Exposures and their Control in Radiographic Film Processing in British Columbia

Report to the Workers' Compensation Board of British Columbia

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Executive Summary

Background Radiographers process x-ray films using developer and fixer solutions which contain such chemicals as glutaraldehyde, hydroquinone, potassium hydroxide, potassium sulphite, sodium thiosulphate, acetic acid, aluminum sulphate, and ammonium thiosulphate. Some of these agents are known to cause or exacerbate asthma, and radiographers have been diagnosed with occupational asthma due to glutaraldehyde sensitization. Radiographers have also reported a wide array of symptoms whose causes have not been identified.

Objectives This study sought to quantify the airborne exposures of radiographers to a selection of these agents, to determine whether there were differences in exposure levels between radiographers working in hospitals and those working in private clinics, to investigate the effectiveness of general and local exhaust ventilation as means of controlling exposures, and to examine other factors, such as tasks and machine characteristics, which might influence exposure levels.

Approach The study began in the summer of 1998 with a telephone survey of 102 facilities randomly selected from all radiography facilities in the province of British Columbia. A standardized questionnaire was administered to elicit information on site characteristics, including measures currently in place to control exposures. The survey was followed with a field study carried out in 32 facilities in the greater Vancouver area and 3 in Prince George, starting in the fall of 1998 and ending in the spring of 1999. Personal exposures to glutaraldehyde (from the developer chemistry), acetic acid (from the fixer chemistry), and sulphur dioxide (a byproduct of sulphites, present in both developer and fixer solutions) were monitored.

Results On the basis of our survey results, we estimated that in 1998 about 1,770 employees worked with x-ray film processing machines in 181 clinics and hospitals throughout the province. Most of these radiographers worked in hospital settings. Typically, the facilities had more than two film processing machines on site, most of which had automated chemical mixing, silver recovery units, and local exhaust ventilation, and were located in rooms with general dilution ventilation.

Average full-shift personal exposures to glutaraldehyde, acetic acid, and sulphur dioxide were 0.0009 mg/m^3, 0.09 mg/m^3, and 0.08 mg/m^3, respectively, all more than one order of magnitude lower than current Workers' Compensation Board of British Columbia exposure limits.

Local exhaust ventilation of the processing machines and use of silver recovery units lowered exposures, whereas the numbers of films processed per machine and the time spent near the machines increased exposures. Personnel in private facilities had higher exposures than those in hospitals. Private clinics were less likely to have local exhaust ventilation and silver recovery units. Their radiographers spent more time in the processor areas, and processed more films per machine.

Implications

Although exposures were low compared to WCB standards, there are good reasons to continue practices to minimize or eliminate exposures: glutaraldehyde and hydroquinone are designated sensitizers whose exposures must be kept "as low as reasonably achievable"; the levels at which health effects occur are not yet clearly established, but appear to be lower than current standards; and health effects resulting from the mixture of chemicals are not understood.

Methods to reduce exposures identified in this study include local exhaust ventilation of the processing machines, use of silver recovery units, and minimizing time spent in the processor areas.

Developments in digital imaging technology are making available options which do not involve wet-processing of photographic film and therefore could eliminate the use of developer and fixer chemicals altogether.

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Table of Contents

List of Tables and Figures

Glossary

Automated Chemical Mixing

Radiographic film chemistry is usually supplied by the manufacturers in a concentrated form. The concentrate must be mixed with water and delivered to the processing machines. This can be done manually, but most current systems use automated methods which may supply several machines. Each system has two large tanks (about 10 gallons each), one for the diluted developer solution and one for the diluted fixer solution. Water supply lines run directly to the tanks. When a tank is empty, a buzzer sounds. This alerts personnel in the area to mount a bottle of concentrate (about 1 gallon) directly on the opened top of the tank. As the concentrate drains into the tank, water is metered in to dilute it at the same time. Once the tank is filled, the empty concentrate bottle is removed and the tank lid is closed. The diluted developer or fixer is delivered from the tanks as required to the processing machine(s) through a metered piping system.

Silver Recovery Unit

Used fixer solutions contain dissolved silver halides. These can be pumped to a silver recovery unit which separates and collects the silver ions using electrolytic or ion exchange methods.

Drainage, "Open" vs. "Sealed"

Rooms housing the processing machines typically have floor drains. Processing machines and silver recovery units have pipes which take spent fluids to this drain. In a few sites, the area of the drain around the pipes was sealed with a fitted plastic cover to minimize the opportunity for gases or vapours from the drain to enter the room. In most cases the drain area around the pipes was left unsealed ("open" drainage).

Local Exhaust Ventilation

The cabinets of most modern radiographic film processing machines are well sealed, so that they can be ventilated. An exhaust duct (usually about 1.5 to 5 inches in diameter) is attached to the back and bottom of the cabinet. The ducting is then attached to a fan which pulls air away from the cabinet and exhausts it, preferably directly to the outdoors. This type of ventilation is typical of "industrial" systems meant to exhaust contaminants directly from their source.

General Room Ventilation

The rooms housing the film processing machines may be connected to the general building ventilation system, often referred to as the HVAC (heating, ventilating, and air-conditioning) system. This is the type of ventilation typically found in large office buildings, with air inlets and outlets (exhaust) in the ceiling of the room. This kind of ventilation operates by diluting contaminants which have entered the room air and is less efficient than local exhaust.

1.0 Introduction

The production of radiographic films involves the same methods as photographic film processing. In radiography, x-rays rather than visible light create a latent image on the film surface by reducing silver halide crystals to elemental silver. The image is amplified and stabilized during the developing process using reducing agents such as hydroquinone. The image is fixed by agents which dissolve and remove the unused silver halides. Automated x-ray film processing machines achieve short development times (seconds to minutes) by using elevated temperatures (28-35 °C), by including glutaraldehyde as a hardening agent within the developer solution, and by actively drying the fixed and washed films with heated air [Hewitt, 1993].

The process entails potential exposures to hydroquinone, glutaraldehyde, formaldehyde, glycols, acetic acid, sodium sulphite, sulphur dioxide, ammonium chloride, silver compounds, and other chemicals. Some of these, in particular the aldehydes, have been shown to cause or exacerbate asthma [Corrado et al., 1986; Burge, 1989; Jachuk et al., 1989; Cullinen et al., 1992; Trigg et al., 1992; Chan-Yeung et al., 1993; Hayes and Fitzgerald, 1994; Kivity et al., 1994; Gannon et al., 1995; Malo et al., 1995]. Occupational asthma has been observed in radiographers, the technical professionals who make the radiographs and process the films [Cullinen et al., 1992; Trigg et al., 1992; Chan-Yeung et al., 1993; Gannon et al., 1995]. In addition, radiographers have reported of a wide variety of symptoms including headaches, sore throat, hoarseness, nasal discharge, sore eyes, fatigue, sinus problems, painful joints, oral ulcers, catarrh, tinnitus, tight chest, skin rash, dyspnea, heart arrhythmias, chest pains, and numbness [Goncalo et al, 1984; Spicer et al., 1986; Gordon, 1987; Smedley et al., 1996]. Studies of radiographers to date have not clarified a link between their exposures and these symptoms. An investigation is currently underway in British Columbia comparing the respiratory health of radiographers and physiotherapists [Wymer et al., 2000].

Because of the suspected occupational illnesses associated with radiography, we sought to evaluate the levels and determinants of exposure to several common chemicals used in radiographic film processing. This study was meant to serve as an initial step in the selection of control strategies to minimize occupational exposures. The specific objectives were

- to examine the potential for radiographers to have airborne exposures to film processing chemicals;
- to determine whether there are differences in exposure levels among radiographers working in hospitals or health care centres, and radiographers working in private clinics;
- to determine the effectiveness of general and local exhaust ventilation systems for controlling exposures; and
- to examine other factors such as task, facility, and machine characteristics which might influence exposure levels.

The study had two components. First, a telephone survey of a random sample of all public and private film processing facilities in British Columbia was conducted to describe the characteristics of the facilities and to determine what measures are currently in place to control exposures. In the second part of the study, personal exposure monitoring was conducted in a subsample of facilities in Prince George and the greater Vancouver area to assess the effectiveness of three types of ventilation systems (general ventilation, manufacturer-specified local exhaust ventilation, and ventilation-engineer-specified local exhaust ventilation), and to examine other determinants of radiographers' airborne exposures to film processing chemicals and their by-products.

2.0 Methods

2.1 Facility Identification

In order to identify all public and private x-ray film processing facilities in the province of British Columbia, the Workers' Compensation Board of B.C. (WCB) compiled, from their records, a list of facilities that remitted x-ray films on behalf of WCB clients for compensation purposes. The list of facilities was double-checked and updated for completeness against the Yellow Pages™ categories "X-ray Laboratories - Medical and Dental" and "Hospitals and Health Care Centres." Hard copies of the Yellow Pages for every city or area in the province were searched. In addition, the web page for the British Columbia Yellow Pages was also searched (www.mybc.com/yellowpages, summer 1998). In total, 181 distinct facilities were identified.

2.2 Telephone Interview

From this list, 100 facilities were randomly selected for a phone interview to obtain information about the basic characteristics of the facilities province-wide. One of the study objectives was to assess the effectiveness of improved ventilation, designed by an industrial ventilation engineer, in controlling exposures, however, we understood that only a few sites in the province might have achieved this level of local exhaust ventilation. Therefore Ed Chessor (Ventilation Engineer, Engineering Services, WCB) identified all facilities in the province which, to his knowledge, had upgraded ventilation according to his specifications, i.e., local exhaust from the processor cabinet at 20 cubic feet per minute (cfm) or more. All of these facilities were included as phone interview sites, even if they were not included in the initial random selection. He identified 16 sites, of which 10 were already included in the random selection. As a result, there were a total of 106 sites identified for telephone interviews.

The initial contact with each location was by a letter to the supervisor in charge (Appendix A). This was followed by a telephone call to set up an appointment for an interview with the supervisor or, where the supervisor was not familiar with the x-ray processing facilities, another senior employee with this expertise.

The phone interviews were conducted in the summer of 1998 using a structured questionnaire (Appendix B). The focus was on characteristics such as facility type (private vs. hospital), the number of personnel employed in the film processing areas, make and number of processors, name brand of developer and fixer chemistry, type of chemical mixing (manual vs. automatic), presence of silver recovery units, the number of films developed per machine and week, and the presence of general and local exhaust ventilation.

2.3 Exposure Monitoring

During the telephone interview, supervisors of the 41 facilities located in the greater Vancouver area and in Prince George were asked whether they would be willing to have their facility participate in an exposure monitoring study. From the list of 36 facilities so identified, stratified random samples of 15 private and 15 public facilities were selected. To this group were added all facilities identified by Ed Chessor as having upgraded their ventilation controls to his specifications, but not included in

the initial random sample. This gave a total of 19 public and 16 private facilities for exposure monitoring.

To select compounds for exposure monitoring, all participants in the telephone interviews were asked to supply material safety data sheets (MSDS) identifying the constituents of the film development and fixing solutions used in their facilities (Appendix C). This investigation indicated that the developer and fixer chemistry used in x-ray processing included a variety of chemical compounds formulated by several manufacturers (Table 1). Despite the number of manufacturers, there was a core list of reagents used by all: acetic acid, aluminum sulphate, ammonium thiosulphate, glutaraldehyde, hydroquinone, potassium hydroxide, potassium sulphite, and sodium sulphite.

Table 1: Range of concentrations of reagents in developer and fixer working solutions, according to manufacturers' specifications

Reagent	Developer, Range of Concentrations, in %	Fixer, Range of Concentrations, in %	Vapour pressure, in mm Hg @ 20 °C	WCB Exposure Limit
acetic acid	p	1-5 (all)	11.4	10 ppm (8-hr)
aluminum chloride	-	0.1-1.0	1.0*	n/a
aluminum sulphate	-	1-5 (all)	n/a	n/a
ammonium thiosulphate	-	7-15 (all)	negligible	n/a
boric acid	-	0.1-1.0	negligible	n/a
carbonates (potassium, sodium)	1-5	-	n/a	n/a
citric acid	-	p	n/a	n/a
gluconic acid	-	0.1-1.0	n/a	n/a
glutaraldehyde (sometime as the bis sodium bisulphite)	0.5-5 (all)	-	17.0	0.25 mg/m^3 (C)
glycols (diethylene, triethylene)	0.5-1.5	-	0.2	n/a
hydroquinone	1-5 (all)	-	0.0001	2 mg/m^3 (C)
5-nitroindazole	p	-	n/a	n/a
1-phenyl-3-pyramzolidone	0.5-1.5	-	n/a	n/a
potassium acetate	1-5	-	n/a	n/a
potassium hydroxide	1-5 (all)	-	1.0	2 mg/m^3 (C)
potassium sulphite	5-10 (all)	-	n/a	n/a
sodium acetate	-	1-5	n/a	n/a
sodium bisulphite	-	1-5	negligible	5 mg/m^3 (8-hr)
sodium sulphite	1-5 (all)	<2	negligible	n/a
sodium thiosulphite	-	1-5	negligible	n/a

p = present, but in concentrations less than the lowest reported by the manufacturer
- = not present
n/a = not available
(all) = contained in chemistry of all manufacturers
(C) = ceiling exposure limit
(8-hr) = 8-hour time weighted average exposure limit
* = relative humidity at 100 °C

Table 1 also lists the vapour pressures and the WCB exposure limits [WCB, 1998] for these chemicals. Glutaraldehyde and acetic acid have the highest vapour pressures, have known health effects for which exposure limits have been established, and have standard air sampling and analysis methods established by the WCB Laboratory [WCB, 1984]. Acetic acid was used in the fixer chemistry of all manufacturers, and the developer chemistry of some. Glutaraldehyde was used as a hardener in the developer chemistry of all manufacturers. As a result, these two reagents were

selected for air sampling. In addition, sulphur dioxide was selected because it is a gaseous degradation product of the sulphite compounds when the fixer solution is heated or left standing for long periods of time.

Table 2 lists the collection apparatus and analytical methods for each chemical, as specified in the WCB Laboratory Analytical Methods Manual [WCB, 1984]. All sample collection tubes had two sections of sorbent to allow determination of whether breakthrough into the second section occurred due to overloading or poor adsorption.

Table 2: Air sample collection and analytical methods

Chemical	WCB Method Number	Collection Apparatus	Analytical Method
acetic acid	2005	SKC 226-119 activated charcoal tubes	ion chromatography
glutaraldehyde	5230	SKC 226-01 silica gel tubes impregnated with 2,4-DNPH	high performance liquid chromatography
sulphur dioxide	5280	SKC 226-80 activated beaded charcoal tubes	ion chromatography

The exposure study took place from the fall of 1998 to the spring of 1999. Each facility was visited on two days. On the first day, all radiographers who worked in the facility's film processing room(s) on a daily basis were informed about the study procedures and invited to participate in the personal air sampling. In addition, data about unvarying characteristics of the processing machine(s) and work room(s) were recorded. This included mapping the room(s), recording the make and model of the film processing machine(s), noting the film processing chemistry used, and taking measurements of the ventilation system(s). Ventilation velocities were measured using a TSI thermoanemometer with a minimum of 8 measurements 0.25 to 4 inches apart across the face of each ventilation duct exhausting the processing machines or the general room air. Measurements were made at least 12 inches downstream of duct changes likely to produce turbulent flow. Duct dimensions were also recorded. An attempt was made to determine where the local exhaust ventilation air was exhausted, by consulting building maintenance personnel and by following the ducting. Processing machines whose local exhaust ducts were not connected to an external fan or which allowed contaminated air to recirculate were considered not to have local exhaust ventilation. All ventilation measurements were repeated on the second field visit, using the same methods.

On the second day, all willing radiographers who worked directly with the processing machines, to a maximum of 5 (randomly selected if more volunteered), were asked to wear personal samplers. Subjects were given an explanation of the sampling setup and told what to do in case there were problems. All were asked to sign a consent form (Appendix D). Each participant was fitted with two MSA Flow-Lite™ constant-flow sampling pumps before starting work. One pump was calibrated to draw air at 1.2 L/min through the sampling train for glutaraldehyde; the other used a flow splitter calibrated to draw air through the sampling trains for acetic acid at 0.5 L/min and for SO_2 at 0.1 L/min. The pumps were calibrated before and after sampling using a Gillibrator® automated soap-film flowmeter. The sampling pumps were attached to a waist belt, the collection devices were clipped onto the employee's lapel, and rubber tubing connecting the collection devices to the pumps

was taped along the subject's back to prevent interference with work. All samples were collected concurrently for a full shift (7.5 to 9 hrs).

One field blank for each chemical was included for each facility. All samples were stored in a refrigerator (4 °C) to await one of the biweekly deliveries to the laboratory for analysis. All chemical analyses were conducted by the WCB Analytical Laboratory. Limits of detection for the analytical techniques were reported by the laboratory as the lowest dilutions of standards used to calibrate the methods: 0.3 microgram for glutaraldehyde, 10.0 micrograms for acetic acid, and 1.0 microgram for sulphur dioxide. The average concentration detection limits (mass detection limit divided by the average air volume sampled) were 0.0005 mg/m^3 for glutaraldehyde, 0.04 mg/m^3 for acetic acid, and 0.017 mg/m^3 for sulphur dioxide.

Initial results of sampling indicated that personal exposure levels were low (often below detection limits), therefore worst case exposure levels at 20 subsequent sites were estimated using full-shift area samples collected with an equivalent sampling train placed atop or beside film processing machines.

During the sampling period, work tasks performed by the subjects were recorded every 10 minutes, using the following task categories: 1) in darkroom feeding film; 2) loading film into daylight processor; 3) observing processed film around processing area; 4) taking picture of patient; 5) waiting in processing area; 6) inputting computer data; 7) out of processor area; 8) refilling chemicals; 9) cleaning processing machine; and 10) cleaning spills. After the completion of the sampling period, each subject was asked a series of questions regarding her/his work history, complaints about odours from the processing chemicals, and whether the sampling day was a "normal" day. In addition, the estimated number of films processed by each machine throughout the measured shift was recorded. Forms used to collect the information during the exposure monitoring survey are included as Appendix E. The forms allowed for collection of data about subjects' use of respirators and other personal protective equipment.

2.4 Data Analysis

Descriptive statistics (means for continuous data and counts for categorical) were used to examine the characteristics of provincial radiographic processing facilities determined by the telephone survey. The characteristics of public and private facilities were compared using t-tests for continuous data and chi^2 for categorical data.

Descriptive statistics (arithmetic and geometric means, geometric standard deviations, minima, and maxima) were used to characterize the levels of airborne exposure to glutaraldehyde, acetic acid, and sulphur dioxide. Because examination of frequency histograms of the exposures variables suggested that the data were approximately log-normally distributed, all exposure data were log-transformed (base e). Data below detection limits were divided by the square root of 2, according to the recommendations of Hornung and Reed [1990]. Stratification on public versus private facility types was done, and inferential tests used to examine differences, as described above. Paired t-tests were also used to compare mean concentrations of personal and area measurements taken in the same facilities.

Ventilation characteristics, including volumetric flow rates, room air volumes per hour, room volumes, and exhaust duct areas for general ventilation, and velocities, flow rates and duct diameters

for local exhaust ventilation, were summarized. The levels of personal exposures associated with three levels of general ventilation (none, < 10 room air volumes per hour, and ≥ 10 room air volumes per hour) and three levels of local exhaust ventilation (none, < 20 cfm, and ≥ 20 cfm) were compared using one-way analysis of variance (ANOVA).

Descriptive statistics were used to summarize characteristics of the sites, film processing machines, and radiographers included in the air monitoring study. Characteristics of sites included the number of radiographers, number of machines, number of rooms in which processors were housed, and the number of films processed per week. Characteristics of machines included make, location, brand of developer used, brand of fixer used, presence of a silver recovery unit, method of chemical mixing, and temperature and humidity in the room where the machine was housed. Characteristics of the radiographers included the radiography experience, shift length, reported availability and use of personal protective equipment (PPE), and tasks performed.

To test whether any additional factors beyond ventilation and facility type were associated with personal exposures, a multiple regression analysis was conducted. 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 $r \geq 0.7$, only one variable was chosen for inclusion in the analysis, the variable considered likely to be most directly related to exposure. 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. Initially an ordinary least squares backwards regression was conducted; all variables with $p \leq 0.10$ were retained. To control for correlation within facility beyond that explained by the factors in the model, we entered these variables into ProcMixed in SAS, designating facility as a random variable.

Because more than 40% of the personal exposures to each analyte were less than the limits of detection of the sampling and analytical methods, we also used logistic regression models to examine factors associated with exposures above and below the detection limits. These models were compared to the linear regression models to determine which factors entering the models were the most stable predictors of exposure.

3.0 Results

3.1 Telephone Interview

Of the 181 radiographic film processing facilities identified in British Columbia in the summer of 1998, 106 were selected for a telephone interview. The supervisor or another senior employee of 102 of the facilities (96%) agreed to participate in the survey.

The reported characteristics of radiographic film processing facilities in British Columbia are outlined in Table 3, stratified by whether the facilities were in publicly owned hospitals or health centres (63.7%), or in privately owned businesses (36.3%). Hospital and private facilities differed considerably in size. On average, private clinics had fewer employees, and fewer film processing machines on site.

Table 3: Characteristics of hospital-based and private radiographic film processing facilities in British Columbia

		All Facilities N=102	Hospital Facilities N=65	Private Facilities N=37
# of employees who work	Mean	9.8	12.7	4.5
with the film processing machines	SD	13.4	15.9	3.7
	Min - Max	1 - 60	1 - 60	1 - 20
				*p=0.002
# of employees who work	Mean	11.9	15.6	5.2
in the processing area	SD	20.0	24.1	4.1
	Min - Max	1 - 150	1 - 150	1 - 20
				p=0.011
# of film processing machines	Mean	2.3	2.7	1.5
on site	SD	2.1	2.5	0.73
	Min - Max	1 - 13	1 - 13	1 - 4
				p=0.005
# of rooms in which film	Mean	1.9	2.2	1.4
processing machines are located	SD	1.7	2.0	0.68
	Min - Max	1 - 10	1 - 10	1 - 4
				p=0.014
# of films processed per week	Mean	1243	1361	1036
	SD	1301	1554	621
	Min - Max	15 - 7450	15 - 7450	100 - 2400
				p=0.23
Ventilation upgraded in the	Yes	17	12	5
last 2 years	No	85	53	32
				p=0.52

SD = standard deviation
Min - Max = Minimum to Maximum
*p-values for tests for differences between hospital and private facilities, t-test or chi^2

If the data are representative of all 181 facilities in the province, it suggests that in British Columbia in the fall of 1998, there were about 1,770 radiographers who worked directly with film processing machines, and about 375 other employees who worked in the vicinity of the machines. It also suggests that there were over 400 x-ray film processing machines in the province, and they developed a total of about 225,000 films per week.

Table 4 outlines the reported characteristics of the 230 processing machines present in the surveyed facilities in the fall of 1998, again stratified by whether they were located in publicly owned hospitals or health centres (76%), or in privately owned businesses (24%). Most machines (57.5%) were located in dark or semi-dark rooms where access must be restricted, but a large proportion (42.6%) were "daylight" machines which can be located anywhere. Hospitals used daylight processors much more often than private facilities. The majority of machines were made by Kodak (60.4%), though a few other manufacturers had significant proportions of the market: Fuji (16.1%), Dupont (11.7%), and Agfa (8.6%). Kodak developers and fixers were also the dominant brand, but three companies each held more than 10% of the market share for developer and fixer chemistry, including two which do not manufacture processing machines: Picker; White Mountain; and Dupont. Each of manufacturers offered the chemistry in several different formulations (see Appendix C). The number of films processed weekly varied by almost 3 orders of magnitude between the processing machines. Almost all the machines (91.7%) had automatic chemical mixing. Similar numbers had silver recovery units attached (92.6%). Most machines (95.2%) were reported to be placed in rooms with general room ventilation, and 83.9% had local exhaust from the machine itself. Private facilities were somewhat less likely to have general and local exhaust ventilation of their machines. In 17 of the 102 facilities (Table 3), supervisors reported that there had been upgrades to the ventilation of the film processing machines in the previous 2 years.

Table 4: Characteristics of x-ray film-processing machines in hospital-based and private facilities in British Columbia

		All Facilities N=230	Hospital Facilities N=175	Private Facilities N=55
Location of x-ray film-processing machines	Darkroom	130	84	46
	Daylight	98	91	7
	Semi-dark (yellow)	2	0	2
				*p<0.001
Make of x-ray film-processing machines	Kodak	139	107	32
	Fuji	37	20	17
	Dupont	27	25	2
	Agfa	20	16	4
	Konica	5	5	0
	Odelt	1	1	0
	AFP	1	1	0
				p=0.003
Number of films processed per machine per week	Mean	510	503	697
	SD	550	499	518
	Min - Max	5 - 3200	5 - 3200	35 - 2000
				p=0.014
Brand of developer used	Kodak	100	78	22
	Picker	35	25	10
	White Mountain	33	17	16
	Dupont	32	31	1
	Agfa	16	13	3
	Autex	11	8	3
	Fuji	2	2	0
	Varix	1	1	0
				p=0.002
Brand of fixer used	Kodak	90	68	22
	Picker	49	39	10
	White Mountain	32	16	16
	Dupont	23	22	1
	Agfa	17	14	3
	Autex	16	13	3
	Fuji	2	2	0
	Varix	1	1	0
				p=0.009
Method of mixing machine chemicals	Automatic	211	156	55
	Manual	19	19	0
				p=0.011
General ventilation in processor room	Yes	219	171	48
	No	11	4	7
				p=0.002
Machine has local exhaust ventilation	Yes	193	150	43
	No	37	25	12
				p=0.19
Machine has silver recovery unit	Yes	213	160	53
	No	17	15	2
				p=0.22

*p-values for tests for differences between hospital and private facilities, t-test or chi^2
SD = standard deviation
Min - Max = Minimum to Maximum

3.2 Exposure Monitoring

Among the 102 facilities participating in the telephone survey, there were a total of 41 facilities in Prince George and the greater Vancouver area that were eligible to participate in the exposure monitoring part of the study. 36 (88%) agreed to participate, and 19 public and 16 private facilities were selected for the study; three of them were in Prince George.

In the exposure monitoring study, a total of 177 radiographers were present during the sampling shifts. Of these, 117 volunteered to participate in the exposure monitoring (66%). A smaller proportion of radiographers volunteered at hospital-based than private facilities (82/135=61% and 35/42=83%, respectively; chi^2=7.297, p=0.007). There were two reasons for the lower participation rate in hospitals: their radiographers knew that there were many employees to choose from, therefore felt less obligation to participate; and some radiographers who worked part-time or on a casual basis in several hospitals declined to participate at a second site. Because we could sample a maximum of 5 radiographers at each site, exposure measurements were made on 97 of the 117 radiographers who volunteered.

3.2.1 Personal Exposures

Table 5 indicates that radiographers' personal exposures to glutaraldehyde, acetic acid, and sulphur dioxide were low. The majority of glutaraldehyde samples were below detection limits, as were a large proportion of both the acetic acid and sulphur dioxide samples. None of the samples exceeded the Worker's Compensation Board of British Columbia 8-hour exposure limits of 24.5 mg/m^3 for acetic acid or 5.2 mg/m^3 for sulphur dioxide. The WCB has a ceiling limit for glutaraldehyde of 0.25 mg/m^3. We measured exposures throughout a full shift, so the measures are not strictly comparable. However, since the maximum full-shift glutaraldehyde exposure measured was less than $1/100^{th}$ of the ceiling limit, it is extremely unlikely that the ceiling limit was exceeded, even for short periods within a shift [Rappaport and Selvin, 1988].

Personal exposures in the hospital settings were significantly lower than those in the private facilities (t-tests, comparison of geometric means: $p_{glutaraldehyde} = 0.001$; $p_{acetic\ acid} < 0.001$; $p_{sulphur\ dioxide} < 0.001$).

3.2.2 Area Concentrations

Because of the low concentrations found in the initial batch of personal samples analyzed at the WCB Laboratory, area samples were taken at 20 facilities subsequently studied to determine whether air concentrations were higher in close proximity to the film processing machines. Table 6 indicates that a greater proportion of the area samples had detectable air concentrations, and arithmetic mean concentrations of acetic acid and sulphur dioxide were 1.6 and 3.1 times higher than those of personal samples respectively. Personal and area glutaraldehyde levels did not differ. In paired t-tests of the mean personal and area exposure levels in the 20 facilities where area samples were taken, only sulphur dioxide levels were significantly higher in area than personal samples (comparison of geometric means, $p_{glutaraldehyde} = 0.29$, $p_{acetic\ acid} = 0.12$, $p_{sulphur\ dioxide} = 0.001$). Area concentrations were also low compared to existing occupational exposure standards.

Differences in area concentrations between hospital and private facilities were not statistically significant (t-tests, comparison of geometric means: $p_{glutaraldehyde} = 0.78$, $p_{acetic\ acid} = 0.47$, $p_{sulphur\ dioxide} = 0.67$).

Table 5: Concentrations of glutaraldehyde, acetic acid, and sulphur dioxide in the breathing zones of radiographers during a full work shift, in 19 hospital and 16 private facilities

	Glutaraldehyde	Acetic Acid	Sulphur Dioxide
All facilities (N=97 air samples)			
% < LOD	53.6	42.3	40.2
Minimum > LOD (mg/m³)	0.0006	0.031	0.020
Maximum (mg/m³)	0.0023	0.80	0.41
Arithmetic mean (mg/m³)	0.0009	0.088	0.078
Geometric mean (mg/m³)	0.0008	0.060	0.040
Geometric standard deviation	1.62	1.85	2.66
Hospitals (N=62)			
% < LOD	64.5	56.5	59.7
Minimum > LOD (mg/m³)	0.0006	0.031	0.024
Maximum (mg/m³)	0.0020	0.12	0.32
Arithmetic mean (mg/m³)	0.0007	0.053	0.041
Geometric mean (mg/m³)	0.0007	0.048	0.027
Geometric standard deviation	1.50	1.51	2.24
Private Facilities (N=35)			
% < LOD	34.3	17.1	5.7
Minimum > LOD (mg/m³)	0.0008	0.042	0.020
Maximum (mg/m³)	0.0023	0.80	0.41
Arithmetic mean (mg/m³)	0.0011	0.12	0.11
Geometric mean (mg/m³)	0.0009	0.089	0.080
Geometric standard deviation	1.71	2.05	2.40

LOD = limit of detection

Table 6: Concentrations of glutaraldehyde, acetic acid, and sulphur dioxide on or near film processing machines during a full work shift, in 11 hospital and 9 private facilities

	Glutaraldehyde	Acetic Acid	Sulphur Dioxide
All facilities (N=22 air samples)			
% < LOD	45.4	22.7	13.6
Minimum > LOD (mg/m³)	0.0007	0.051	0.058
Maximum (mg/m³)	0.0020	0.700	1.03
Arithmetic mean (mg/m³)	0.0009	0.14	0.24
Geometric mean (mg/m³)	0.0008	0.102	0.159
Geometric standard deviation	1.78	2.35	2.89
Hospitals (N=13)			
% < LOD	53.8	30.8	7.7
Minimum > LOD (mg/m³)	0.0009	0.051	0.058
Maximum (mg/m³)	0.0020	0.70	0.62
Arithmetic mean (mg/m³)	0.0009	0.14	0.21
Geometric mean (mg/m³)	0.0008	0.090	0.15
Geometric standard deviation	1.74	2.55	2.68
Private Facilities (N=9)			
% < LOD	33.3	11.1	22.2
Minimum > LOD (mg/m³)	0.0007	0.054	0.10
Maximum (mg/m³)	0.0020	0.31	1.03
Arithmetic mean (mg/m³)	0.0010	0.15	0.29
Geometric mean (mg/m³)	0.0008	0.12	0.18
Geometric standard deviation	1.90	2.11	3.38

3.2.3 Ventilation

In the facilities studied, there were 102 film processing machines, most housed in separate rooms. The majority of these rooms had general ventilation (77%; Table 7). Most of the machines themselves had local exhaust ventilation of the processor cabinet (85%; Table 8). Only 6 machines (6%) had neither type of ventilation.

The quality of the ventilation was variable, with about 37% of rooms having exhaust flows equivalent to 10 or more room air volumes per hour, and about 32% of machines having local exhaust flow rates of at least 20 cubic feet per minute (cfm). None of the machines had both high local exhaust flow rates and high general ventilation rates. It is interesting to note that 7 processing machines (located in 3 hospitals and 2 private facilities) with exhaust ducts had no fan attached to exhaust the air. These were counted as not having local exhaust ventilation.

Ventilation of the film processing machines was more frequently present and of better quality in the hospital facilities than in the private clinics (chi^2, contingency table, numbers of machines with various ventilation rates, all facilities, Tables 7 and 8; $p_{general\ ventilation} = 0.059$, $p_{local\ exhaust\ ventilation} = 0.015$).

Table 7: Characteristics of the general ventilation in rooms housing film processing machines in the 19 hospital and 16 private facilities where exposures were measured

	All Facilities		Hospitals Facilities		Private Facilities	
No. of rooms	86		63		23	
No. with no general room ventilation (%)	20	(23%)	12	(19%)	8	(35%)
No. with flow < 10 room air volumes/hr (%)	34	(40%)	23	(37%)	11	(48%)
No. with flow ≥ 10 room air volumes/hr (%)	32	(37%)	28	(44%)	4	(17%)
Mean room exhaust flow rate (SD) (cfm)	231	(326)	289	(359)	71	(110)
Mean room air volumes/hr (SD)	10.4	(12.3)	12.2	(13.5)	5.4	(6.0)
Mean room volume (SD) (ft^3)	1,485	(1,419)	1,777	(1,525)	685	(550)
Mean room exhaust duct area (SD) (ft^2)	1.0	(1.9)	0.89	(0.84)	1.3	(3.3)

SD = standard deviation

Table 8: Characteristics of the local exhaust ventilation of film processing machines in the 19 hospital and 16 private facilities where exposures were measured

	All Facilities	Hospitals Facilities	Private Facilities
No. of processing machines	102	77	25
No. with no local exhaust ventilation (%)	15 (15%)	8 (10%)	7 (28%)
No. with local exhaust ventilation but no flow measurements possible (%)	21 (21%)	13 (17%)	8 (32%)
No. with volumetric flow rate < 20 cfm (%)	33 (32%)	26 (34%)	7 (28%)
No. with volumetric flow rate ≥ 20 cfm (%)	33 (32%)	30 (39%)	3 (12%)
Mean volumetric flow rate (SD) (cfm)	21.9 (26.2)	22.3 (20.8)	20.1 (40.6)
Mean duct diameter (SD) (inches)	2.9 (1.2)	3.1 (1.0)	2.3 (1.3)

SD = standard deviation

3.2.4 Relationship between Ventilation and Exposures

The effect of ventilation on the personal exposures of radiographers was examined by considering the ventilation characteristics of the dominant machine with which they worked. There were problems measuring ventilation velocities in some rooms and local exhaust ducts, therefore only 93 of 97 personal exposure measurements could be used to examine the effects of general ventilation, and only 84 of the exposure measurements could be used to examine local exhaust effects.

No reductions in exposure were observed with general ventilation of the rooms where the film processing machines were located (Table 9).

Local exhaust ventilation of the main machine used was associated with reduced exposures among radiographers, with reductions of 20 to 46%, compared to no local exhaust (Table 9). The highest ventilation flow rates (≥ 20 cfm) usually appeared to be associated with lower exposures than were lower exhaust rates.

Table 9: Arithmetic and geometric mean personal exposures to glutaraldehyde, acetic acid, and sulphur dioxide according to the ventilation characteristics of the main machine used by the radiographer being sampled in 35 hospital and private facilities

	N	Glutaraldehyde (mg/m^3)	Acetic Acid (mg/m^3)	Sulphur Dioxide (mg/m^3)
General Room Ventilation				
Arithmetic means				
None	18	0.0009	0.071	0.063
Room air volumes/hour < 10	42	0.0009	0.086	0.081
Room air volumes/hour ≥ 10	37	0.0008	0.069	0.051
		*p=0.57	p=0.64	p=0.24
Geometric means				
None	18	0.0008	0.035	0.059
Room air volumes/hour < 10	42	0.0008	0.048	0.062
Room air volumes/hour ≥ 10	37	0.0007	0.035	0.059
		p=0.60	p=0.29	p=0.94
Local Exhaust Ventilation				
Arithmetic means				
None	25	0.0010	0.10	0.094
Volumetric flow rate < 20 cfm	24	0.0007	0.079	0.051
Volumetric flow rate ≥ 20 cfm	35	0.0008	0.053	0.066
		p=0.043	p=0.10	p=0.17
Geometric means				
None	25	0.0009	0.061	0.086
Volumetric flow rate < 20 cfm	24	0.0007	0.038	0.050
Volumetric flow rate ≥ 20 cfm	35	0.0007	0.033	0.049
		p=0.019	p=0.058	p=0.001

*p-values for tests for differences in concentration by ventilation rate, one-way ANOVA

Figures 1, 2, and 3 show the relationship between glutaraldehyde, acetic acid, and sulphur dioxide concentrations and local exhaust ventilation flow rates graphically.

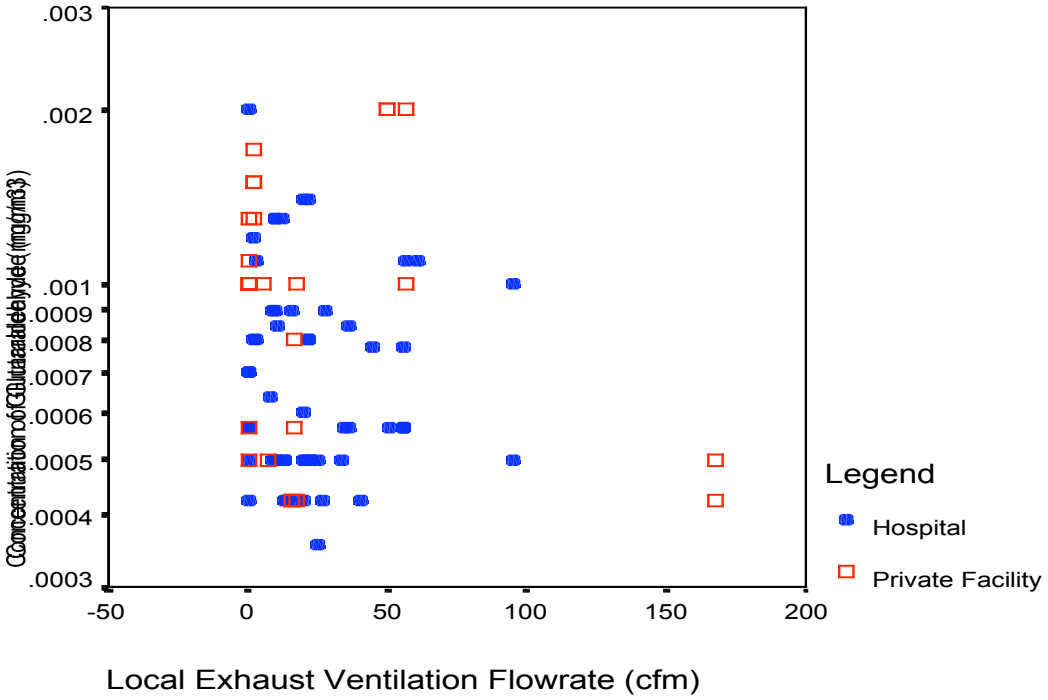

Figure 1: Relationship between glutaraldehyde concentrations and local exhaust ventilation flow rates

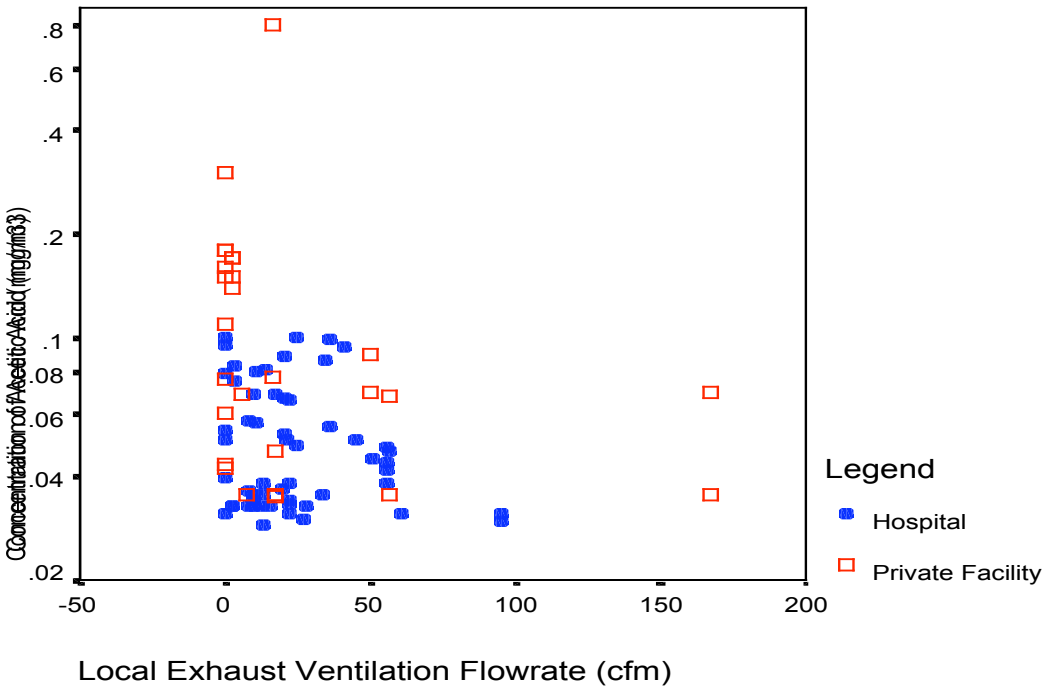

Figure 2: Relationship between acetic acid concentrations and local exhaust ventilation flow rates

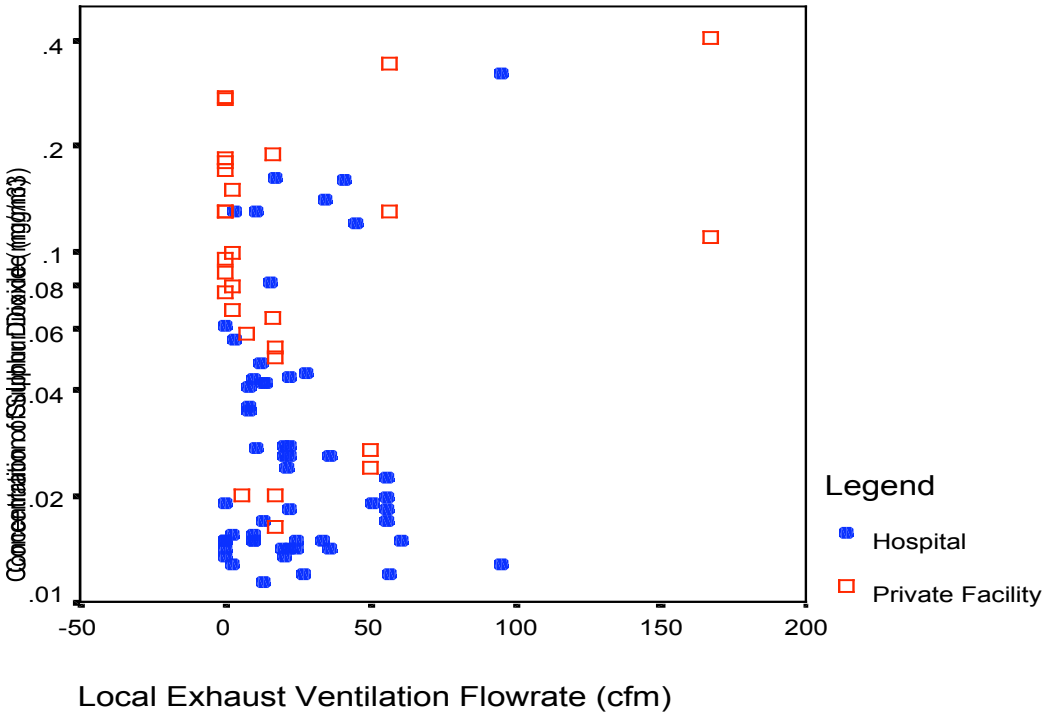

Figure 3: Relationship between sulphur dioxide concentrations and local exhaust ventilation flow rates

3.2.5 Other Characteristics of the Sites in the Exposure Monitoring Survey

Characteristics of the 35 facilities included in the exposure monitoring survey are summarized in Table 10. To determine how representative the subset of sampled sites were of facilities province-wide, these characteristics can be compared to those of the 102 facilities sampled in the telephone interview, presented in Table 3. The hospitals in the sampled subset were on average larger than the provincial average, with more radiographers on site, more film processing machines, and more films processed every week. This is expected given that the exposure study was based in the Lower Mainland, the location of the largest hospitals in the province. The private clinics included in the exposure study were similar in size to those province-wide, although they processed more films per week, on average.

Table 10: Characteristics of the 19 hospital and 16 private facilities where exposures were measured

	All Facilities N=35	Hospitals Facilities N=19	Private Facilities N=16
Mean no. of radiographers on site (SD)	17.3 (16.8)	27.6 (16.9)	5.1 (2.4)
Mean no. of machines on site (SD)	2.9 (2.1)	4.1 (2.2)	1.6 (0.6)
Mean no. of rooms in which processing machines located (SD)	2.4 (1.7)	3.3 (1.8)	1.4 (0.6)
Mean no. of films processed/week (SD)	1933 (1525)	2548 (1781)	1203 (646)

SD = standard deviation

Tables 11 and 12 indicate characteristics of the rooms housing the film processing machines and of the machines themselves at the exposure study sites. The temperatures and relative humidities in the film processing rooms did not vary much between facilities or by facility type (Table 11). Developer and fixer concentrate were added to make up working solutions on about one-quarter to one-third of sampling days. In most facilities, the concentrate was added to a central working solution system that fed all the machines housed in a room.

Table 11: Data collected within the 86 rooms housing film processing machines at the facilities where exposures were measured

	All Facilities N=86	Hospitals Facilities N=63	Private Facilities N=23
Mean temperature on sampling day, in °C (SD)	22.1 (1.5)	22.4 (1.4)	21.1 (1.5)
Mean relative humidity on sampling day, in % (SD)	45.6 (6.9)	44.8 (7.3)	47.7 (5.3)
Mean number of bottles of developer concentrate added on sampling day (SD)	0.26 (0.54)	0.26 (0.54)	0.26 (0.54)
Mean number of bottles of fixer concentrate added on sampling day (SD)	0.33 (0.62)	0.32 (0.62)	0.35 (0.65)

SD = standard deviation

The characteristics in Table 12 can be compared to those from the telephone survey sites, listed in Table 4. Once again, the hospitals in the exposure study subset differed somewhat from those province-wide: they used daylight processors more frequently; they used Picker processing chemistry

more frequently than Kodak; and they did not use manual chemical mixing for any of their machines. Private facilities in the exposure study were very similar to those province-wide, except that they were less likely to use Kodak machines. None of the machines had chemical spills on the sampling days.

Table 12: Characteristics of 102 film processing machines at the facilities where exposures were measured

	All Facilities N=102	Hospitals Facilities N=77	Private Facilities N=25
Location of film processing machines			
Darkroom	47	26	21
Daylight	55	51	4
Make of machines			
Kodak	57	47	10
Fuji	14	4	10
Dupont	17	15	2
Agfa	12	9	3
Odelft	1	1	0
AFP	1	1	0
Mean no. of films processed /machine/week (SD)	702 (357)	607 (255)	814 (431)
Brand of developer used			
Kodak	28	20	8
Picker	31	27	4
Dupont	19	19	0
White Mountain	8	1	7
Agfa	8	5	3
Autex	5	2	3
Fuji	2	2	0
VAR-IX	1	1	0
Brand of fixer used			
Picker	42	38	4
Kodak	19	11	8
Dupont	13	13	0
Agfa	9	6	3
Autex	9	6	3
White Mountain	7	0	7
Fuji	2	2	0
VAR-IX	1	1	0
Method of mixing chemicals			
Manual	0	0	0
Automatic	102	77	25
Machine has silver recover unit	93	70	23
Machine has open drainage	96	77	19
Number of spills on sampling day	0	0	0

SD = standard deviation

Table 13 summarizes characteristics of the radiographers included in the exposure monitoring survey, and the tasks they performed on the sampling days. The study participants had an average of 9 years of experience at the facility in which they were employed and 17 years of experience in radiography. The typical shift length was 7.5 hours.

On the sampling days, the hospital facilities processed an average of 115 films per machine, on target for the weekly workload of about 600 films per machine reported for these facilities. The large majority of hospital radiographers reported that the workload on the sampling day was average. Private facilities averaged 204 films per machine on the sampling days, busier than the reported average weekly workload of about 800 films per machine. Despite this, only a small proportion of radiographers from the private facilities reported that the workload was busy on the sampling day.

The tasks of the radiographers were observed every 10 minutes throughout the sampling days. The most frequent tasks recorded were taking x-rays, time outside the processing area, waiting in the processing area, and observing film. Relatively little time was spent in a darkroom or loading film. Cleaning the processing machine, and refilling chemicals were rarely observed, and no spills occurred during the sampling days.

Although gloves and goggles were available at most of the facilities, especially hospitals, only 2 individuals reported using gloves during the sampling days. No other personal protective equipment use was reported or observed.

The majority of subjects reported smelling the processing chemicals on the sampling day, however, measured levels of personal exposure to glutaraldehyde, acetic acid, and sulphur dioxide were not associated with reported odour (t-tests, all $p > 0.25$).

Table 13: Characteristics of 97 radiographers whose exposures were measured, and their work on the sampling day

	All Facilities N=97		Hospitals Facilities N=62		Private Facilities N=35	
Radiography experience						
Mean years on site (SD)	8.9	(6.1)	8.8	(5.9)	9.0	(6.6)
Mean total years (SD)	16.8	(9.6)	14.2	(9.1)	21.4	(8.7)
Number female (%)	80	(82)	48	(77)	32	(91)
Mean shift length (hours) (SD)	7.5	(0.48)	7.5	(0.47)	7.6	(0.50)
Number of films processed in dominant machine on sampling day (SD)	147	(105)	115	(87)	204	(111)
Reported workload on sampling day						
Slow (%)	36		31		46	
Average (%)	56		58		51	
Busy (%)	8		11		3	
Mean % time spent on the sampling day*						
Taking x-rays (SD)	37	(14.0)	39	(15.4)	34	(10.7)
Outside processing area (SD)	21	(13.8)	23	13.4)	19	(14.4)
Waiting in processing area (SD)	20	(9.0)	18	(9.9)	22	(7.0)
Observing film, by processor (SD)	12	(6.0)	11	(5.8)	15	(5.6)
In darkroom (SD)	4	(5.8)	2	(3.5)	8	(6.5)
Loading film in daylight processor (SD)	3	(4.3)	3	(3.9)	2	(4.8)
Inputting data to computer (SD)	3	(9.0)	4	(11.1)	0	(0)
Cleaning processing machine (SD)	0.06	(0.4)	0	(0)	0.2	(0.7)
Refilling chemicals (SD)	0.05	(0.4)	0	(0)	0.1	(0.6)
Cleaning spills (SD)	0	(0)	0	(0)	0	(0)
Reported PPE availability						
Gloves available on site, in %	88		98		69	
Goggles available on site, in %	56		69		31	
Dust mask available on site, in %	19		21		14	
Cartridge respirator available on site, in %	6		7		6	
Apron available on site, in %	12		19		11	
Reported use of PPE on sampling day						
Wore gloves, in %	2		2		3	
Wore other protective equipment, in %	0		0		0	
Reported smelling processing chemicals on sampling day, in %	66		73		54	

SD = standard deviation

* 3 of the sampled hospital radiographers could not be tracked throughout their work day, therefore task information is based on 59 hospital radiographers, and 94 in total.

PPE = personal protective equipment

3.2.6 Relationship between Exposures and Facility, Machine, or Task Characteristics

In order to determine which facility, machine, and radiographer characteristics were related to exposure levels, after adjusting for other associated factors, we conducted multiple regression analyses with glutaraldehyde, acetic acid, and sulphur dioxide exposure levels as the dependent variables in 3 separate analyses.

To prepare for the analysis, we first examined correlations between independent variables. Facility type (hospital versus private), known to be associated with exposure levels (section 3.2.1 above), was also strongly associated with many of the other independent variables. Since the aim of the modelling was to discern which characteristics of hospital versus private facilities affected exposure levels, facility type was not initially offered to the models.

Both local exhaust ventilation (categorized as no local exhaust ventilation, ventilation flow rates > 0 and < 20 cubic feet per minute (cfm), and ventilation flow rates ≥ 20 cfm) and general ventilation (room air volumes per hour, continuous) were included in the models, because assessing the effectiveness of ventilation was a primary objective of the study.

Other variables were selected for offering in the models if there were reasonable grounds for the hypothesis that they could be related to exposure (i.e., p-value < 0.25 in univariate analyses against exposure level, and direction of effect in univariate analyses could be logically explained). Variables selected for the analyses included the number of films processed in the dominant machine used by the radiographer on the sampling day; the number of processing machines per room; percent of time spent on tasks associated with increased exposure levels (working in the darkroom, loading film into daylight processor, waiting in processing area); whether or not fixer was added; whether or not developer was added; whether the machine had open drainage; and the presence of a silver recovery unit. Tasks associated with decreased exposure levels (taking x-rays and those involving time outside processing area) were not included in the multivariate models, because they replaced the effects of tasks associated with increased exposure, yet were only passively associated with exposure.

Table 14 describes the multiple linear regression models for glutaraldehyde, acetic acid, and sulphur dioxide. Only the number of films processed was a consistent predictor of increased exposure for all three agents. Time spent in a film processing area increased acetic acid and sulphur dioxide exposures, and time in a darkroom increased acetic acid exposure. Local exhaust ventilation lowered glutaraldehyde and acetic acid exposure. The use of a silver recovery unit was also associated with decreased exposure to acetic acid and sulphur dioxide. The proportions of exposure variance explained by these models ranged from 13 to 38%.

Adding facility type to the models in Table 14 (data not shown) removed the number of films processed per machine from all three models because the number of films processed in hospital facilities was lower than in private facilities. Adding facility type also removed percent time spent in a darkroom from the acetic acid model because there was a smaller proportion of darkrooms in hospitals than in private facilities. The models which included facility type instead of the number of films processed or time in darkroom explained somewhat more variance (glutaraldehyde $r^2 = 0.14$, acetic acid $r^2 = 0.38$, sulphur dioxide $r^2 = 0.38$), especially in the sulphur dioxide model, suggesting that there is some additional difference between hospitals and private radiography clinics which remains unaccounted for.

Table 14: Multiple regression models, coefficients (and p-values), for glutaraldehyde, acetic acid, and sulphur dioxide concentrations (all log-transformed, base e)

	Glutaraldehyde	Acetic Acid	Sulphur Dioxide
Number of films processed per machine	0.001(0.03)	0.0014(0.02)	0.0028(0.003)
% time spent in darkroom	-	0.020 (0.05)	-
% time spent in processor area	-	0.018 (0.008)	0.021 (0.05)
Silver recovery unit present	-	-0.50 (0.04)	-0.92 (0.03)
Local exhaust ventilation < 20 cfm	-0.27 (0.04)	-0.40 (0.01)	-
Local exhaust ventilation ≥ 20 cfm	-0.17 (0.15)	-0.44 (0.003)	-
Number of observations	84	82	94
model p-value	0.01	0.0001	0.0003
model r^2	0.13	0.38	0.19

- = not in model
r^2 = the proportion of variance explained

Table 15 shows the results of the multiple logistic regression which compares the odds of exposure above versus below detection limits. Once again, the number of films processed in the dominant machine used by the sampled radiographer was a consistent predictor of increased exposures to all agents. The odds ratios indicate that the odds of exposure to glutaraldehyde, acetic acid, and sulphur dioxide above the detection limit was about 1.5 to 2-fold higher after processing 100 films. The results for percent time spent in the dark room were similar to those of the linear regression analyses. Spending 5% of one's work day in a darkroom increased the odds of detectable exposures to acetic acid and sulphur dioxide by 1.9- and 1.7-fold. Adding another film processing machine to a room increased the odds of detectable exposures to acetic acid and sulphur dioxide by 3- and 2-fold respectively. Adding developer also increased exposure to acetic acid. As in the linear regression analysis, local exhaust ventilation lowered exposures. For glutaraldehyde and acetic acid, the odds of detectable exposures were three to fourteen times lower with local exhaust ventilation than without.

As with the linear regression models, adding facility type to the logistic regression models removed the effect of the number of films processed and percent time spent in a darkroom (data not shown).

Table 16 shows the results of multiple linear regression analyses, controlling for correlation within facility, by including facility as a random variable in a mixed effects analysis. The within-facility correlation was moderate (r from 0.44 to 0.55) for all three agents. By comparing the models presented in Tables 14 and 16, we can observe the variables which were affected by within-site correlation and therefore removed from the new models: number of films processed per machine; time spent in the darkroom; and the presence of a silver recovery unit. After controlling for within-facility correlation, local exhaust ventilation remained a predictor of decreased exposure for glutaraldehyde and acetic acid, and percent time spent in the processor area remained a predictor of increased exposure to acetic acid and sulphur dioxide.

Offering facility type to these models did not remove any of the final variables from the models. Facility type was an explanatory variable for both acetic acid and sulphur dioxide and is included in the model descriptions in Table 16.

Table 15: Multiple logistic regression models showing odds ratios (and p-values) for exposures to glutaraldehyde, acetic acid, and sulphur dioxide, comparing the odds of concentrations above versus below detection limits

	Glutaraldehyde	Acetic Acid	Sulphur Dioxide
# films processed/machine (per 100 films)	1.6 (0.076)	1.6 (0.11)	2.1 (0.017)
# machines/room (per additional machine)	-	3.2 (0.005)	2.4 (0.028)
Time spent in darkroom (per 5%)	-	1.9 (0.035)	1.7 (0.042)
Developer added (yes vs. no)	-	3.2 (0.048)	-
Local exhaust ventilation < 20 cfm	0.28 (0.049)	0.069 (0.001)	-
Local exhaust ventilation ≤ 20 cfm	0.24 (0.025)	0.20 (0.033)	-
Number of observations	82	82	82
model p-value	0.012	< 0.0001	0.0009
model r^2	0.11	0.27	0.17

- = not in model
r^2 = the proportion of variance explained

Table 16: Multiple regression models, coefficients (and p-values), for glutaraldehyde, acetic acid, and sulphur dioxide concentrations (all log-transformed, base e), with facility as a random variable

	Glutaraldehyde	Acetic Acid	Sulphur Dioxide
% time spent in processor area	-	0.012 (0.04)	0.022 (0.006)
Local exhaust ventilation < 20 cfm	-0.30 (0.026)	-0.26 (0.14)	-
Local exhaust ventilation ≥ 20 cfm	-0.14 (0.26)	-0.33 (0.05)	-
Facility type (hospital vs. private)	-	-0.39 (0.02)	-0.99 (0.0005)
Number of observations	84	82	94
model p-value	0.0001	0.004	< 0.0001
model OLS r^2	0.083	0.35	0.31
Within-facility correlation	0.47	0.55	0.44

- = not in model
model OLS r^2 = the proportion of variance explained; since it is not available for the ProcMixed model, the ordinary least squares r^2 for the same model is reported; this does not take into account the within-facility correlation.

4.0 Discussion

4.1 Description of Radiography in British Columbia

The participation in the telephone survey was excellent (96%), therefore should not be affected by selection bias.

Based on our telephone survey, we estimated that there were about 1,770 employees who worked with x-ray film processing machines in the province in 1998. This compares with an enumeration of 1,223 "medical radiation technologists" who were members of the Health Sciences Association in June of 1996. Apart from the year of enumeration, differences in these numbers could be accounted for by inclusion in our estimate of personnel who were not radiographers, radiographers who worked part-time in multiple locations, or radiographers who did not belong to the Association.

The large majority of provincial radiographers work in hospital settings (83%), with machines that have automated chemical mixing (92%) and local exhaust ventilation (84%). All the developing fluids used contain glutaraldehyde, hydroquinone, potassium hydroxide, potassium sulphite, and sodium sulphite; all the fixer solutions contained acetic acid, aluminum sulphate, and ammonium thiosulphate.

The reporting in the telephone interviews was in excellent agreement with our research personnel's observations in those sites subsequently visited. For example, ventilation is likely to be one of the most difficult items for an untrained person to assess, yet in only three of the 35 sites was the presence of general room ventilation misreported. The same was true for local exhaust ventilation. There was no consistency in the direction of misreporting.

4.2 Exposures of Radiographers

4.2.1 Exposure Levels

Agreement by facilities to participate in the exposure survey was excellent (88%), as was agreement to participate in the monitoring by radiographers in private clinics (83%). A smaller proportion of hospital radiographers agreed to the monitoring (61%); whether this lower participation rate affected exposure measurements is not known.

Exposures of radiographers to glutaraldehyde, acetic acid, and sulphur dioxide in this study were low in comparison to current WCB exposure limits [WCB, 1998]. Arithmetic mean concentrations were less than one-sixtieth of the standards (0.25 mg/m^3 ceiling, 25 mg/m^3 8-hour, and 5 mg/m^3 8-hour, respectively). In two published studies of radiographers' exposures to glutaraldehyde, reported concentrations have also been low: 0.003 - 0.006 mg/m^3 in one study [Lienster et al., 1993]; and less than 0.009 mg/m^3 in the other [Gannon et al., 1995]. Hewitt [1993] reported that in measurements in a radiography processing room conducted by the British Health and Safety Executive, no sulphur dioxide was detected (detection limit not indicated). We have not found reports of measurements of radiographers' exposures to acetic acid.

These low exposure levels must be considered in the context of reported health effects. In the study of Gannon et al. [1995], occupational asthma due to glutaraldehyde was confirmed in bronchial

challenge tests of two individuals working in radiography, despite exposure measurements below detection limits. These cases appeared clinically similar to three endoscopy nurses with the same diagnosis whose airborne exposures were considerably higher (mean personal glutaraldehyde levels of 0.041 to 0.17 mg/m^3). There have been other reports of occupational asthma among radiographers [Cullinen et al., 1992; Trigg et al., 1992; Chan-Yeung et al., 1993], as well as reports of other symptoms of unknown etiology [Goncalo et al, 1984; Spicer et al., 1986; Gordon, 1987; Smedley et al., 1996], but no exposure data were reported in these studies.

The still very sparse exposure-response data suggest that adverse health outcomes, of glutaraldehyde at least, can be observed at exposures much lower than WCB exposure limits. The current WCB Regulation recognizes this by designating glutaraldehyde as a sensitizer and requiring exposures to "be kept as low as reasonably achievable." Hydroquinone, another constituent of developers, has the same designation.

There are other reasons why the exposures observed in this study should not be interpreted solely on the basis of WCB exposure limits:

1) Dermal exposures, not measured in this study, may contribute to disease. Few tasks with potential for skin-wetting exposures took place during the study period (e.g., cleaning the processor, refilling chemicals, or cleaning spills), however, it is possible that routine handling of x-rays involves some small recurrent exposures throughout every work day.

- Radiography exposures involve a mixture of many agents. Glutaraldehyde itself has been identified as a sensitizer which can cause asthma in radiographers, but it is also possible that the mixture of agents could contribute to a heightened sensitivity, or to other non-asthma symptoms. Many agents present in the fixer and developer solutions (e.g., hydroquinone) were not measured in this study.
- Exposure standards of some other agencies are lower than the WCB limits. For example, the World Health Organization recommends that exposures to sulphur dioxide not exceed 0.5 mg/m^3 averaged over a 10-minute period in order to protect asthmatics, nor exceed 0.125 mg/m^3 averaged over 24 hours [WHO, 1999]. Although exposures were measured with a different averaging period in this study, the data suggest that both of these guidelines could have been exceeded.

Radiographers' perceptions of odours were not related to exposure levels, therefore lack of perceived odour should not be used as an indicator of low exposure. Odour thresholds and olefactory fatigue vary considerably between subjects. Acetic acid has an odour threshold ranging from 2.5 to 250 mg/m^3, and that for sulphur dioxide ranges from 1.18 to 12.5 mg/m^3 [Ruth, 1986]. The minima are close enough to the highest full-shift average exposures to these agents to expect that some subjects would have smelled these chemicals during higher peak exposures over short periods in their work days. The odour threshold for glutaraldehyde has been reported as 0.16 mg/m^3 [ACGIH, 1997]. Because measured exposures to glutaraldehyde were considerably lower than this, glutaraldehyde is less likely to have been detected by the study subjects.

4.2.2 Ventilation

Local exhaust ventilation of the film processing machines was associated with lower personal exposures to all three agents in univariate analyses, and remained a predictor of reduced exposures to glutaraldehyde and acetic acid even after controlling for other factors. Although this indicates that local exhaust ventilation is an effective method of exposure control for radiography, the exposures

were reduced by less than 50%, and volumetric flow rates greater than 20 cfm did not give consistently better results.

The less than optimum performance of local exhaust ventilation was not expected and suggests investigation of points of gas and vapour release not controlled by the current ventilation design. A possibility is the discharge tray where heated air used to dry the x-ray films and the films themselves exit the cabinet. Sulphur dioxide is a byproduct of the drying process, and was not controlled by the current local exhaust ventilation design, supporting the idea that the film discharge tray could allow gas release. Other locations in the processor rooms which do not normally have local exhaust ventilation include the floor drains to which processor chemicals are discharged and the tanks in which the developer and fixer chemicals are mixed and stored. These are likely to be less important, for the following reasons. Open drainage was not a predictor of exposure in any of the models. The mixing tanks were closed except on the rare occasions when developer or fixer concentrates were added, and these additions were not consistent predictors of exposure. A final possible explanation for the only moderate success of local exhaust ventilation is that some of the exhaust ducts may have fed into the return air ducts of the general ventilation system rather than exhausting to the outdoors. If this were the case, contaminated air could be recirculated in a diluted form back into the building air.

General room ventilation was not found to be related to reduced exposure levels. We used the room's volume and mechanical exhaust air flow rate to estimate the room air exchange rate. Tracer gas methods of measuring air exchange rates would take into account any additional air exchange between adjacent rooms, as well as natural ventilation with outdoor air through poor seals. It is possible that with this more accurate measure of air exchange, a relationship between general exhaust ventilation and exposure would have been detected, however, our results suggest room ventilation is unlikely to be a major source of exposure reduction.

4.2.3 Other Determinants of Exposure

Personnel in private facilities had average exposures 60 to 170 % higher than those in hospitals and health care facilities. Hospitals more frequently had local exhaust ventilation and silver recovery units, they processed fewer films per machine, and their radiographers spent less time in darkrooms and in the processor area. All of these factors were related to lower exposures, and are likely to explain the lower levels observed in the hospital settings. More exposure variance, especially in sulphur dioxide levels, was explained in the models which included facility type. This suggests that some remaining difference between hospital and private facilities remains unaccounted for.

Factors which were the most stable predictors of exposure in the models were the number of films processed per machine, time spent in the processor area, and local exhaust ventilation. Other factors appeared influential in some models, but not others. Adding developer and having more than one machine per room were associated with a greater likelihood of exposures above the detection limit. The use of silver recovery units was associated with lower exposures to acetic acid and sulphur dioxide in the initial multivariate analysis. The reason for this effect is unknown, but it is likely that silver recovery units allow additional time for fixer solutions to cool and become less volatile before the waste fluid exits to the drain.

The models explained 8 to 38% of the variance in exposure. In observational studies examining the

determinants of exposure to other agents in other industries, investigators have been able to explain as little as 3% and as much as 83% of exposure variability [Burstyn and Teschke, 1999]. Exposure variance is often more difficult to explain when exposures are low and a large proportion of exposure measurements are below detection limits, as was the case in this study. However, it is also possible that factors which we did not record contributed to exposure. For example, future studies could attempt to assess flow rates of air emissions from the discharge trays of the processor machines, and conduct more sophisticated measurements of room ventilation.

Some factors were not predictors of exposure in any of the models: the addition of fixer during the work shift; and open drainage of the processing machines. The addition of fixer and developer chemistry and sealed drains were only rarely observed, therefore effects of these factors may have been difficult to detect. Other characteristics were observed infrequently (e.g., loading films and cleaning machines) or varied little (e.g., relative humidity and temperature); effects of these factors were not detected in this study. None of the machines in the exposure study used manual mixing and there were no spills on the sampling days, therefore the effects of these factors could not be evaluated.

4.3 Study Limitations

Though the limits of detection of the exposure monitoring methods used in this study were well below WCB exposure limits, the methods were unable to detect exposures in more than 40% of the personal measurements. More sensitive sampling and analysis methods would be extremely useful to permit exposure-response analyses which can examine whether effects occur at very low levels, as suggested by some evidence to date.

Dermal exposures were not assessed in this study, so their contribution to total dose is unknown. Such exposures may be contributors to sensitization. Measurement of dermal exposures is not standardized or simple. Although quantification of chemicals or their metabolites in biological fluids, such as urine or blood, is ideal as an indicator of total dose from all routes of exposure, such methods require that the metabolism and kinetics of the agent are known. When biological monitoring is not possible, methods which assess skin exposure by means of patches, body dosimeters, or tracers may be used, but these have many limitations in interpretation.

This study did not measure all the possible chemicals used in radiography. Of those not included, the glycols, potassium hydroxide, and hydroquinone are the most deserving of follow-up because of their frequency of use and/or existing exposure standards. However, all are considerably less volatile than the chemicals measured in this study, so it seems unlikely that airborne exposures to these chemicals would be as high as those measured here.

The exposure portion of this study included many large hospitals in the Vancouver area. It is not clear whether the results are generalizable to smaller public facilities in less populous areas. Because the private facilities in the exposure study resembled those in the telephone survey, their results are expected to be applicable throughout the province.

4.4 Conclusions and Recommendations

The results of this study indicate that radiographic film processing personnel in British Columbia have exposures to glutaraldehyde, acetic acid, and sulphur dioxide at levels well below current WCB exposure limits. However, because glutaraldehyde is a sensitizer, and because there is some evidence that health effects, including asthma, may occur at levels lower than these standards, efforts to minimize exposures remain the best practice.

Most facilities in the province employ local exhaust ventilation of processing machine cabinets and have silver recovery units. Both measures were associated with reduced exposures in this study, and are reasonable control strategies. To ensure the usefulness of local exhaust ventilation systems, the ducting from the processor cabinets must be connected to a fan designed for the system, capable of exhausting the contaminated air at a flow rate of at least 20 cfm to the outdoors.

Sulphur dioxide levels were not controlled by standard processor cabinet ventilation. We hypothesized that this may be due to contaminated air exiting the machine at the film discharge tray. Local exhaust ventilation hoods at these locations may reduce exposures, but would need to be designed and tested. As a preliminary recommendation, the exhaust flow rate should be at least twice the flow rate of air discharged from the machine (or three times if the temperature of the air leaving the processor is over 50 °C).

Radiographers who spent more time in film processing rooms had higher exposures in this study, therefore administrative measures or machine placements to reduce the time spent in proximity of the machines would be effective control measures. Sealing open drains would be good practice, though we did not observe an increase in exposures with open drainage in this study.

Another prevention option may eventually eliminate the chemical exposures altogether: the adoption of digital imaging processes. Digital imaging can be done using digital x-ray cameras, or using traditional cameras, but capturing the image on reusable "direct-capture thin-film-transistor" detectors instead of photographic film. While the digital images can still be transferred to photographic film using traditional wet-chemical processors, the technology allows the alternatives of viewing the images on a computer screen or dry-printing them on film. Such technologies were observed in use at two of the 35 sites in the exposure monitoring survey. Digital imaging is slowly being adopted in the industry because it allows computer transfer and manipulation of the x-ray images, improving their diagnostic utility.

Any future studies of wet-chemical film processing should include measurements of dermal exposure to both the volatile and non-volatile constituents of the developers and fixers, should investigate methods to reduce detection limits of airborne exposures, and should attempt to assess exposures during spills and manual mixing. Studies investigating the relationship between both dermal and airborne exposures and health effects would greatly improve our ability to design and locate control measures.

5.0 References

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