)*
Total eligible	144[1] (100)
Participated in personal monitoring, acute questionnaire, lung function	111 (77.1)
Participated in all aspects of study, including above *plus* skin prick tests and chronic questionnaire	101 (70.1)

[1]Including known refusals

8.2.2 Characteristics of participants – demographics and baseline health

Demographic characteristics of the study group and the external comparison group are shown in Table 8.7. Although we attempted to obtain a comparison population of approximately similar age, the results show that the comparison population was about 6 years older on average. The proportion of smokers was not significantly different between groups, but as expected due to the age difference, the smokers in the comparison group had smoked more than in the study group. These differences were taken into account when comparing respiratory symptoms and function between these groups. A total of 38% of the participants from the entertainment industry reported themselves to be occasional or frequent marijuana smokers. This was related to cigarette smoking (with 53% of current cigarette smokers also smoking marijuana and only

27% of non-smokers of cigarettes reporting marijuana smoking). Similar information was not available for the external comparison group. The groups did not differ with respect to history of childhood or current asthma, atopic status (having a positive skin test to common environmental antigens), or history of heart disease.

Table 8.7 Demographic and baseline health characteristics of entertainment industry health study subjects and BC Ferries comparison group

	Entertainment Industry Group	*BC Ferries Control Group*	*p**
n	101	70	
Age [mean (sd)	33.5 (10.2)	39.8 (8.7)	<0.0001
range	18.5 – 56.1	22.4 - 55.9	
Height (inches) [mean (sd)	68.3 (3.5)	67.0 (3.9)	0.03
range]	61.0 – 76.0	59.1 - 76.0	
Weight (lbs) [mean (sd)	168.3 (35.5)	180.7 (42.9)	0.04
range]	110.0 - 270.0	121.3 - 396.8	
Female, n (%)	33 (32.7%)	28 (40.0%)	0.3
Nonwhite, n (%)	9 (8.9%)	7 (10.0%)	0.8
History of childhood asthma, n (%)	12 (11.9%)	5 (7.1%)	0.3
Current asthma diagnosis, n (%)	9 (8.9%)	5 (7.1%)	0.7
Atopic (+ skin test)	46 (45.5%)	28 (40.0%)	0.5
Heart disease (treated in past 10 yrs)	1 (1.0%)	0 (0%)	0.4
Smoking status			
Non-smokers, n (%)	45 (44.6%)	26 (37.1%)	
Ex-smokers, n (%)	24 (23.8%)	21 (30.0%)	0.6
Current smokers, n (%)	32 (31.7%)	23 (32.9%)	
Smoking amount (Packs/day x yrs smoked)			
Current & Ex-smokers [mean (sd)	10.6 (11.6)	15.2 (12.0)	0.06
range]	0.1 - 54.0	0.5 - 44.0	
Current Smokers [mean (sd)	11.0 (10.9)	18.2 (10.7)	0.02
range]	0.6 - 43.9	0.7 - 39.5	
Ex-Smokers [mean (sd)	10.0 (12.7)	11.9 (12.8)	0.6
range]	0.1 - 54.0	0.5 - 44.0	

* p: comparing entertainment industry and control groups, from chi-square analysis (categorical variables) or ANOVA (continous variables)

8.2.3 Characteristics of participants: job and exposure features

Job characteristics of the participants in the health study are shown in Table 8.8. These results are almost identical to those shown in chapter 7 above, but as there were slightly fewer participants in the full health study than in the exposure study, the results are repeated here for clarity. Job titles differ slightly as here participants were asked for their *usual* job title. The most common job titles included were production assistants, video arcade employees, and makeup/hair/prosthetics technicians.

Table 8.8 Job titles of 101 entertainment industry subjects who participated in the health study

Job title	*n*
Production assistant	13
Video arcade playmaster	10
Makeup/hair/prosthetics technician	9
Special effects technician	8
Stagehand	8
Sound technician	7
Production manager	6
Grip	6
Lighting technician	6
Costumes technician	5
Assistant director	4
Trap crew	4
Stand-in	3
Props technician	3
Cameraperson	3
Set decorator	2
Computer/video technician	2
Musician	1
Electronics technician (arcade)	1

Most of the participants worked on indoor sets and locations and participants were about evenly split according to their reported proximity to the fog machines (Table 8.9). About 1/3 of participants reported working within 10 feet of the machine on a regular basis. This is somewhat higher than the proportion of subjects observed working this close to the fog machine on the study day (see details in chapter 7).

Characteristics of the study testing protocols that may be relevant to interpretation of the results are shown in Table 8.10. Although study testing start times ranged from 7 am to 10 pm, the majority of testing was performed in the afternoon and evening, with the exception of TV/movie sites, where the majority of testing started in the morning. This variability in study start times can have an influence on changes in lung function over the testing period due to normal circadian (or daily) rhythms in lung function. Typically, lung function values are lowest early in the morning and tend to peak at approximately noon.[6] The variability in testing times was taken into account when interpreting the acute ‘cross-shift’ lung function results.

Table 8.9 Typical work location (reported, current production) of 101 entertainment industry subjects who participated in the health study

Location	*n*
Mostly Indoors	80
Mostly Outdoors	2
Both, about the same	19
Working 10 ft or less from fog machine	36
Working inside studio/stage within 20 ft but not within 10 ft of fog machine	31
Working inside studio/stage but more than 20 ft from production set	31
Outside production set	3

Table 8.10 Study protocol data relevant to test interpretation, stratified by type of production.

	All Productions *Mean (sd)* *range*	*TV/Movie* *Mean (sd)* *range*	*Theatre* *Mean (sd)* *range*	*Concert* *Mean (sd)* *range*	*Arcade* *Mean (sd)* *range*	*p*
n	101	53	26	11	11	
'Pre-shift' testing time (24h clock), mean (sd), range	13.7 (4.4) 7 – 22 h	10.4 (2.4) 7 – 17 h	17.3 (3.8) 9 – 20 h	15.5 (2.8) 12 – 22 h	19.3 (0.5) 19 – 20 h	<0.001
'Post-shift' testing time (24h clock), mean (sd), range	17.9 (4.1) 10 – 25 h[1]	14.9 (2.3) 10 – 21 h	20.4 (3.1) 14 – 23 h	20.9 (3.2) 17 – 25 h	23.2 (0.4) 23 – 24 h	<0.001
Total testing duration (hrs), mean (sd) range	4.2 (1.5) 1.4 – 13.0	4.6 (1.6) 2.6 – 13.0	3.2 (1.0) 1.4 – 5.6	5.1 (1.6) 2.6 – 7.6	4.1 (0.3) 3.5 – 4.4	<0.001
Duration of fog exposure before pre-shift testing (minutes), mean (sd) range	2.7 (8.5) 0 - 45	4.3 (10.8) 0 – 45	1.2 (5.9) 0 - 30	0.5 (1.5) 0 - 5	0.5 (1.5) 0 - 5	0.2

[1] 25 h refers to 1 am

Work week and exposure characteristics of the participants, stratified according to the type of production are shown in Tables 8.11 and 8.12 below. Employees in the different types of production differed with respect to the number of days worked in the past 2 years, days worked per week, and hours worked per day. Also note that employees from the video arcade were considerably younger than the other participants.

Participants from the TV and movie production sectors reported significantly more hours per day and more days in the past 2 years exposed to theatrical fogs than in the other sectors. Estimates of cumulative exposure, based on these durations and on exposure intensity values derived from the exposure modeling described in chapter 7, showed that TV/movie sector employees had cumulative exposures 7 to 13 times higher than employees in live theatre, music concerts or the video arcade.

There was no significant relationship between the type of production and either cigarette smoking or marijuana smoking (data not shown).

Table 8.11 Work week and exposure characteristics of 101 entertainment industry subjects, in current production, stratified by type of production (results for all productions in bold)

	All Productions Mean (sd) range	*TV/Movie Mean (sd) range*	*Theatre Mean (sd) range*	*Concert Mean (sd) range*	*Arcade Mean (sd) range*	*p*
n	**101**	53	26	11	11	
Age (years)	**36.1 (10.1)** **18.5 – 56.1**	34.3 (8.4) 20 –54.5	35.0 (12.5) 18.5 -56.1	38.0 (8.1) 24 – 54.2	22.1 (6.1) 19.1 – 40.3	<0.01
Total number of days worked in past 2 years	**318 (185)** **8 – 730**	357 (164) 8 - 700	271 (231) 14 - 730	355 (105) 160 – 500	208 (170) 51 – 550	<0.05
Total number of days worked on current production	**49.5 (96.1)** **1 - 600**	34.9 (28.7) 1 - 100	23.9 (14.6) 3 - 60	37.3 (120.3) 1 - 400	not applicable	0.5
Days worked/week, current production / job	**4.4 (1.6)** **1 - 7**	4.3 (1.2) 1 – 5	5.8 (0.9) 4 - 7	1.5 (1.5) 1 - 6	4.3 (1.3) 2 – 6	<.0001
Hours/day, current production / job	**10.4 (3.9)** **4 - 18**	13.0 (2.2) 6 – 18	5.5 (1.8) 4 - 10	12.5 (3.0) 8 - 18	7.5 (0.7) 6 - 8	<.0001

The increased exposure among participants in the TV and movie sector was also evident from the exposure monitoring as shown in Table 8.13, as this sector had significantly higher exposure levels on the sampling days. In contrast, the duration of exposure to theatrical fogs (expressed as the percentage of the testing period during which the person was observed in visible fog) on the sampling day was highest among the video arcade employees.

When participants were stratified according to categories of increasing cumulative exposure to fogs, additional patterns emerged (Table 8.14). As predicted from the results shown above, the TV/movie sector had the highest cumulative exposure with 100% of the participants categorized in the highest exposure group. Special effects technicians and makeup/hair/prosthetics technicians were also more likely to be in the highest exposure category. Most live theatre personnel were in the lowest cumulative exposure category. Use of mineral oil for fog production was also linked to the higher exposure categories. Testing times also differed, with those in the higher exposure categories tending to be tested earlier in the day and for somewhat longer testing durations. This is consistent with the observation noted earlier that TV/movie sites were the only ones where it was possible to begin testing in the mornings.

There was no significant relationship between cumulative exposure and either cigarette smoking or marijuana smoking (data not shown).

Table 8.12 Estimated duration and cumulative exposure to theatrical fog by type of production (results for all productions in bold)

	All Productions Mean (sd) range	*TV/Movie Mean (sd) range*	*Theatre Mean (sd) range*	*Concert Mean (sd) range*	*Arcade Mean (sd) range*	*p*
n	**101**	53	26	11	11	
% of days exposed to fog, current production / job	**71.1 (40.0)** **0 – 100**	66.4 (30.2) 0 – 100	74.8 (35.2) 0 - 100	90.1 (20.2) 50 - 100	65.5 (27.0) 5 - 100	0.09
Hours/day exposed to fog, current production / job	**5.6 (4.1)** **1 – 15**	8.2 (3.8) 0 – 15	1.6 (2.1) 0 - 10	3.8 (1.2) 1 - 5	4.3 (1.5) 2 – 8	<.0001
Days exposed to fog in past 2 years	**153.7 (150.3)** **0 – 600**	184.9 (127.4) 4 – 600	83.6 (103.7) 0 - 400	170.4 (114.2) 20 – 350	152.8 (162.8) 10 – 550	<0.05
Hours exposed to fogs over the past 2 years (calculated from each job)	**973 (1204)** **0 – 6480**	1531 (1392) 21 – 6480	159 (217) 0 - 612	688 (612) 63 – 2040	497 (471) 60 - 1650	<.0001
Cumulative exposure to fogs over the past 2 years (mg/m3 – hrs)	**686 (1245)** **0 – 6075**	1202 (1543) 7 - 6075	88 (174) 0 - 636	179 (175) 9 - 480	119 (188) 5 – 660	<0.0001

Table 8.13 Measured and observed exposures to fogs of 101 entertainment industry subjects, stratified by type of production (results for all productions in bold)

	All Productions Mean (sd) range	*TV/Movie Mean (sd) range*	*Theatre Mean (sd) range*	*Concert Mean (sd) range*	*Arcade Mean (sd) range*	*p*
n	**101**	53	26	11	11	
Inhalable aerosol concentration on sampling day (mg/m^3), mean (sd), range	**0.73 (0.96)** **0.02 - 4.11**	1.04 (1.17) 0.06 - 4.11	0.44 (0.60) 0.02 - 3.22	0.35 (0.23) 0.11 - 0.84	0.34 (0.13) 0.10 - 0.50	0.007
% of testing period in visible fog on sampling day (observed), mean (sd), range	**33.9 (27.6)** **0 – 96.9**	36.9 (29.7) 0 – 96.9	15.2 (19.7) 0 – 71.6	39.4 (11.7) 23.1 -65.3	58.0 (17.4) 30.4 – 88.1	<.0001

Table 8.14 Work week, exposure, and testing characteristics of entertainment industry subjects, stratified by cumulative exposure category

	Total	*Cumulative Exposure Category*				*p*
		< 20 hrs-mg/m³	*20 – 200 hrs-mgs/m³*	*200 – 800 hrs-mg/m³*	*> 800 hrs-mg/m³*	
n	101	23	29	28	21	
Age	33.5 (10.2)	31.6 (12.8)	31.4 (9.0)	35.0 (9.5)	36.7 (8.9)	0.2
Special effects technician, n (%)	8 (7.9%)	1 (4.3%)	0	2 (7.1%)	5 (23.8)	<0.01
Makeup/hair/prosthetics technicians, n (%)	9 (8.9%)	1 (4.3%)	0	3 (10.7%)	5 (23.8%)	<0.05
Production type, n (%)						
TV/movie	53 (52.5%)	2 (8.7%)	11 (37.9%)	19 (67.9%)	21 (100%)	
Live theatre	26 (25.7%)	15 (65.2%)	7 (24.1%)	4 (14.3%)		<.0001
Concerts	11 (10.9%)	2 (8.7%)	5 (17.2%)	4 (14.3%)		
Arcade	11 (10.9%)	4 (17.4%)	6 (20.7%)	1 (3.6%)		
Fog type used, n (%)						
Glycol	45 (44.5%)	13 (56.5%)	15 (51.7%)	11 (39.3%)	6 (28.6%)	
Mineral oil	48 (47.5%)	8 (34.8%)	10 (34.5%)	15 (53.6%)	15 (71.4%)	0.09
Both	5 (5.0%)	0	3 (10.3%)	2 (7.1%)	0	
Other	3 (3.0%)	2 (8.7%)	1 (3.4%)	0	0	
'Pre-shift' testing start time, mean (sd)	13.7 (4.4)	17.3 (3.8)	14.3 (4.8)	12.5 (3.8)	10.4 (2.2)	<0.001
Testing duration in hours, mean (sd)	4.2 (1.5)	3.3 (0.9)	4.3 (1.3)	4.3 (1.2)	5.0 (2.1)	<0.01

8.2.4 Respiratory health outcomes: compared to the external control group

Tables 8.15 and 8.16 show the baseline health characteristics of the entertainment industry group compared to the external control group. The entertainment industry group had increased prevalence of all the respiratory symptoms measured (including nasal symptoms, cough, phlegm, wheezing, chest tightness, shortness of breath on exertion, and current asthma symptoms) and reduced average levels for FEV_1 and FVC (both measures of pulmonary function) and an increased number of persons with FEV_1 or FVC in the abnormal range (<80% of the predicted value). These differences were statistically significant ($p<0.05$) for nasal symptoms, shortness of breath, current asthma symptoms (in the past 12 months), and for average values of FEV_1 and FVC (taking into account the small differences in age and smoking habit between the two groups). Almost 10% of employees in the entertainment industry reported often having voice problems on a 'usual' basis and 20% having frequent skin rashes. No comparison data were available for these specific symptoms to determine whether these rates are elevated over ‘expected’, however, there was no increase in the prevalence of eczema (a scaly, dry skin rash) or eye irritation.

Table 8.15 Respiratory symptoms among entertainment industry participants and BC Ferries control group

	Entertainment Industry Group n (%)	*Control Group* n (%)	p*
Cough	19 (18.8%)	7 (10.0%)	0.1
Phlegm	27 (26.7%)	14 (20.0%)	0.2
Wheezing	31 (30.7%)	17 (24.3%)	0.1
Chest tightness with breathlessness	19 (18.8%)	9 (12.3%)	0.3
Shortness of breath walking up hill	26 (25.7%)	10 (14.3%)	0.04
Current asthma symptoms	17 (16.8%)	5 (7.1%)	0.03
Eye irritation symptoms	13 (12.9%)	12 (17.6%)	0.3
Nasal symptoms	69 (68.3%)	33 (47.1%)	< 0.01
Voice symptoms	11 (10.9%)	n/a	
Skin rashes	20 (19.8%)	n/a	
Adult onset eczema	9 (8.9%)	7 (10.0%)	0.6

* p: comparing entertainment industry and control groups, after controlling for differences in age and smoking status and amount (using logistic regression)

Table 8.16 Baseline lung function of entertainment industry health study subjects and BC Ferries control group

	Entertainment Industry Group mean (sd) range	*Control Group* mean (sd) range	p[1]
FEV_1 (% of predicted)	96.9 (11.4) 67.2 - 127.2	99.8 (15.4) 35.4 - 139.8	<0.05
FVC (% of predicted)	101.9 (10.5) 80.0 - 131.4	105.5 (12.4) 80.4 - 140.9	0.05
low FEV_1 , n (%) (< 80% predicted)	7 (7.0%)	4 (5.7%)[2]	0.4
low FVC , n (%) (< 80% predicted)	2 (2.0%)	0	0.2

1 p: controlling for differences in age, smoking status and amount (using generalized linear modeling, and logistic regression modeling)
2 Two of these persons had a history of childhood asthma, whereas none of the entertainment industry group with low FEV1 had a history of childhood asthma.

These results suggest that when compared to a control group of BC workers exposed to other ‘non-specific’ respiratory irritants at work, the entertainment industry employees are at risk for upper and lower airway irritation and airflow obstruction, measured both subjectively (i.e., symptoms) and objectively (pulmonary function tests).

8.2.5 Ongoing symptoms and lung function: relationship to work factors

Respiratory and other symptoms

As described in the methods section, we evaluated 'work-relatedness' of symptoms by enquiring about factors that aggravate symptoms and about symptom timing in relation to employment. When compared to the external control group, participants from the theatrical industry reported increased rates of work-related phlegm, wheezing, chest tightness, and nasal symptoms (statistically significant, $p < 0.05$, only for chest tightness)(Table 8.17). The rate of work-related cough was lower in the entertainment industry group as a whole, compared to the control group. Work-related voice and skin problems were not assessed in the control group. As shown here, the prevalence of voice symptoms that had a specific work-related pattern was relatively low in the entertainment industry group (2%).

Table 8.17 Comparison of prevalences of work-related symptoms in entertainment industry group vs. BC Ferries control group

	Entertainment Industry Group n (%)	*Control Group n (%)*	*Odds ratio (95% CI)**	*p**
Work-related cough	6 (6.0%)	7 (10.0%)	0.5 (0.2, 1.6)	0.3
Work-related phlegm	7 (7.0%)	4 (5.7%)	1.9 (0.5, 6.0)	0.7
Work-related wheezing	8 (7.9%)	3 (4.3%)	2.9 (0.7, 11.5)	0.3
Work-related chest tightness	11(10.9%)	1 (1.4%)	15.3 (1.8, 127)	0.02
Work-related eye symptoms	3 (3.0%)	1 (1.4%)	2.8 (0.3, 28)	0.5
Work-related nasal symptoms	58 (57.4%)	30 (42.9%)	1.8 (0.9, 3.5)	0.06
Work-related voice symptoms	2 (2.0%)	n/a [2]		
Work-related skin problems	5 (5.0%)	n/a [2]		

* odds ratios and 95% confidence intervals, p-values: after adjusting for differences in age, smoking status and amount, and atopic status
[1] Skin symptoms analysis adjusted for age and atopic status only
[2] These symptoms were not assessed in the control group

Table 8.18 shows these same symptoms, with the entertainment industry group categorized according to increasing levels of cumulative exposure to theatrical fogs in the 2 years prior to study. Evaluation of the exposure-response trends (i.e., evaluating if rates increase as cumulative exposure increases) showed that both work-related wheezing and chest tightness were significantly related to increasing cumulative exposure ($p<0.05$). Eye symptoms are not included in this table as the numbers of persons reporting this symptom was too small to evaluate by exposure category.

Further evaluation of these symptoms *within the entertainment industry group only* is shown in Table 8.19. Here the symptom prevalence rates were evaluated taking into account other factors that contribute to these symptoms (age, smoking status and amount smoked, atopic status) as well as cumulative exposure to theatrical fogs (for each 1000 mg-hours/m^3) and type of fog being produced on the set. The results from this analysis are shown as 'odds ratios'. Odds ratios are approximately equal to 'relative risks'. An odds ratio equal to 1 indicates no difference in the risk of having the symptom, given exposure; an odds ratio of 2 indicates an approximate doubling of the risk for the symptom, given the exposure; an odds ratio of 0.5 indicates approximately half the risk for the symptom, given the specified exposure. When the 95% confidence interval for the odds ratio *excludes* the value '1', the 'p-value' for the comparison is <0.05 and the result is statistically significant.

This analysis shows that when smoking, age, and atopic status are taken into account, there remained statistically significant exposure-response relationships between cumulative exposure to fogs and work-related cough and phlegm. The odds ratios for cumulative exposure

Table 8.18 Prevalence of work-related symptoms in entertainment industry group according to category of estimated cumulative exposure in the previous 2 years (results for symptoms related to exposure in bold)

	Control Group	*Entertainment Industry Group Estimated cumulative exposure category*			
		< 20 hrs-mg/m³	*20 – 200 hrs-mgs/m³*	*200 – 800 hrs-mg/m³*	*> 800 hrs-mg/m³*
n	70	23	29	28	21
Work-related cough	10.0%	4.4%	3.4%	3.7%	14.3%
Work-related phlegm	5.7%	0%	3.4%	10.7%	14.3%
Work-related wheezing*	**4.3%**	**0%**	**6.9%**	**10.7%**	**14.3%**
Work-related chest tightness*	**1.4%**	**4.4%**	**10.3%**	**14.3%**	**14.3%**
Work-related nasal symptoms	42.9%	65.2%	51.7%	57.1%	57.1%
Adult onset eczema	10.0%	4.4%	6.9%	7.1%	19.0%
Current asthma symptoms	7.1%	17.4%	10.3%	21.4%	19.0%

* **BOLD** indicates p-value evaluating the trend for rates to increase across groups (chi-square test for trend) < 0.05

shown in Table 8.19 indicate the increased risk for having the symptom associated with an increase in cumulative exposure of 1000 mg-hrs/m^3.

In addition to an association between symptoms and cumulative exposure, there is also an indication that the type of chemical being used to produce fog is important. Glycol use in the current production was associated with increased work-related cough (Odds Ratio: 4.6, 95% CI: 0.5, 39), increased work-related phlegm production (Odds Ratio: 3.5, 95% CI: 0.4, 32), and increased work-related chest tightness (Odds Ratio: 2.5, 95% CI: 0.6, 10.7). The job titles costume and/or makeup (combined) were associated with increased adult onset eczema (Odds Ratio 4.8 95% CI: 0.8, 27). None of these associations were statistically significant at the p<0.05 level. This is not unexpected given the small size of the study. Further study will be needed to determine if these findings are due to chance; however, the finding that glycol exposure was linked to 3 of 5 work-related symptoms suggests strongly that glycol exposure may be an important contributor to the symptoms identified.

These results did not differ when marijuana smoking was included in the analysis in addition to cigarette smoking.

Table 8.19 Multiple regression analyses of demographic and work-related factors related to work-related respiratory symptoms. (internal analyses, within the entertainment industry subjects only, n=101) (results for symptoms related to work factors in bold)

	Work-Related Cough Odds Ratio LCL - UCL	*Work-Related Phlegm Odds Ratio LCL - UCL*	*Work-Related Wheezing Odds Ratio LCL – UCL*	*Work-Related Chest Tightness Odds Ratio LCL – UCL*	*Work-Related Nasal Symptoms Odds Ratio LCL - UCL*
Personal factors					
Age	0.9 0.8 – 1.0	1.1 1.0 – 1.2	1.0 0.9 - 1.1	1.1 1.0 - 1.2	1.03 1.0 – 1.1
Current smoking amount (packs/d *x* yrs smoked)	1.1 0.9 – 1.2	1.05 1.0 – 1.2	1.0 0.9 - 1.1	1.0 0.9 - 1.1	1.0 0.9 – 1.03
Ex Smoking amount (packs/d *x* yrs smoked)	0.8 0.4 – 1.6	0.5 0.1 – 4.0	1.05 1.0 - 1.12	1.03 1.0 – 1.1	1.0 0.9 – 1.07
Atopic Status	1.0 0.1 – 8.5	21.8 1.5 – 138	1.4 0.3 – 6.8	1.3 0.2 – 5.2	2.3 1.0 – 5.5
Work factors					
Cumulative exposure to fog over 2 years (1000 mg-hrs/m^3)	**2.0*** **1.2 – 3.4**	**2.4*** **1.2 – 4.7**	1.4 0.9 – 2.1	1.3 0.8 – 2.1	0.8 0.6 - 1.2
Glycol fog used in current production	4.6 0.5 - 40	3.5 0.4 - 32	1.0 0.2 – 5.2	2.5 0.6 – 10.6	1.1 0.5 – 2.5

* **BOLD** indicates work factors with p-value <0.05

Physiologic measures of pulmonary function

Results of analyses of lung function measures in relation to exposure factors, within the entertainment industry group, are shown in Tables 8.20 and 8.21. Table 8.20 shows adjusted mean values for the two measures of pulmonary function, expressed as percent of predicted values. There is a significant linear trend of decreasing FVC across increasing categories of cumulative exposure to fogs. The lowest exposure category in the entertainment industry study group had intermediate levels of lung function (both FVC and FEV_1), being lower than the control group and higher than the remainder of the entertainment industry groups. For FVC, values tended to be similar (and lowest) across the three highest cumulative exposure groups in the entertainment industry. For FEV_1, values were lowest in the 2 middle exposure groups and then somewhat higher in the highest exposure group. This finding *may* be a reflection of the commonly encountered 'healthy worker' effect, by which persons most affected by occupational exposures tend to self-select away from jobs where they will be exposed to irritants. The healthy worker effect results in the highest exposure group having only the subset of employees most resistant to the effects of exposure.

Table 8.20 Mean levels of pulmonary function among entertainment industry group according to category of cumulative exposure in the previous 2 years (values are adjusted mean levels, after taking into account between group differences in age, smoking status and amount, and atopic status)

	Control Group	*Entertainment Industry Group*			
		Cumulative exposure category			
		< 20 hrs-mg/m³	*20 – 200 hrs-mgs/m³*	*200 – 800 hrs-mg/m³*	*> 800 hrs-mg/m³*
n	70	23	29	28	21
FVC (% predicted), mean (se)*	**105.8 (1.4)**	**103.5 (2.4)**	**100.5 (2.2)**	**101.8 (2.2)**	**101.5 (2.5)**
FEV_1 (% predicted), mean (se)	100.2 (1.6)	98.3 (2.7)	94.9 (2.5)	95.3 (2.4)	98.7 (2.8)

* **BOLD** indicates $p < 0.05$, linear trend of decreasing FVC with increasing cumulative exposure category (generalized linear modeling)

Table 8.21 shows the results of multiple regression modeling in which factors associated with FVC and FEV_1, were examined in combination, in internal analyses among entertainment industry participants only. In this table, results are shown as coefficients (and standard errors). A multiple regression coefficient indicates the change in lung function variable (i.e., FVC or FEV_1,) per 1-unit change in the predictor variable.

As expected, current smoking is associated with reduced FEV_1 but not FVC. This reflects the airflow obstruction associated with cigarette smoking. After taking into account smoking (and age, gender, and history of asthma), the analyses indicated that persons typically working within 10 feet of the fog generating machine on the current production had reduced values for both FVC and FEV_1 of about 5 percentage points, compared to those working further from the machine (both $p \leq 0.05$). Make-up/hair/prosthetics technicians also had significantly reduced values for FVC. Including marijuana smoking in the models did not change these results.

Table 8.21 Multiple regression analysis coefficients (and standard errors) of demographic and work-related factors related to pulmonary function outcomes (internal analyses, within the entertainment industry subjects only, n=101)

	FVC (% predicted)	*FEV_1 (% predicted)*
Intercept	91.6 (3.8)	97.0 (4.2)
Personal factors		
Age	0.34 (.11)	0.06 (.12)
Female	5.9 (2.3)	5.5 (2.6)
Current smoking amount (packs/d x yrs smoked)	-0.10 (.14)	-0.36 (.15)*
Ex Smoking amount (packs/d x yrs smoked)	-0.07 (.14)	-0.05 (.16)
History of childhood asthma	2.0 (3.2)	-4.2 (3.6)
Work factors		
Usually works within 10 feet of fog machine (reported, average over current production)	**-5.2 (2.1)***	**-4.8 (2.4)***
Makeup/hair/prosthetics technician	**-8.4 (3.4)***	-3.3 (4.3)

* **BOLD** indicates work factors with p-value <0.05

Working within 10 feet of the fog generating machine was also significantly associated with FEV_1 in the abnormal range, with 13.9% of those usually working within this distance from the machines having $FEV_1 < 80\%$ of the predicted value, compared to only 3.1% of those usually working further from the machines ($p<0.05$).

8.2.6 Acute symptoms and lung function changes: relationship to fog exposures on the day of testing

The acute (or short-term) impact of exposure to fogs was evaluated by comparing the actual measured exposure on the testing day to changes in symptoms and pulmonary function during the same day. For these comparisons, measured exposure was evaluated as a continuous variable and grouped into 4 exposure categories as shown in Table 8.22. As noted above, the highest concentrations were seen among persons in the TV and movie sector, when mineral oil was used to generate the fog, and among those initially tested in the morning.

Table 8.22 Production and type of fog used, by categories of increasing personal exposure on test day

	Personal aerosol exposure on testing day (in mg/m³)				*p*
	< 0.2 mg/m³	*0.2 – 0.4 mg/m³*	*0.4 – 0.7 mg/m³*	*> 0.7 mg/m³*	
n	24	30	23	24	
Type of production, n (%)					
TV/movie	11 (46%)	13 (43%)	9 (39%)	20 (83%)	<0.01
Theatre	7 (29%)	11 (42%)	5 (22%)	3 (12%)	
Concert	5 (21%)	1 (3%)	4 (18%)	1 (4%)	
Arcade	1 (4%)	5 (17%)	5 (22%)	0	
Type of fog, n (%)					
Glycol	18 (75%)	12 (40%)	7 (30%)	8 (33%)	<0.05
Mineral oil	3 (12%)	16 (53%)	15 (65%)	14 (58%)	
Both	1 (4%)	1 (3%)	1 (4%)	2 (8%)	
Other	2 (8%)	1 (3%)	0	0	
Pre-shift testing start time, mean (sd)	15.0 (4.5)	15.2 (4.1)	13.5 (4.9)	10.8 (3.3)	<0.001
Testing duration (hours), mean (sd)	4.3 (1.5)	3.9 (0.9)	4.7 (2.1)	4.1 (1.1)	0.2

No significant association was seen between acute changes in lung function measured over the 4 hour testing period and personal aerosol concentration (Table 8.23). Similar examination of acute symptom prevalence rates showed a significant trend with an increasing number of persons reporting acute symptoms in the nose, throat, or voice as the aerosol exposure increased ($p<0.05$) (Table 8.24). However, no such trend was evident for the other symptoms.

Further examination of associations between acute symptoms and other characteristics of exposure revealed that several of the acute symptoms were associated more closely with the type of fog being used rather than the total concentration of aerosol (from any type of fog). As shown in Table 8.25, increased dry cough or throat, eye symptoms, and systemic symptoms were more common when glycol was used. No significant association was seen between the type of fog used and acute declines in lung function over the 4 hours, although the trend suggested a higher risk for acute cross-shift decline in lung function when mineral oil was used.

Table 8.23 Acute changes in lung function (FVC and FEV_1, as continuous and categorical variables) stratified by level of personal aerosol concentration on the testing day

	*All productions / sites combined**	*Personal aerosol exposure on testing day (in mg/m³)* < 0.2 mg/m³	0.2 – 0.4 mg/m³	0.4 – 0.7 mg/m³	> 0.7 mg/m³	*p*
n	100	24	30	22	24	
% change in FEV_1 (actual), mean (sd), range	0.12 (3.7) -11.6, 9.4	-0.22 (4.1) -8.1, 8.4	-0.78 (3.7) -11.6, 7.3	0.91 (3.7) -4.3, 9.7	0.86 (3.0) -4.0, 6.7	0.3
% change in FVC (actual), mean (sd), range	1.1 (3.9) -11.7, 17.2	0.53 (4.9) -6.2, 17.2	0.44 (2.3) -3.6, 7.2	1.6 (5.2) -11.7, 10.3	2.0 (2.7) -3.6, 6.2	0.4
4% or greater decline in FEV_1, n (%)	11 (11%)	4 (17%)	4 (13%)	2 (9%)	1 (4%)	0.5
4% or greater decline in FVC, n (%)	6 (6%)	3 (13%)	0	3 (14%)	0	0.1

* one participant did not have reliable cross-shift pulmonary function testing completed

Table 8.24 Prevalence of acute symptoms among entertainment industry participants (n, %) stratified by level of personal aerosol concentration on the testing day

	All productions / sites combined	*Personal aerosol exposure on test day (in mg/m³)* < 0.2 mg/m³	0.2 – 0.4 mg/m³	0.4 – 0.7 mg/m³	> 0.7 mg/m³	*p*
n	101	24	30	23	24	
Nose, throat, voice symptoms (at least 2 symptoms)	12 (12%)	1 (4%)	2 (7%)	2 (9%)	7 (29%)	<0.05
Dry cough and/or dry throat	31 (31%)	8 (33%)	7 (23%)	8 (35%)	8 (33%)	0.8
Any cough (dry cough and/or cough with phlegm)	9 (9%)	1 (4%)	3 (10%)	4 (17%)	1 (4%)	0.3
Any chest symptoms (wheeze, chest tightness, breathlessness)	8 (8%)	1 (4%)	3 (10%)	2 (9%)	2 (8%)	0.9
Any eye symptoms	18 (18%)	6 (25%)	5 (17%)	5 (22%)	2 (8%)	0.5
Any systemic symptoms	27 (27%)	7 (29%)	8 (27%)	5 (22%)	7 (29%)	0.9

Table 8.25 Acute symptoms, stratified according to the type of fog being used on the testing day

	Type of fog used on the testing day				
	Glycol only	*Mineral oil only*	*Both*	*None*	*p**
n	45	48	5	3	
Nose, throat, voice symptoms (at least 2 symptoms), n (%)	6 (13%)	4 (8%)	1 (20%)	1 (33%)	0.4
Dry cough and/or dry throat, n (%)	20 (44%)	10 (21%)	1 (20%)	0	0.01
Any cough (dry cough and/or cough with phlegm), n (%)	6 (13%)	3 (6%)	0	0	0.2
Any chest symptoms (wheeze, chest tightness, breathlessness), n (%)	4 (9%)	4 (8%)	0	0	0.9
Any eye symptoms, n (%)	12 (27%)	6 (12%)	0	0	0.08
Any systemic symptoms, n (%)	18 (40%)	9 (19%)	0	0	0.02
$\geq$ 4% cross-shift drop in FEV_1, n (%)	3 (7%)	7 (15%)	1 (20%)	0	0.2
$\geq$ 4% cross-shift drop in FVC, n (%)	2 (4%)	4 (9%)	0	0	0.4

* p value, comparing glycol alone to mineral oil alone

Results from multivariable modeling (odds ratios and 95% confidence intervals), taking into account gender differences in symptom reporting, sampling duration, testing start time, and all potential work and exposure factors together, are shown in Table 8.26. Only those exposure factors that were either significant in at least one model, or associated with an odds ratio greater than 2.0, are shown here.[1]

These results confirm the 'unadjusted' results seen in Table 8.25 above and suggest that increased aerosol mass (especially in the size range of 3.5 – 10 microns) is linked to increased acute upper airway (nose and throat) symptoms, but that overall aerosol mass is not a strong predictor of other acute responses. Rather, the use of glycol to generate fog is a better predictor of increased acute cough, increased acute symptoms linked to dryness (dry cough or dry throat, eye symptoms), and increased acute systemic symptoms. Further investigation of the individual systemic systems revealed that this effect was limited to increased acute headache, dizziness, and tiredness (but not nausea and stomach ache – results not shown). Increased acute chest symptoms (wheezing, chest tightness and breathlessness) were associated with the presence of acrolein measured by area (site) sampling (results not shown). The significance of this finding is unclear as acrolein was only detected in a small number of samples and it did not appear to be associated with the type of fog product being used.

These findings are consistent with known toxicologic effects of glycols (drying of mucous membranes resulting in irritated throat and eyes)[7;8] and acrolein (an unsaturated aldehyde, known to be a very strong respiratory irritant).[9;10] The association of upper airway (nose and throat)

[1] The only symptom complex for which results differed when the personal aerosol concentration fractions were added to the model was upper airway symptoms. Acute upper airway symptoms were more strongly associated with the tracheobronchial fraction than total aerosol mass.

symptoms with total aerosol mass is consistent with results seen in studies conducted by our research team among workers in the lumber industry.[11]

Table 8.26 Multiple logistic regression analyses (odds ratios, 95% confidence intervals) of demographic and work-related factors related to acute symptoms. (internal analyses, within the entertainment industry subjects only, n=101)

	Nose/throat/ voice symptoms	*Dry cough and/or dry throat*	*Any cough (dry or with phlegm)*	*Chest symptoms*	*Eye symptoms*	*Systemic symptoms*
Personal factors						
Female (yes/no)	4.1 (1.0, 17.0)[1]	2.1 (0.8, 5.7)	0.6 (0.1, 3.1)	2.9 (0.6, 14.3)	1.4 (0.4, 4.4)	1.5 (0.5, 4.1)
Short sampling period (yes/no)[2]	2.5 (0.6, 11.7)	0.3 (0.1, 1.3)	1.3 (1.2, 7.7)	0.5 (0.05, 5.0)	1.6 (0.4, 6.0)	1.5 (0.4, 4.8)
Current smoker (yes/no)	1.3 (0.3, 6.4)	1.8 (0.6, 5.1)	1.3 (0.2, 6.6)	3.9 (0.6, 27.2)	0.9 (0.2, 3.2)	1.7 (0.6, 5.4)
Former smoker (yes/no)	0.6 (0.1, 4.4)	1.1 (0.3, 3.5)	0.9 (0.1, 5.8)	2.8 (0.3, 24.7)	0.5 (0.1, 2.1)	1.7 (0.5, 5.6)
Work factors						
Glycol (yes/no)	1.6 (0.4, 6.7)	**4.7** **(1.7, 12.9)**	2.3 (0.5, 10.7)	1.7 (0.3, 8.8)	2.5 (0.8, 7.9)	**3.9** **(1.4, 10.9)**
Aerosol concentration (mg/m^3)	**2.2** **(1.1, 4.4)**	1.1 (0.6, 2.0)	0.6 (0.2, 2.1)	0.7 (0.3, 1.9)	0.4 (0.1, 1.6)	1.1 (0.6, 2.0)

1 Odds ratios (and 95% confidence intervals) from logistic regression models including all variables with values listed, **BOLD** indicates work factors with elevated odds ratios, $p < 0.05$

2 Included to adjust for differential sampling durations (short is defined as a sampling duration of less than 3 hours)

Similar models investigating factors associated with acute cross-shift declines in pulmonary function (4% or greater declines in FVC and FEV_1) did not reveal any significant work or exposure factors linked to these outcomes. This analysis was limited by the relatively short 'cross-shift' time interval and the fact that start times were unevenly distributed over the day. As lung function values naturally follow a diurnal (or daily) pattern, increasing during the late morning and early afternoon and then declining in mid to late afternoon, it is difficult to evaluate the acute effects of exposure on lung function unless the study size is large enough to control for sample duration and start time effects.

8.3 Summary and Conclusions

In summary, we carried out a pilot study of the potential respiratory health impact of exposure to fogs among 101 employees in the entertainment industry. These 101 persons worked in the TV/movie sector, live theatre, music concerts, and a video arcade. Testing included lung function tests and a brief acute symptom questionnaire, both completed twice on one day (before and after a work period during which fog was used on the 'set'), a comprehensive respiratory and general health questionnaire, enquiring about ongoing symptoms, a detailed work and exposure history, and personal monitoring of aerosol exposure concentration on the study day. The participation rate for individual participants was 70%. Results were compared to those from an external control group of BC workers.

Compared to the control group, the entertainment industry employees had increased rates for most of the ongoing or chronic symptoms evaluated: nasal symptoms, cough, phlegm, wheezing, chest tightness, shortness of breath on exertion, and current asthma symptoms. They also had reduced average levels for both measures of lung function: FEV_1 and FVC. These differences were statistically significant ($p<0.05$) for nasal symptoms, shortness of breath, current asthma symptoms (in the past 12 months), and for both FEV_1 and FVC. These results suggest that entertainment industry employees may be at risk for chronic upper and lower airway irritation and airflow obstruction, measured both subjectively (i.e., symptoms) and objectively (pulmonary function tests).

We examined whether or not these health effects were related to specific exposures in two ways. First we identified whether these ongoing symptoms were linked to work exposures 'in general' (either occurring only at work of shortly after, or if they were exacerbated by any workplace exposures). Again, compared to controls, the entertainment industry employees had increased rates of work-related phlegm, wheezing, chest tightness, and nasal symptoms. It was not possible to study 'work-related' asthma or chronic voice problems as the number of people in this study was too small to make meaningful comparisons for these less common health outcomes. These findings support the general finding described above of chronic upper and lower airway irritation in relation to work factors.

Second, we examined relationships between ongoing symptoms and lung function on the one hand and specific fog exposure factors on the other hand. When the control group was included in the analysis, we found that increased work-related wheezing, increased work-related chest tightness, and decreased lung function (FVC) were all significantly associated with increasing 'cumulative exposure' to fog over the previous two years. (Cumulative exposure refers to the product of estimated fog intensity and duration of exposure.) When we looked only among the entertainment industry employees (i.e., excluding the control group), we found that increased work-related cough and phlegm were both associated with increased cumulative exposure to fogs. Reduced levels of lung function (both FEV_1 and FVC) were associated with working close to the fog machine (within 10 feet on average). These findings all support the conclusion of an association between fogs exposure and chronic respiratory irritation and resulting airflow obstruction.

We also examined acute changes in symptoms and lung function (over a period of about 4 hours on the study day) and compared these to the aerosol exposures and work factors measured on the same testing day. Increased upper airway symptoms (nose, throat, and voice symptoms) were associated with increased measured personal aerosol concentration. Increased acute symptoms of dry cough or dry throat and increased acute headache, dizziness, and tiredness were significantly associated with the use of glycol to produce fog on the testing day. In contrast, acute reductions in lung function were more often seen when mineral oil was used to produce fog on the testing day, although this was not statistically significant. No 'exposure-response' relationships were seen between other acute symptoms and exposure factors measured on the study day.

In conclusion, these findings indicate that both acute and chronic upper airway irritation is seen in association with increased exposure to theatrical fog aerosol regardless of the type of fog raw materials used. Chronic lower airway or chest symptoms (asthma-like symptoms in the past 12 months, wheezing, chest tightness) and airflow obstruction appear to be linked to chronic (but not acute) exposure to fog aerosols. This suggests that the exposure is provoking non-specific respiratory irritation and airway narrowing, rather than specific 'allergic' sensitization. The use of glycol fog was linked to additional acute symptoms associated with drying properties of glycol agents.

These results are consistent with the results from previous studies which found increased nasal and respiratory symptoms among persons working in 'smoke' productions compared to those in 'non-smoke' productions (NIOSH 1991)[13]; increased respiratory, throat, and nasal symptoms linked to glycol exposure (Mount Sinai/Environ)[12]; and increased throat symptoms and decreased FVC linked to mineral oil exposure (Mount Sinai/Environ)[12]; but no objective evidence of specific occupational asthma (NIOSH 1993)[13].

References, Chapter 8

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9 Summary and Recommendations

9.1 Summary of Results

This study of theatrical smokes and fogs in the British Columbia entertainment industry was an ambitious undertaking that involved a number of parts: a survey of special effects technicians about their jobs, including the materials and equipment they use to create atmospheric effects; laboratory investigations of the constituents of the glycol fluids and their potential for pyrolysis under normal operating conditions; field testing of measurement methods to allow industry personnel to easily check exposure levels; and a cross-sectional study of exposures to theatrical fog aerosols, their size distribution, selected constituents, and the impact on the health of employees in the industry. The following is a brief summary of the results of these investigations.

9.1.1 Survey of special effects technicians

23 members of IATSE Local 891 were interviewed, 32% of those contacted. Almost all of the interviewees worked primarily in television and movie production, and consequently worked long shifts, averaging over 12 hours. Because the technicians interviewed were largely from the TV and movie sector of the industry, and because they included only about one-third of those originally selected for interviews, it is unknown whether their working conditions and styles were representative of other sectors or of non-participants.

About half of the technicians interviewed owned their own fog machines, but most also used other equipment as well. Glycol-using machines (i.e., those that use heat to generate fog) were usually used with fluids supplied by the manufacturer, but this was not so for other machine types. Nearly half the technicians sometimes formulated their own fluids. Many machines could be used to create diverse effects, including source smoke, large volume smoke, smoldering, atmospheric haze, low lying fog, and steam effects. Mineral oil-based machines were limited to a more circumscribed set of effects, as were 'crackers', 'bee-smokers', and 'steamers'. Only smoke cookies were used to create coloured smoke.

9.1.2 Constituents and thermal products of glycol fluids

Bulk samples of 15 glycol-based fluids were collected from the special effects technicians included in the survey or exposure-monitoring portions of the study: two 'home brews'; 13 commercially available fluids, five from LeMaitre, two each from Rosco and CITI, and one each from Antari, Atmospheres, MBT, and MDG. In gas chromatography-mass spectrometry, most fluids were found to have the same proportions of specific glycols as reported on their Material Safety Data Sheets.

Glycol-based fluids, unlike mineral oils, are heated to produce fogs. Therefore the 15 bulk fluids were heated in an environmental chamber in the laboratory to 343 ºC, the maximum temperature to which they were normally expected to be exposed in fog machines, to simulate the fog-producing process and to determine if heating could produce combustion or other by-products. Except for one home-brew, there were no increases in concentrations of typical combustion gases such as carbon dioxide (CO_2) and carbon monoxide (CO), nor declines in the oxygen concentration, indicating that pyrolysis of the glycol fluids did not occur at this temperature.

Potential breakdown products were also measured. Aldehydes (formaldehyde, propionaldehyde and hexaldehyde) were detected in most samples, and certain polycyclic aromatic hydrocarbons (naphthalene and acenaphthylene) from a small number of samples. The study design was unable to distinguish whether these agents were contaminants present in the unheated fluids or products of the heating process.

9.1.3 Simple monitoring methods for use in the industry

To identify techniques for measuring theatrical fogs that could be used by industry personnel to rapidly assess levels of exposure, we evaluated three commercially available real-time direct-reading monitors: the M903 nephelometer, the DataRAM personal aerosol monitor, and the APC-100 laser single-particle counter. We also evaluated whether employees' reports of the amount of time they spent in a visible fog atmosphere could be used to estimate exposure. The validities of all four methods were assessed by comparing their measurements to personal exposures monitored using standard filter-based techniques.

The DataRAM and the nephelometer were best able to predict personal exposures (40% and 38% of the variability in personal exposures explained, respectively). This performance is particularly impressive since the test instruments were not worn by the study subjects, but instead set at one location near the fog machines. The APC-100 and self-reported percent time in visible fog were poorer predictors (22% and 11% of the variability in personal exposures explained, respectively).

The DataRAM, although expensive ($8,000), is easy to use, small enough to wear as a personal monitor and silent, therefore it was selected as the preferred method of those tested. Other instruments that use similar light scattering technology are available and might also be good choices. Any instrument chosen would need to be calibrated against standard monitoring methods. Calibration curves for the DataRAM were derived as part of this study.

9.1.4 Levels of exposure

We conducted a cross-sectional study of the exposures of 111 entertainment industry personnel working in 19 productions/locations in the TV and movie sector, live theatre, music concerts, and a video arcade. Some sites were visited more than once, for a total of 32 sampling days. On about half the days, mineral oils were used to produce atmospheric haze effects, and on the other half, glycols were used to produce a variety of special effects, including haze.

The average fog aerosol concentration measured in the breathing zones of the study subjects was 0.70 mg/m^3 (range 0.05 to 17.1 mg/m^3) with exposures to mineral oils on average about twice as high as exposures to glycols (0.94 vs. 0.49 mg/m^3). Exposures of TV and movie personnel were more than twice as high as those of personnel in other productions (1.01 vs. 0.40 mg/m^3). The overall average measured in this study was nearly identical to that measured in the Mount Sinai/Environ study[1], though that study found almost no difference in average levels for the two fluid types, but found a considerably greater range in exposures for mineral oils (0.001 to 68 mg/m^3). The earlier NIOSH study[2] found levels of glycols that covered a range similar to those measured in our study, from 0.05 to 7.6 mg/m^3, and a somewhat lower range of mineral oil concentrations (from one site only), from not detectable to 1.35 mg/m^3. The averages and ranges of measured levels in these three studies are remarkably similar, given that occupational exposure concentrations are notoriously variable – 10-fold and greater differences are not uncommon.

The average personal mineral oil mist exposure in this study exceeds the proposed ACGIH TLV[3] for all mineral oils (0.2 mg/m^3), and the level (0.5 mg/m^3) requiring an exposure control plan for severely refined oils (i.e., one-half the Exposure Limit of 1 mg/m^3) according to the British Columbia WCB regulation[4]. In movie and television productions, the average mineral oil exposure exceeded the WCB standard itself. None of the glycol samples exceeded the current 8-hour glycerin mist standard of 10 mg/m^3. Note that WCB exposure limits are lower for personnel whose shifts are longer than 8 hours.

Our measurements also determined that the fog aerosols were small enough that a large proportion of them could enter the smallest airways and air sacs of the lungs. These small aerosols can also stay suspended in air for hours to days, an attractive feature for the stability of the effect, but one that prolongs exposures.

Exposures to aldehydes and polycyclic aromatic hydrocarbons, both potential breakdown products of the fluids, were very low. The levels were similar to background levels in urban air, and might easily be attributable to other sources, such as off-gassing building materials, vehicle exhaust or cigarette smoke.

The most important factors related to increased exposures to the fogs were proximity to the fog machine, greater numbers of fog machines in use, and greater proportion of time spent in the visible fog. Certain jobs had exposures that differed from those predicted by these factors: grips had higher exposures and sound technicians lower. These factors can be used as a starting point for designing controls to reduce exposure levels.

9.1.5 Health effects

We conducted a pilot study of the respiratory health of 101 of the 111 subjects of the exposure monitoring study. Before and after the exposure sampling period, subjects performed lung function tests and answered a brief acute symptom questionnaire. On another day, they answered a more comprehensive work history and health questionnaire. BC Ferries employees were used as external controls.

Compared to the control group, the entertainment industry employees had reduced lung function (both FEV_1 and FVC) and increased chronic respiratory symptoms: nasal symptoms, cough, phlegm, wheezing, chest tightness, shortness of breath on exertion, and current asthma symptoms.

We examined whether or not these health effects were related to work in general or to cumulative exposure to fog aerosols over the previous two years. Compared to controls, the entertainment industry employees had increased rates of *work-related* phlegm, wheezing, chest tightness, and nasal symptoms. When the control group was included in the analysis, increased work-related wheezing, increased work-related chest tightness, and decreased lung function (FVC) were all significantly associated with increasing cumulative exposure to fog over the previous two years. When we examined only the entertainment industry employees, increased work-related cough and phlegm were both associated with increased cumulative exposure to fogs. Almost all of the subjects in the two highest cumulative exposure categories were from the

TV and movie industry. Reduced levels of lung function (both FEV_1 and FVC) were also associated with working close to the fog machine (within 10 feet on average).

We also examined acute changes in symptoms and lung function in relation to exposures on the testing day. Increased upper airway symptoms (nose, throat, and voice symptoms) were associated with increased measured personal aerosol concentration. Increased acute symptoms of dry cough or dry throat and increased acute headache, dizziness, and tiredness were significantly associated with the use of glycol fogs that day. In contrast, acute reductions in lung function were more often seen when mineral oil fogs were used on the testing day.

These findings indicate that both acute and chronic upper airway irritation are observed with increased exposure to theatrical fogs regardless of the type of fluid. Chronic lower airway or chest symptoms and airway narrowing appear to be linked more strongly to chronic exposure than to acute exposure. These results are consistent with those found in previous studies, and, overall, the results suggest that fog exposure is provoking non-specific respiratory irritation and increasing the risk for chronic airflow obstruction, rather than causing specific 'allergic' sensitization.

9.2 Strengths and Limitations of the Study

The main limitations of this study are related to participation. Only 31% of the special effects technicians randomly sampled from IATSE Local 891 were interviewed about the characteristics of their jobs, the products they use and the effects they create. In addition, agreement to participate was achieved for only 32% of the eligible productions using fogs during the cross-sectional survey of exposures and health effects. This means that we cannot be sure that the special effects technicians and the productions included in the study are representative of the industry as a whole, i.e., there may be some systematic differences between technicians and productions that participated and those that did not.

Despite this problem, this study was the first to attempt to include a broad cross-section of the fog-using entertainment industry, and as a result, it did include a much more varied range of personnel and settings than any of the previous studies. It was the first study to investigate lung function and exposures in movie, television, music, and video arcade personnel, and the first to focus on the non-performance staff of the industry.

Although only 30% of productions agreed to be included in the study, the participation rate among employees in those productions was very reasonable: 77% for the exposure monitoring and 70% for the health measurements and questionnaires. This means that it is unlikely that the exposures, health effects, and exposure-response relationships observed were subject to selection biases.

Because of the difficulties encountered in recruitment of productions, the total number of employees included in the study was considerably lower than our target of 150 to 200. The effect of the smaller sample size was to reduce the 'power' of the study to detect statistically significant differences in health, exposure, or exposure-response, even where such differences may in fact exist. Despite the lower than anticipated study power, many of the observed effects were found to be statistically significant. Because of the small study size, it is still important, however, to consider observed differences which were not statistically 'significant'.

The reduced study size hindered our ability to examine the separate effects of mineral oils and glycols. We were able to consider their individual respiratory health effects in a very simple way, by separately examining the two main fluid types, but we could not examine the effects of each according to level of exposure. It is likely that it would always be extremely difficult to consider cumulative exposure to the different fluid types separately, because study subjects were unable to identify the types of fluids to which they had been exposed in the past. A very long and costly prospective study would be the only way to overcome this limitation. However, it is possible, given the difficulties with participation in the entertainment industry, that such a prospective study could not be done.

In order to consider the health effects of chronic exposures to theatrical fogs, cumulative exposures had to be estimated. This is almost always the case in studies considering past exposures. In this study, we were able to use information from a predictive model to help estimate past exposures quantitatively, a more sophisticated method than available in many others studies. It is still likely that exposures have been misclassified to some extent. In most cases, such misclassification is 'non-differential' in nature (i.e., not related to health status) and the effect would be to reduce exposure-response relationships – a 'conservative' bias that underestimates effects.

The BC Ferries workers were not a perfect control group; they were older on average, and had smoked more. They also included individuals who were exposed to vehicle exhaust. These features of the control group should also produce a bias that would tend to underestimate the effects for the entertainment industry comparisons. A positive feature of the BC Ferries controls is that they and the entertainment industry subjects both had concerns about their exposures and their health, so their answers to questions were likely to be similarly affected by such concerns.

Additional strengths of this study include the determination of the accuracy of Material Safety Data Sheets for glycol-based fluids, the investigation of the potential for heated fogs to decompose, determination of the size distributions of the aerosols, the measurement of aldehydes and polycyclic aromatic compounds on production sets, the investigation of tools for industry personnel to monitor exposures, and the consideration of marijuana smoking in the internal analyses of health effects.

Despite these 'firsts', a number of outstanding issues remain. For example, the source of low levels of aldehydes and PAHs on production sets and in the air after experimental heating of glycols is not yet known. Identification of non-glycol or non-mineral oil contaminants in the bulk fluids has not been attempted. This would be especially important for 'home-brew' fluids. It is important to note that, though about half the interviewed special effects technicians used such products, a home-brew fluid was observed in use on only one day of 32 in the cross-sectional study.

9.3 Recommendations

Mineral oils were used in about half of the productions in the cross-sectional survey, and exposures, particularly in movie and television productions, exceeded exposure standards. The industry should start working on exposure control plans in order to comply with regulations and to prevent the health effects observed in this study.

Glycols, used in the other half of productions, did not entail exposures that exceed regulatory limits, however, the current limits are colloquially known in occupational hygiene circles as 'nuisance dust' standards, often applied to substances for which there is little exposure-response information. The health study we conducted suggested that acute symptoms consistent with the drying effects of glycols were observed with exposures on the testing day. This and the indication that fog exposures seem to be provoking non-specific respiratory irritation and airflow obstruction, suggest that the 'nuisance dust' standard is inappropriate for glycols and that exposure minimization would be a reasonable approach for these fluids as well.

Exposure reductions might be achieved in a number of ways:

- A remarkable finding of this study was the high proportion of productions in which fogs were used to produce generalized atmospheric haze. Our understanding is that such effects, at least in the television and film industries, might easily be created by other means that do not involve introducing aerosols into the work environment. Such methods might include use of filters on cameras or post-filming computer-generated effects.
- Also surprising are the types of settings in which theatrical fogs are being used. It is reasonable to ask, in every instance in which fog use is considered, whether the effect is necessary to the work environment. Examples of settings in which fog aerosols were used in this study, but in which they did not seem crucial to the operation, were a dog show and a video arcade.
- In some settings, particularly where the effect required is very short-lived, *fresh* water mists or steam might be viable options.
- Another method which might be tested is a fogger designed for use in clean rooms (for visualizing air flow without leaving residue that might contaminate electronic circuits): the MSP Portable Ultrapure Cleanroom Fogger™ [5]. It uses deionized water and liquid nitrogen, and is advertised to produce a neutrally buoyant and highly visible fog. A factor that must be considered here is how much nitrogen is used and whether levels might ever be sufficient to reduce oxygen concentrations in the air.
- The factors associated with higher exposure in this study also give guidance on how to minimize exposures to mineral oils and glycols where they continue to be used: maximize the distance between employees and the fog machines, and minimize the number of machines used, the duration that they are on, and the amount of time that employees spend in the visible fog atmosphere. For example, fog effects needed during filming could be left to near the end of a shift, so that the remaining aerosol is given time to settle after the shift ends when no one is on site. This is a common strategy used in the mining industry when rock blasting is done.

A method which is often considered for reducing exposures is respirators. We have not recommended a respirator program here. Respirators are difficult to wear over long periods of time, and are therefore not usually considered a routine exposure control method, but rather an interim control while awaiting other solutions. They make communication difficult, and are often not maintained or worn properly. In the entertainment industry where the public may also be exposed (e.g., live performances), and where performers are unlikely to be able to wear respiratory protection, respirators seem an especially poor solution.

Another method which is often considered when exposures to an agent exceed exposure limits or cause health effects is substitution with another agent. For example, it might be tempting as a result of this study to consider switching entirely from mineral oil to glycols, or to a completely different agent. Substitution is considered one of the most effective hygiene control measures, because it presents the opportunity to eliminate the hazard. This is the basis for our recommendations to consider the water or the water/nitrogen methods described above. However, we also want to promote caution when considering substitution. A problem that can arise when selecting alternate chemicals is that there is less known about the health effects of the new product than the old, so it cannot be certain that it is less hazardous. Water is certainly less hazardous than both glycols and mineral oils, as long as fresh water is used everyday so that it cannot become a breeding ground for microorganisms. And nitrogen normally forms 80% of the air we breathe, so should also not pose a problem, as long as it does not reach concentrations high enough to displace oxygen. Other substitutes must be very carefully evaluated before they are introduced.

Individuals associated with the entertainment industry have suggested other solutions including ventilation of sets, restrictions on the use of certain types of fluids (mineral oil, home-brew), limiting the number of personnel on sets where special effects are used, posting advisories, and education strategies. No matter what interventions are agreed upon, where fogs continue to be used, it is important to follow-up with monitoring to ensure that control measures do result in reduced exposures.

References, Chapter 9

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