EXPOSURE TO POTTERY KILN EMISSIONS:

A Pilot Study to Measure Potters' Exposures

to the Vapours And Ærosols Emitted During the Firing Process

by

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ABSTRACT

Area samples for gases and metals were taken at 10 sites from each of five categories: professional studios, recreation centres, elementary schools, secondary schools, and colleges. Reported concentrations are in $\mu g/m^3$ unless otherwise specified. Means and maxima are reported for substances detectable at 50% or more of all sites: nitrogen dioxide (0.021 ppm, 0.060 ppm), aluminum (1.13, 15.6), barium (0.015, 0.091), boron (0.534, 5.25), iron (0.549, 4.04), manganese (0.013, 0.094). Only maximum values are reported for substances with fewer than 25 of the 50 measurements above detection limits: sulfur dioxide (0.508 ppm), fluorides (0.152 ppm), formaldehyde (0.102 ppm), carbon monoxide (7 ppm), antimony (0.010), beryllium (0.002), cadmium (0.114), chromium (0.431), cobalt (0.169), copper (0.002), lead (0.208), lithium (0.015), magnesium (4.25), mercury (0.017), nickel (0.291), selenium (0.249), silver (0.003), vanadium (5.22), and zinc (1.50). There were no detectable levels of arsenic or gold.

Personal metal exposures were sampled at 24 sites. Means and maxima are reported for metals present at more than 50% of all sites. Where more than 50% of all values are below detection limits, only maxima are reported. Aluminum (7.82, 62.8), barium (0.085, 0.368), beryllium (0.005) boron (0.655, 3.89), cadmium (0.999), chromium (0.306), cobalt (0.069, 0.863), copper (0.075, 0.312), iron (2.51, 27.0), lead (0.788), lithium (0.125), magnesium (1.87, 9.57), manganese (0.056, 0.174), nickel (0.175), silver (1.76), zinc (0.359, 3.58). There were no detectable levels of antimony, arsenic, gold, mercury, selenium, or vanadium.

In general, measured concentrations were well below North American occupational limits.

Personal metal exposures tended to exceed kiln area concentrations, suggesting other important sources of metal exposure.

Small, ventilated kiln rooms, with contaminant concentrations ranking among the highest measured, indicate a potential for higher contamination.

Industrial exhaust hoods accompanied by HVAC systems proved the most effective ventilation strategy.

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1. INTRODUCTION

1.1 Goal

Some ten thousand British Columbia potters work in small private studios, co-operative facilities, educational institutions, or recreation centres. There has been considerable concern that this diffuse, largely unregulated activity, involving thousands of individuals, may involve exposures to unacceptable levels of kiln emissions. Pottery production is not concentrated in regulated worksites. Pottery kiln emissions and the health risks associated with these emissions have not been adequately characterized. This study was undertaken to provide information needed to 1) assess the extent to which potters and others may be exposed to pottery kiln emissions in commercial, educational, recreational, or residential studios and 2) provide a preliminary evaluation of variables affecting exposures.

1.2 Objectives

The purposes of this study were to a) quantify emissions of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), fluoride (F), formaldehyde, carbon monoxide (CO), and several glaze metals [aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), lithium (Li), magnesium (Mg), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), vanadium (V), and zinc (Zn)] in professional, educational, recreational and home pottery studios; b) quantify personal metal exposures over the time the kiln was firing; c) compare emission levels to the Workers' Compensation Board of British Columbia Permissible Concentrations; d) compare personal exposures to the

concentrations detected by kiln area samples; e) compare emissions from firing green ware (the bisque firing) to those from firing glazed bisque ware (the glaze or glost firing); f) examine emission differences by site category (professional, recreation centre, elementary school, secondary school, and post secondary institution); g) determine the effects of ventilation on emissions; h) relate emissions to quantities and types of clay; i) relate emissions to quantities and types of glaze materials; j) determine the effects of the firing environment (indoor/outdoor, room size) on emissions; and k) assess measures taken to minimize exposures.

1.3 Background

Although there are numerous books and articles warning potters about the dangers of kiln emissions (McCann, 1992; Rossol, 1987; Rossol, 1982), there is a paucity of primary literature containing published measurements of emission concentrations.

1.3.1 The Exposed Population

It has been speculated that kiln emissions may contain a number of airborne contaminants which are regulated under the Workers Compensation Board (WCB) of British Columbia Industrial Health and Safety Regulations. Although school teachers, college instructors, and studio technicians who teach pottery in educational institutions are covered by these regulations, exposure to kiln emissions is not limited to adult workers currently covered by the WCB. Many potters work from their homes where spouses and children are also potentially exposed (McDiarmid and Weaver 1993). Other potentially exposed groups would include children, youths and adults taking art classes in studio rooms where kilns are fired, sick or injured people who make pottery as part of their rehabilitation, and the

people who instruct them. Because the exposed population may include individuals with pre-existing health problems or with increased susceptibility, and because exposures may be chronic, occupational exposure limits (e.g. the W.C.B.'s Permissible Concentrations) may not define safe levels for everyone.

1.3.2 The Pottery Process

A piece of green ware, formed from raw clay, is generally fired in an electric kiln at temperatures between 875 °C and 1230 °C to form bisque ware. The duration of firing depends on the total mass of clay, its thickness, and moisture content, kiln condition, maximum firing temperature, and personal preferences related to rate of temperature increase. A 4 to 5 hour bisque firing is of short duration. The habit of "candling" or "presoaking" kiln contents overnight at low temperatures (from 180 °C to ensure dryness to 500 °C to drive off organic gasses) can extend firings into the 18 to 20 hour range.

To make porous pottery water tight, brittle bisque ware more durable, and to add decoration, bisque ware is usually coated with an aquæous suspension containing various metallic salts. This suspension, commonly called "the glaze" is applied by brushing, dipping, or spraying. Once the glaze is dry, pottery is most commonly re-fired in electric or gas kilns to vitrify the coating. The final colours in the glaze ware are the result of high temperature reactions involving the metal salts. The electric glaze firings are oxidation firings of 4 to 13 hour durations with maximum temperatures commonly between 1015 °C and 1230 °C. Lustre glazes applied over previously glazed material are fired to 800 °C over a short duration (< 5 hours). Gas kilns are typically fired to 1305 °C over periods ranging upward

from 10 hours with limited oxygen creating a reduction environment during the latter part of the firing. Overnight candling of gas kilns is common, pushing firing times over 20 hours.

1.4 Reported Kiln Emissions

A number of compounds are reportedly emitted during the bisque firing. Those commonly cited are carbon monoxide, nitrogen dioxide, sulfur dioxide, fluoride and formaldehyde (Fuortes, 1989; Rossol, 1982). Although fluoride emissions are normally cited as hydrogen fluoride, the Ministry of Labour in London reports that emitted fluoride is often in particulate form as ammonium fluosilicate (Luxon 1963). Where gas kilns are used to fire green ware, carbon monoxide and nitrogen dioxide can be expected as combustion products from the burners (Fuortes 1989; McCann 1992). However, these, along with other aforementioned emissions, can also originate from contaminants in the clay. Researchers have even detected elevated radon levels associated with the presence of pottery in an European school (Ennemoser, Schneider et al. 1992). The composition and quantities of the above contaminants may vary with the type of clay and the location from which it was originally dug.

There are 23 potentially hazardous metals whose compounds are commonly listed in source books as glaze materials: aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, gold, iron, lead, lithium, magnesium, manganese, mercury, nickel, platinum, selenium, silver, vanadium, and zinc (Hamer and Hamer 1991; McCann 1992). Exposure to these metal salts may occur while mixing or applying glazes to bisque ware, or during the glaze firing.

The emission of metal aerosols into the atmosphere surrounding the kiln may well be cause for concern (Rossol 1982; Rossol 1987; Dinman 1988). The behaviour of these metals during the firing process can be difficult to predict. Uneven heat distribution within the kiln may lead one to underestimate actual temperatures to which some pieces are subjected. Variations in firing protocol (i.e. the rate of temperature change and the duration of temperature plateaux) and the mix of glaze materials within the kiln may also play a role in determining emission profiles.

Because these metals are suspended in a slurry of clay, the emissions previously cited for bisque firings may also be emitted during the glaze firing.

1.5 Exposure Variables

A number of variables are expected to affect exposure potential during kiln firing: the composition and quantity of materials being fired (clays, glazes), the firing fuel, kiln type and size, the firing environment (indoor/outdoor, room size), ventilation, and the proximity of other activities to emission sources.

1.6 Health Effects

Kiln emissions contain a mixture of elements and compounds whose potential health effects are summarized in Table 1. Because published measurements are lacking, literature addressing pottery health issues warns of these health outcomes without first establishing whether concentrations are likely to reach levels high enough to elicit such effects. Without supporting data, many potters are skeptical of the literature and tend to dismiss it as alarmist. Others suffer considerable anxiety as a result of these warnings.

To facilitate the resolution of these issues, we must provide an appropriate context for the evaluation of potential health effects. Actual exposure levels must

first be determined. Once these exposures have been quantified, they can then be compared to the levels at which the health effects are known to occur. This information will allow existing problems to be addressed, and unfounded concerns laid to rest.

Table 1: A Summary of the Potential Health Effects of Pottery Kiln Emissions

	Carbon Monoxide	Fluorides	Formaldehyde	Nitrogen Dioxide	Sulfur Dioxide	aluminum	antimony	arsenic	barium	beryllium	boron	cadmium	chromium	cobalt	copper	gold	iron	lead	lithium	magnesium	manganese	mercury	nickel	selenium	silver	vanadium	zinc
carcinogenic								√		√		√	√										√				
cardiovascular							√	√		√				√				√	√		√	√				√	
dermal/epidermal								√		√		√	√	√									√	√	√	√	√
gastro-intestinal								√									√									√	
hematological	√							√				√	√					√						√			
hepatic								√		√		√	√	√													
immune modulator	√		√	√						√		√	√	√		√						√		√			
membrane irritants		√		√																√						√	
metal fume fever												√			√			√									√
neuropathic						√		√							√			√	√		√	√		√		√	
renal							√	√				√	√		√			√	√			√	√				
reproductive		√				√					√	√		√				√				√	√	√			
respiratory		√	√	√	√	√	√	√	√	√		√	√	√	√							√	√	√		√	√
sensitizer			√											√	√									√			
skeletal		√									√																
teratogenic																		√							√		

(Anonymous 1986; Dinman 1988; Raffn, Mikkelsen et al. 1988; Jensen 1990; Amdur, Doull et al. 1991)

1.7 Specific Aims

1.7.1 Site Selection

To randomly select 10 sampling sites from each of the 5 following categories: small businesses, elementary schools, secondary schools, recreational facilities/hobby potteries; and post-secondary institutions.

1.7.2 Area Sampling

To take area breathing zone measurements 76 cm from the firing kiln and 1.6 m above the floor to establish air concentrations of nitrogen dioxide, sulfur dioxide, fluorides (aerosol and gas), formaldehyde, carbon monoxide, aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, gold, iron, lead, lithium, magnesium, manganese, mercury, nickel, selenium, silver, vanadium, and zinc.

1.7.3 Personal Sampling

To measure personal exposure to the aforementioned 22 aerosol metals using personal monitors.

1.7.4 Potential Determinants of Exposure

To gather information on kiln type and size, firing fuel, clay type and quantity, glaze materials, firing environment (indoor/outdoor, room size), ventilation, and the proximity of other activities to emission sources.

2. METHODS

2.1 The Search for Information on Kiln Emissions

Two local suppliers of pottery equipment and materials were contacted for information. While both were aware of concerns about kiln emissions, neither could cite any measurements that may have been taken. One manufacturer of kiln exhaust systems, expressed concern about fluoride emissions but did not appear to have undertaken studies to validate the effectiveness of exhaust systems in reducing these emissions.

Telephone calls were made to representatives of the pottery industry in England. Contact was made with the Director of Technical Research at Royal Doulton (Forrester, 1994) Production and Kiln Managers at Wedgewood (Johnson & Bolton, 1994), and a representative of British Ceramic Research (Pimento, 1994). While emissions of lead and fluoride into the external environment are monitored regularly, there was no apparent concern about worker exposures to kiln emissions within the potteries.

A number of telephone contacts were made in the United States. Skutt Ceramic Products in Portland and the Edward Orton Jr. Ceramic Foundation in Westerville, Ohio are working jointly to manufacture a direct venting kiln exhaust system (Skutt, 1994). Jim Skutt referred to the Parker Reist article (Reist, 1984). While research into this venting system has apparently demonstrated some clearly advantageous outcomes with respect to glaze quality, the people at Orton provided no concrete information about its effects on indoor air quality (Fronk, 1994).

William Hunt, editor of Ceramics Monthly Magazine, was unable to provide information on kiln emissions claiming that very little hard science has been done (Hunt, 1994).

Art safety expert Monona Rossol, Arts Crafts and Theater Safety, N.Y., knowledgeable about the need for kiln ventilation, commented that most exposure measurements would not be in the public domain but would be the property of businesses where studies had been conducted (Rossol, 1994).

Mike McCann at the Centre for Safety in the Arts, New York, a firm supporter of kiln exhaust systems, confirmed that published measurements were rare (McCann, 1995).

The Alfred University School of Ceramics (Alfred, Massachusetts) and the departments of Ceramics and Ceramic Engineering (manufacturers of tiles for the Space Shuttle program) at the University of Illinois in Urbana were contacted. While some measurements of sulfur dioxide during bisque firings had been taken at Alfred, the use of more than 400 materials in their glaze labs made the study of specific glaze emissions impractical (Fredrickson, 1994). Contacts in both departments at the University of Illinois were neither aware nor concerned about indoor exposure from pottery kilns (Anonymous, 1994).

An extensive literature search included a) linking pottery, kiln emissions, and health effects in computerized searches of medical data bases and b) a search through available pottery books and magazines at the University of British Columbia fine arts library and the library at the Emily Carr College of Art and Design, Vancouver, B.C. This search and contacts with professionals in ceramics and art safety indicated 4 published papers dealing with levels of contaminants other than lead. One epidemiological study examined cadmium (and lead) in potters hair samples (Bache 1991). One article reported elevated carbon

monoxide levels (40 ppm) near a kiln (Lange 1978). A third (Reist, 1984), reported measurements taken under controlled conditions adjacent to a kiln: carbon monoxide (59 ppm average with peak values reaching 113 ppm), sulfur dioxide (0.06 ppm), formaldehyde (0.05 ppm), lead (0.38 $\mu g/m^3$), and very low levels of fluorine, barium, cadmium, and lithium emissions. A surveillance programme for plate painters exposed to cobalt in two Danish porcelain factories between 1982-1992 showed airborne cobalt exposure declining from 80 to 27 $\mu g/m3$ (Christensen and Poulsen 1994).

A number of articles reported lead levels for pottery workers. Breathing zone samples were taken in a major American china manufacturing facility during the 1970's revealing lead exposures of 0.01 to 0.87 mg/m^3 (Ruhe and Donohue 1979). A 1987 surveillance indicated some California pottery and ceramics workers with blood lead levels exceeding 25 $\mu g/dL$ (Maizlish, Rudolph et al. 1990). Blood lead determinations in the Italian ceramics industry showed mean blood lead levels dropping from 50 to 29 $\mu g/dL$ (60 to 39 $\mu g/dL$ for glazers) as lead usage declined during a 3 year study (DeRosa, Toffolo et al. 1983). A later Italian study showed blood lead levels exceeding 40 micrograms/dL in 22.3% of workers applying lead glazes to ceramics and 19.1% of kiln workers transporting and loading products into kilns (DeRosa, Bartolucci et al. 1991).

Elevated blood lead levels up to 130 $\mu g/100$ mL have been seen in the families of workers exposed to lead (Fischbein, Wallace et al. 1992), and children in pottery-producing areas have been shown to have mean urinary lead levels of 15.8 $\mu g/L$ compared to 10.6 $\mu g/L$ for the children in the control area (Katagiri, Toriumi et al. 1983).

2.2 Selection of Sampling Sites

This study was designed to assess kiln emissions across a broad spectrum of exposure conditions. To achieve this end, 10 kiln sites in each of 4 different exposure categories (1. small businesses, 2. recreational facilities/hobby potteries, 3. elementary schools, and 4. secondary schools) were selected. Due to the limited number of available sites in a fifth category, post-secondary educational institutions, only 6 institutions were included in this study, but gas and electric kilns at 4 of these were measured separately in order to make up 10 measurements.

All sites, with one exception, were within the Greater Vancouver Regional District (GVRD), B.C. The exception was made because of the limited number of available post secondary facilities in the GVRD.

Because kiln firing is not a daily operation in most studios, and in some cases is infrequent, inclusion in the study was dependent upon the ability to co-ordinate available measurement days with individual firing schedules. Potential sampling dates and random lists of participants (one per site category) were established separately. Sites were then contacted in list order to fill available dates. This approach was designed to capture the distribution and prevalence of exposure variables such as type of firing (greenware vs. glazed pottery) and the variety of clays, glaze materials and firing conditions amongst potters.

2.2.1 Professional Potters

A list of members was obtained from the B.C. Potters Guild. Special members (student, senior, group, and family) were excluded. All regular members living within the catchment area (a total of 139) were numbered. The 'sampling analysis tool' from Microsoft Excel was used to randomly select 20 numbers within the range. The individuals whose names co-

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incided with the selected numbers were contacted by letter and asked to respond by telephone. After 10 days, follow-up calls were made. Telephone interviews were used to determine eligibility and interest. The following criteria were used to determine inclusion in this category: 1.) the potter must be selling work or displaying work in galleries, museums, etc.; 2.) a significant portion of the work week must be spent making pottery; and 3.) individuals must be generating income from their pottery. Of the 20 individuals originally contacted, 2 had moved out of the catchment area; 1 ran a pottery shop but did not pot herself; 2 were hobby/social potters using recreation centre facilities; 1 was no longer potting because of arthritis; 1 was hospitalized; 1 declined; 1 worked jointly with another potter already on the list; 1 had retired. The first 10 of the remaining 11 sites were measured between Sep 27 and Dec 8, 1995, and included in this study. The 11th site was measured as a courtesy to the potter, but was not included herein.

2.2.2 Hobby Potters (Recreation Centres)

Although this category was originally intended to include hobby potters working from their homes, it was difficult to compile a comprehensive list of home hobbyists. To define the category in such a way that members were easily identifiable, it was decided to limit the category to recreation centres. All recreation centres in Vancouver, North Vancouver, Richmond, Burnaby and Coquitlam were contacted by telephone to determine which had active pottery programs. Of the 19 recreation centres, 16 were identified as having pottery programs. Letters were sent to all 16. These were then numbered 1 to 16 and the random number analysis tool from Microsoft Excel was used to order these numbers. Starting with the

first site in the random list, letters were followed up by telephone. It was necessary to call 11 Recreation Centres to secure a list of 10 willing participants. Of the ten willing participants, a second site declined to participate before measurements could be made and the next backup site was conscripted from the list. Ten sites were measured between September 21 and November 23, 1995.

2.2.3 School Sites (Elementary and Secondary)

Five school districts (Vancouver, North Vancouver, Richmond, Burnaby, and Coquitlam) were included in this study. To ensure consistent sampling frames from district to district, the telephone book was used to number, in alphabetical order, all elementary schools and, as a separate category, all secondary schools within each targeted district. The numbers assigned to schools within a given category and district were then randomly ordered using the random number analysis tool from Microsoft Excel. This resulted in separate randomly ordered lists for elementary and secondary schools in each district. Sites were then selected in the order indicated by these telephone book lists.

The number of schools chosen per district was related to the number of schools per category in that district. Because one of the districts had recently replaced kiln exhaust systems in all schools with a direct venting system, reducing variability, schools from this district were selected half as frequently as those in other districts where variability was greater. Where proportional selection, due to rounding errors, resulted in more than 10 sites per category, balancing the number of sites by district was used as the deciding criterion. These procedures resulted in 2 schools being chosen per category (elementary / secondary), per district.

Because the 5 school districts have different management models, there were minor differences in the way the sites were selected.

Burnaby - The school district hygienist provided the investigator with lists of schools with kilns. Schools were then selected from this list in the order indicated by the two randomized telephone book lists. Selected schools were then communicated to the district hygienist who contacted school administrators to secure permission for measurements to be taken. Three elementary schools were identified. The list was ordered, and the first two choices were measured.

Of 6 secondary schools with active kilns, the first choice was measured. Site 2 was not measured because of problems co-ordinating measurement dates. Site 3 was not firing within the time frame available to the researcher. The teacher at site 4 did not wish to participate. Site 5 was measured.

Coquitlam - This district works on a de-centralized management model. Once permission was secured from the school board, schools with active kilns were identified and permission to take measurements was secured from individual school administrators. The first elementary school on the randomized list was measured. Sites 2 through 4 were not firing. Site 5 was measured.

The first 2 secondary schools on the list were measured.

North Vancouver - A list of available school sites with active kilns was provided by the district art consultant. Eight elementary and six secondary schools were identified. Individual schools were contacted by the investigator in the order indicated by the randomized telephone book lists.

Staff at the first elementary school were unable to predict a time frame during which firing might take place. Sites 2 and 3 were measured.

The first secondary school was measured. The opportunity to measure site 2 was lost because of an instrument failure. A measurement date for site 3 could not be agreed upon. Site 4 was measured.

Richmond - The investigator provided an ordered list of sites to the district hygiene officer. The latter determined which schools had active kilns, and cleared measurements with school administrators and teachers. The first elementary school on the randomized telephone book list was not available. The second was measured. The district hygienist was unable to secure a second measurement site from the list of 39 elementary schools. As a result, the last school in the elementary category was selected from another district.

The first site on the randomized telephone book list of secondary schools was not measured because the studio had been moved and the kilns were not reconnected because of budget limitations. Sites 2 and 3 were measured.

Vancouver - The randomized telephone book lists were provided to the district hygienist who initially wished to assume responsibility for determining appropriate sites and making school contacts. However, after some time passed and no sites were delivered, it was left to the investigator to determine which schools had active kilns and to secure school permission to take measurements. The first three sites on the randomized list of elementary schools were not firing during the predicted duration of the study. Site 4 did not return calls. Site 5 was measured. Site 6 did not return calls. The kiln at site 7 was not working. Sites 8 - 10 were not firing. Contact

was not made with appropriate personnel at sites 11, 12, and 14. The kiln at site 13 was disconnected. Site 15 was measured. By the time the study was drawing to a close and the need for an additional elementary school to replace the second Richmond school and complete the category became apparent, it was possible to measure the first site contacted.

The first site on the randomized telephone book list of secondary schools was not measured because the art teacher was unable to confirm a measurement date in advance. Sites 2 and 3 were measured.

All school sites were measured between Oct 26, 1995 and April 3, 1996.

2.2.4 Post Secondary Institutions

Because there were only 3 post secondary institutions offering pottery programs within the geographical boundaries that defined the other four categories, it was decided to include in this category all B.C. colleges whose travelling distances would not necessitate an overnight stay. Using college calendars to determine which institutions had pottery programs, it was determined that 7 sites met the initial requirements. Three of the sites had been contacted for information before this study began. The remaining sites were initially contacted by letter. After 2 weeks, follow-up telephone calls were made.

It was discovered that one of the out of town sites only had outdoor kilns that were fired when the weather was dry. The difficulty in predicting appropriate measurement days resulted in this site not being measured. All 6 of the remaining sites were measured. At 4 of the 6 sites, the firing of electric and gas kilns was separated by location (2 sites) or by time (2 sites). At each of these 4 sites, gas and electric kilns were measured independently

of one another. This resulted in a total of 10 site measurements (4 gas and 6 electric kilns at a total of 6 institutions) between October 19, 1995 and March 5, 1996.

2.3 Sample Collection and Analysis

2.3.1 Duration of Measurements

It was originally intended that all sampling would begin when kilns were first turned on. However, the practice of soaking or candling green clay at low temperatures for prolonged periods, commonly overnight, extended some firings beyond durations which could be practically measured. In cases where clay was soaked or candled overnight, measurement commenced early the following morning, before the normal sequence of temperature increases began. At all other sites, monitoring began from the time the kiln was turned on or shortly thereafter. All monitoring continued until the kilns were shut off, with 2 exceptions where firings continued beyond the time buildings were closed and secured by custodial staff. Measurement durations ranged from 2.5 to 12 hours.

2.3.2 Sampling Location

During each site measurement, instruments to sample air for carbon monoxide, nitrogen dioxide, sulfur dioxide, aldehydes, fluoride (particulate and gaseous), and metals were mounted 76 cm. from the kiln on a tripod T-bar positioned 1.6 m. above the floor to simulate breathing zone exposures. Where a willing participant was on site during sampling, that person was affixed with a personal sampling device to assess individual exposure to metal emissions.

2.3.3. Nitrogen Dioxide (NO2): the Odyssey 2001

Continuous monitoring of NO2 was accomplished with a Transducer Research Inc. (Naperville, IL) Odyssey 2001 electrochemical analyzer which recorded voltage values each minute using an internal data logger. This instrument was calibrated four times using a 200 ppm calibration gas diluted to 0.5, 1, 1.5, and 2.5 ppm. These calibrations were done in July, 1995, before the study began, in September when the study started, midway through the study in January, 1996, and when data collection was completed in April. NO2 concentrations for the thirty sites measured between September and December were calculated using the September instrument calibration curve. Data from the remaining sites were calculated using the January calibration curve. Potential variation during an interval was calculated as the percentage variation between pre-period and post-period calibration curves. Because the Odyssey had an auto-zero function which, for 5 minutes each half hour, displayed voltages associated with zero NO2, each set of measurement data was readily corrected for "zero drift". Increments of 1 millivolt represented 2.9 ppb for the pre Christmas period and 4.6 ppb for the post Christmas period.

2.3.4 Carbon Monoxide and Sulfur Dioxide : the TMX410

Carbon monoxide (CO) and sulfur dioxide (SO2) were both monitored continuously with an Industrial Scientific (Oakdale, PA) TMX 410 passive electrochemical gas analyzer. The TMX 410 displays CO concentrations in 1 ppm increments and SO2 concentrations in 0.1 ppm increments. Continuous output was recorded each minute with an internal data logger. Engineers at Industrial Scientific maintain this instrument is accurate within 5% or 1 display increment (whichever is greater) when

calibrated correctly and measurements are taken at the calibration temperature. Where temperatures vary from calibration temperatures, these engineers claim that uncertainty could be as high as ±15%.

Carbon Monoxide (CO) Calibration

The instrument was recalibrated every 4 to 6 weeks using bottled air to set zero levels and 46 ppm carbon monoxide to set the span. Span drift and variations in sampling temperature were noted as sources of error. Reliability was determined from the magnitude of instrument drift and the manufacturer's comments about the effects of temperature on reliability.

Sulfur Dioxide (SO_2) Calibration

Because the available calibration gas (10 ppm) has a concentration 4 times greater that the current government occupational standards (2.5 ppm), and because electrochemical sensors may be inaccurate at low concentrations, it was felt that an external calibration to verify SO_2 readings was warranted. Consultant Jesse Wong, from J.C. Andelle Inc., was hired to do an external SO_2 calibration of the TMX 410 and verify company claims. Using a 392 ppm NIST traceable SO_2 calibration gas from Scott Marrin, certified at ± 1% , applied concentrations were achieved by diluting the 392 ppm calibration gas with purified air using a mass flow controller based dilution system. Direct readings from the TMX 410 were then correlated with applied concentrations of 8, 6, 4, 2, 1.6, 1.2, and 1 ppm calibration gas and subsequent instrument readings were corrected accordingly.

High and low LED readouts were plotted for each of the applied gas concentrations on the graph below. Because the resulting response curves have radically different slopes above and below an applied concentration of 2.0 ppm SO_2, combined data for both high and low curves were then averaged to determine formulæ for two separate regression lines (one above and one below 2 ppm applied) and these formulæ were used to correct instrument readings.

Figure 1: SO $_2$ Calibration Curves
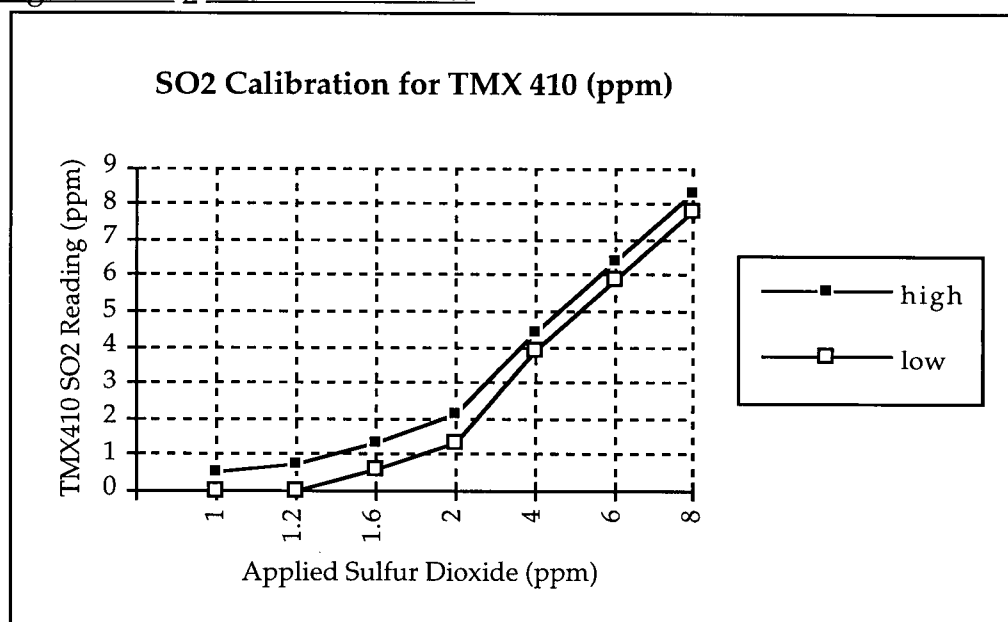
The TMX 410 SO_2 sensor was reset every 4-6 weeks using bottled air to set zero levels and 10 ppm sulfur dioxide to set the span.

The limit of detection for SO_2 as measured by the TMX 410 was established to be the X intercept of the regression line for values below 2 ppm. Instrument accuracy was calculated from errors in mean values at each of four concentrations plus the extent to which the instrument fluctuated around each mean.

SO$_2$ was also collected and analyzed along with fluoride as outlined below.

2.3.5 Chromatographic Analysis: Fluoride, Sulphate, and Formaldehyde

Fluoride ærosol was collected on Gelman 37 mm mixed cellulose ester filters with 0.8 µm pores. Fluoride and SO$_2$ vapour which pass through the filters were collected downstream on Gelman cellulose ester support pads which had been pre-treated with 0.8 mL of fixative solution (12.5 mg sodium carbonate and 10 mL glycerol diluted to 500 mL with de-ionized water) and allowed to air dry overnight. Pumps were calibrated to flow rates of 1.1 litres/minute. These rates were monitored daily with an Accuflow electronic bubble meter. Six field duplicates were collected and analyzed.

Sulfur dioxide, fluoride ærosol and fluoride gas were each analyzed in accordance with a modified NIOSH method 7906 (NIOSH 1994). Prefilters and backup pads were placed in plastic urine cups and covered with the smallest practical volume (10 mL) of de-ionized water. These urine cups were then placed in an ultrasonic bath for 20 minutes. Samples were taken from the resulting solution with a syringe and filtered into test vials. Ion chromatography, calibrated using standard concentrations of 0.2, 0.5, 2, 10, and 20 µg of fluoride and sulphate/mL, was used to quantify these anions. To ensure conversion of SO$_2$ or sulfite (SO$_3^-$) to sulfate (SO$_4^{2-}$), 25 microlitres of 3% H$_2$O$_2$ in water were added to each sample. The 10 mL extraction volume was established after concentrations from 8 backup pads soaked in 50 mL and 3 prefilters soaked in 25 mL of de-ionized water were seen to be very low.

Two samples were lost due to pump problems. Analyses of the remaining samples were completed in 4 separate batches using an aquæous eluent solution of sodium borate (5-28 mM) in a Dionex DX-300 Gradient Chromatography System (Sunnydale, CA) equipped with a 4 mm AS4A-SC IonPac column. The conductivity detector (CDM-3) was coupled with an anion self regenerating supressor (ASRS-I).

In total, fifty-five prefilter samples were analyzed along with 6 field blanks and 5 additional blank filters from laboratory stock. One back-up pad was lost. The fifty-four remaining backup pad samples were analyzed along with 8 field blanks, 4 treated backup pads from laboratory stock and 4 untreated backup pads from laboratory stock. A total of 21 lab blanks and 11 spiked samples (10 μg/mL) were analyzed.

Aldehydes were collected in SKC sorbent formaldehyde tubes containing silica gel impregnated with 2,4 dinitrophenyl - hydrazine (DNPH). All tubes were stored at -4°C before use and after use. Pumps were calibrated to flow rates of 0.2 litres/minute. These rates were monitored daily with a burette and a stop watch.

Aldehydes were analyzed by high performance liquid chromatography in accordance with the WCB aldehydes method (WCB 1995). Analysis was performed using the Dionex DX-300 Gradient Chromatography System with the Variable Wavelength Detector - II. Samples were run through a Waters Nova-Pak C18, 4μm column (Millipore Waters Chromatography Division, Mississauga). The aquæous stationary phase was 0.1% phosphoric acid. HPLC grade acetonitrile made up the mobile phase.

Formaldehyde concentrations were determined using formaldehyde standards of 1.0, 5.0, and 10 μg/mL. Data were re-analyzed for other

aldehydes using a single mixed standard containing 15 µg/mL equivalent concentrations of acetaldehyde, acrolein, benzaldehyde, butyraldehyde, crotonaldehyde, formaldehyde, hexaldehyde, isovaleraldehyde, propionaldehyde, tolualdehyde, and valeraldehyde (Supelco mixed aldehyde/ketone standard TO 11/1P-6A, catalog #4-7285).

Fifty formaldehyde samples were analyzed in 4 separate batches with a total of ten field blanks, six unused formaldehyde tubes from laboratory stock, and thirteen lab blanks, nine 1.0 µg/mL. standards, nine 5.0 µg/mL. standards and fifteen 10 µg/mL. standards (including autocal cuvettes).

Accuracy and precision of fluoride, sulfate, and formaldehyde data were determined using replicate spiked samples. Mean values and co-efficients of variation were calculated by run and across all runs. Percent variations from the mean of all spiked samples and from the target values were determined.

All duplicate fluoride and SO4 samples were below limits of detection. Replicate 10 µg/mL spiked fluoride and SO4 samples were analyzed for each of the 4 sample batches. Co-efficients of variation were calculated for each batch date and for all batches combined. The amount 'mean values by batch' varied from the 'mean value across all batches' was expressed as a simple percentage.

2.3.6 Metals

Metals were collected on Gelman 37 mm mixed cellulose ester filters with 0.8 µm pores. Pumps were calibrated to flow rates of 1.1 litres/minute. These rates were monitored daily with an electronic bubble meter. A total of 81 metal samples were collected from the selected sites. 63 of these 81

samples were area samples. One area sample was taken in the standard sampling position at each of the 50 sites. At eight sites, duplicate samples were taken at the same location and over the same time frame as the original sample. At one site, a second area sample was taken over the last three hours of an eleven hour firing. At 2 sites, area samples were taken as personal surrogates at the glazing area. At one site, an area sample was taken as a personal surrogate at the teachers desk. One area sample was taken as a personal surrogate at a student work bench.

Levels of aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, gold, iron, lead, lithium, magnesium, manganese, mercury, nickel, selenium, silver, vanadium, and zinc were analyzed with a T.S. Sola (Finnigan Mat Scientific, Germany) inductively coupled plasma atomic emission spectrophotometry - mass spectrometer (in accordance with WCB Method 1051 (WCB 1989). Barium analysis was inadvertently omitted from 24 samples.

Metal analysis was run in 3 batches. Nine field blanks were submitted and analyzed along with the first twenty-five metal samples. The number was reduced to 5 field blanks for the second twenty-five samples and 5 for the final 34 samples.

2.3.7 Combined Exposures

The Workers Compensation Board of B.C. considers the effects of a mixture of contaminants to be additive, unless proven otherwise. The following equation was used to calculate an equivalent exposure ("E") to the mixture of contaminants present at each site.

$$E = \frac{C_1}{L_1} + \frac{C_2}{L_2} \ldots + \frac{C_n}{L_n} \text{ (WCB 1980).}$$

"C_i" represents the concentration of substance 'i' (corrected for firing duration). "L_i" is the WCB Permissible Concentration for that substance. The equivalent exposure ("E") must not exceed 1.

2.4 Documenting Potential Determinants of Exposure

Characteristics of kiln environments were recorded: location (indoor/outdoor), proximity to other activities, spatial dimensions, layout (documented with photographs), local exhaust and general ventilation.

Kilns were identified as either gas, electric, or raku[1]. Brand, model, and volume were recorded, as were data on temperature control and temperature display.

The characteristics of each firing were recorded: type of firing (bisque, glost, mixed, raku), maximum firing temperature, duration, and kiln contents by weight.

Clays being fired were given the most specific designation possible using type, brand name, and other pertinent descriptors. (e.g., Plainsman M-340 mid temperature stoneware).

Potters were asked to identify and quantify glaze materials used in the current kiln load. Recipes were recorded for those glazes mixed in the pottery studio. Brands and names were recorded for pre-mixed glazes.

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[1] Raku pots are gas fired in small kilns to temperatures around 1000 °C. Firings are brief, usually less than 30 minutes. Once maximum temperature is achieved, pots are removed from the kiln while still red hot and enveloped in combustible material (e.g. newspaper). This depletes oxygen and creates a reducing environment. Raku firings are labour intensive and raku potters spend much of their day working around their kilns.

Ventilation strategies employed with indoor electric kilns were observed and assigned to one of eight structure/function categories as follows.

1) HVAC systems

2) exhaust hoods
-active (equipped with an exhaust fan)
-passive (relying on convection currents)
-commercially available (an easily installed unit including hood, fan, & flexible ducting; available from kiln suppliers)
-custom designed (professionally installed hoods of varying size attached to permanent, non-flexible ductwork)

3) overhead and 4) wall mounted room exhausts
-professionally installed exhaust vents attached to permanent, solid ductwork

5) slot exhaust
-slot vents professionally installed adjacent to the kiln lid; attached to permanent, solid ductwork

6) direct kiln exhausts specifically designed low flow exhaust systems which draw air directly from the kiln interior.

7) domestic wall and window fans
-available from home improvement centres

8) passive ventilation
-open windows, doors, other passive vents; or no measures taken.

Smoke tubes were used to determine the extent to which air from the perimeter of the kiln lid was drawn into the exhaust system. Air flow was characterized once during the early part of the firing, and again as the process neared completion. The effects of convection currents, caused by higher kiln temperatures, on exhaust efficiency were examined.

2.5 Methods of Data Analysis

2.5.1 Frequency Distributions

The shape of the distribution curve for each of the contaminants was examined using the Z-score histograms option in Statview™ (Abacus Concepts Inc., Berkeley, CA). Data were alternately treated as normal then log normal and the more appropriate approximation was chosen.

2.5.2 Censored Data

Where data were distributed log normally, calculations of summary statistics were performed assuming all values less than the limit of detection had an average value of $LOD/\sqrt{2}$ (Hornung and Reed 1990). For average NO_2 concentrations, the only values distributed normally, concentrations below detection limits were assigned a value of $LOD/2$.

2.5.3 Substances with Data from Direct Reading Instruments

Peak concentrations were determined and average concentrations over the entire sampling duration were calculated for all agents measured using direct reading instruments.

Because NO_2 and CO are known to be fuel specific for gas kilns, analyses exploring differences by firing type and by clay mass were limited to the 32 electric kiln sites that could be clearly designated as either bisque sites (20) or glaze sites (12).

Measurable carbon monoxide emissions from electric kilns were plotted over 'proportion of time to completion' for firings (both bisque and glaze firings) not preceded by a long soak period (12 sites). Time/temperature data were recorded from 8 kilns where pyrometers were in use. The relationship between time and temperature at these sites was

then used to approximate temperature profiles for the remaining sites. Using temperature values calculated from the proportion of completion time elapsed' and 'completion temperature', carbon monoxide emissions were plotted against temperature for all 12 sites.

2.5.4 Contaminants with Concentrations Averaged over Firing Durations

Averaged concentrations were calculated and reported for metals, fluoride, formaldehyde, and SO_2. There were insufficient data above detection limits to support the calculation of summary statistics for fluoride, formaldehyde or SO_2 emissions.

The numbers of sites with measurable metals were reported separately for area and personal samples. Highest measured concentrations were compared to PCs for each metal and protection factors (the magnitude by which Permissible Concentrations exceed exposures, i.e. PC ÷ exposure) were calculated. For each site category, geometric means and standard deviations were determined for those metals found in more than half the samples. These were then compared.

Differences between paired area and personal metal samples were determined. Where less than 5 paired samples had at least one of the two values above the limit of detection, no statistical analysis was performed. Similarly, where the excess was unidirectional across all samples, no statistical analysis was performed. In all other cases, the non-parametric Wilcoxon Signed-Rank Test was used to determine differences between personal and area exposures, substituting $LOD/\sqrt{2}$ for values below the limit of detection.

Metals were examined by firing type. 11 sites were eliminated from this analysis because both greenware and glazed bisque ware were being

fired simultaneously. This left 20 bisque sites and 17 glaze sites including gas (not raku) kilns. These 37 sites were used to determine differences between metal emissions from the firing of greenware and glazed bisque ware. Mann Whitney tests were used to compare measured values.

ANOVA was used to determine the effects of site category (professional, hobby, elementary, secondary, post secondary) on area exposures. Ventilation strategies were compared using the Kruskall-Wallis test.

Simple linear regression analysis was used to explore a possible association between area exposures and room size.

With 48 different clays in use, efforts to determine clay specific emissions required the grouping of clays by 100 degree temperature intervals.

2.5.5 Consistency of Duplicate Samples

<u>By Site</u>

Side by side replicate metal samples were taken at 8 sites. The sum of the absolute differences between duplicate samples was divided by the sum of the mean values for each of the 22 metals to yield a percent variation for each metal. Median variations were recorded for each site. Percent variations for pairs of known values across the 8 sites were found to have an approximately normal distribution. Assuming that values for censored replicate measurements vary from zero to $LOD/\sqrt{2}$, the average variation between censored values was assigned a value of $LOD/2\sqrt{2}$.

Across All Sites

Intra-class correlations (ICC's) were used to look at the consistency of replicate pairs for each metal across all 8 sites. A score of 1 point was assigned to each member of a replicate pair having an uncensored value. Censored values were given a score of zero. ICC's were calculated for those metals with a total score of 5 or more (i.e. less than half the entries were censored). This method was used because the two replicates were theoretically indistinguishable from one another (i.e. there was no systematic difference between paired measurements arbitrarily labelled "sample" and "replicate sample"). σ^2 values were determined using an ANOVA option in Statview.

$$\text{ICC} = \frac{\sigma^2 \text{location}}{\sigma^2 \text{error} + \sigma^2 \text{measurement} + \sigma^2 \text{location}}$$

3. RESULTS

For each contaminant of interest, the number of values above detection limits is tabulated along with maximum and minimum values. Means, medians, and standard deviations are reported for those substances with more than half the measured values above limits of detection, as are geometric means and geometric standard deviations for log normally distributed data. Individual values can be found tabulated in the appendix.

3.1 Nitrogen Dioxide (NO_2) Results

Table 2: Summary of NO_2 Results

NO_2	1 min. Peak Values	Average Values
# above 0.003 ppm	49	44
Min (ppm)	0.006	<0.003
Max (ppm)	0.311	0.060
Mean (ppm)	0.063	0.021
S.D. (ppm)	0.064	0.013
Median (ppm)	0.040	0.021
Geometric Mean (ppm)	0.044	
Geometric S.D.	2.3	

Nitrogen dioxide data were available from 49 sites. Peak NO_2 concentrations, averaged over 1 minute, ranged from 0.006 to 0.311 ppm. Their distribution was found to approximate a log normal function with a geometric mean of 0.044 ppm and a geometric standard deviation of 2.3. Average NO_2 concentrations across all sites, however, were found to be normally distributed. These ranged from the limit of detection to 0.060 ppm with a mean concentration of 0.021 ppm and a standard deviation of 0.013 ppm.

<u>Reliability/precision of NO$_2$ results</u>

Individual values were calculated using integral millivoltage increments that averaged 0.003 ppm for the pre Christmas period and 0.005 ppm for the post Christmas period. These values play a role in determining limits of detection and precision for individual readings.

While two calibrations done before sampling began indicated a minimal variation in instrument response (± 0.003 ppm over the range of all data points), there was more drift between the three calibration curves determined during the measurement period. The two curves bracketing the first 30 measurements yielded concentrations which varied by ± 13%. The second pair of curves, bracketing the remaining 20 site measurements yielded concentrations which varied by ± 54%.

Limits of detection for individual readings were 0.003 ppm ± 13% for the pre Christmas period and 0.005 ppm ± 54% for the post Christmas period.

3.2 Carbon Monoxide (CO) Results

Table 3: Summary of CO Results

CO	TMX 1 min. Peak	TMX Average
# above 1.0 ppm	26	15
Min (ppm)	<1	<1
Max (ppm)	95	7
Mean (ppm)	9	
S.D. (ppm)	17	
Median (ppm)	2	
Geometric Mean (ppm)	3	
Geometric S.D.	5	

Carbon monoxide was detected at 26 of the 50 sites measured. At 10 of these sites, only greenware was being bisqued. Eight sites were only firing glazed

bisque ware. The remaining 8 sites were firing both. The two highest 1 minute spikes (95 and 68 ppm) occurred when exhaust rates for gas kilns were damped to diminish the intake of fresh air, balance internal temperature, limit the availability of oxygen inside the kiln, and create a chemically reducing environment. One of the spikes was of such brief duration that the average firing concentration for that site was below the limit of detection. Detected values for both peak and average concentrations were found to be distributed log normally. Peak concentrations had a mean value of 9 ppm and a geometric mean of 3 ppm with a geometric standard deviation of 5. Average concentrations had a high value of 7 ppm. Because 70% of all sites had average values below detection limits, other summary statistics are not reported.

Figure 2 below displays carbon monoxide emissions over time (as a proportion of time to completion) for firings of 12 electric kilns (both bisque and glaze firings) not preceded by a long soak period.

Figure 2: Emission Profile for Carbon Monoxide over Time
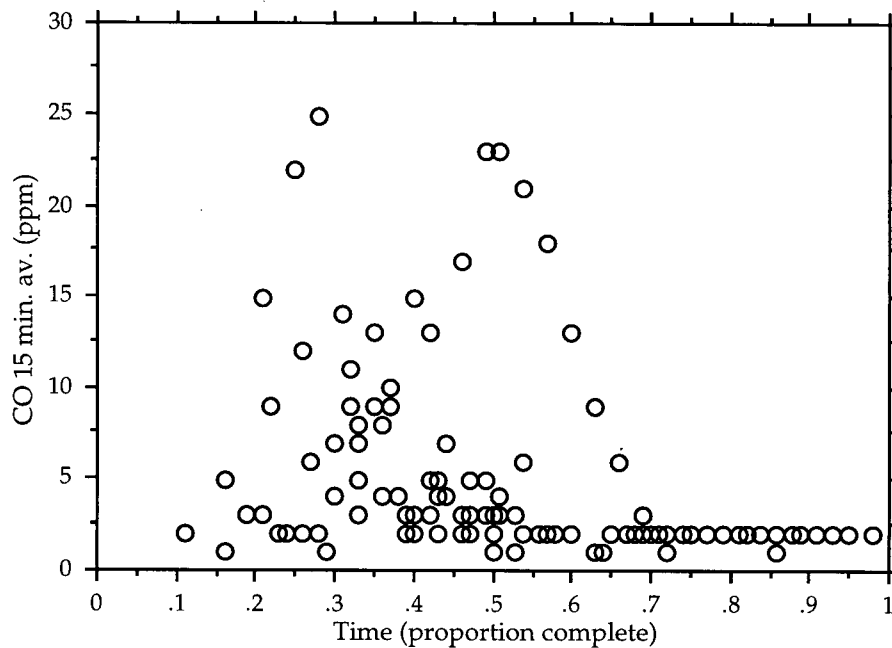
As can be seen, emitted CO was detectable from the time the firing was ten percent complete until it had reached seventy percent completion. In most cases, values fall between twenty and fifty-five percent.

Data from eight kilns where pyrometers were in use indicated an approximately linear relationship between time and temperature. Using this assumption of linearity, the product of 'the proportion of completion time' x 'completion temperature' was used to estimate temperatures for the remaining sites where no kiln temperature data was recordable. Both recorded and estimated temperatures were used for the following plot of carbon monoxide vs. temperature.

Figure 3: Emission Profile for Carbon Monoxide over Temperature
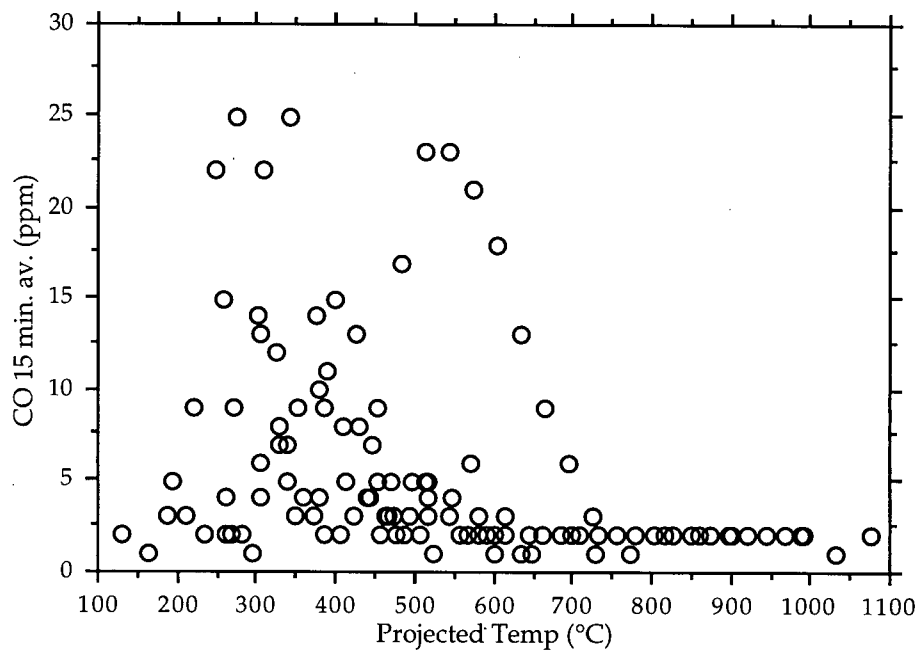
From the above graph, it would appear that measurable carbon monoxide emissions may begin around 150°C and continue until 750°C. Most values appear to fall between 200°C and 600°C. The prolonged flat tail above 750°C, representing only 2 sites, is likely associated with limitations in clearing CO rather than continuous low level emissions.

Reliability/precision of CO results

No zero drift was noted between calibrations. The 46 ppm span remained consistent within 1 ppm ($\pm$2%). Fluctuations in sampling temperatures over a 30 °C range introduce some uncertainty. Assuming fluctuations due to temperature are no more than the 15% reported by the manufacturer, total variation from span drift and temperature variations would not be more than 17%. The 1 ppm detection limit for CO is the lowest displayed concentration value.

3.3 Sulfur Dioxide (SO$_2$) Results

Table 4: Summary of SO$_2$ Results

SO$_2$	TMX 1 min. Peak	TMX Average	IC Average
# above the LOD*	3	2	7
Min (ppm)	<1.1	<1.1	<0.002
Max (ppm)	6.6	1.6	0.508

*see limits of detection in the table 'Non Metal Area Data', Appendix.

The TMX 410 (LOD = 1.1 ppm) was only able to detect SO$_2$ at 3 sites. Peak concentrations were registered as 5.0, 5.0, and 6.6 ppm with calculated average values of 1.6 ppm, 1.2 ppm, and <1.1 ppm respectively. Ion chromatography (IC) was able to improve the detection of SO$_2$ to include 5 sites where none was detected by the TMX 410. Average values at these 5 sites ranged from 0.003 to 0.014 ppm. At the one site where average values derived from each of the two methods could be compared, quantification by the IC method led to a lower value than that calculated using data from the TMX 410 (0.5 vs. 1.6 ppm). Measurements at this site were taken over 12 hours. All TMX data during the first 4 hours were censored. Over the last 8 hours of the shift, data from this electrochemical gas analyzer yielded an average exposure of 2.4 ppm. Assuming all the SO$_2$ determined by the ion chromatography method was emitted during the last 8 hours of the firing, the average exposure determined by this method would have been 0.76 ppm.

Reliability/precision of SO$_2$ results

Calibration curves for SO$_2$ using the TMX 410 established the limit of detection for this method to be 1.1 ppm. Fluctuations of ± 0.3 ppm over the entire calibration range, combined with errors in mean values at each of four concentrations, were used to calculate the following percentage variations.

Table 5: Precision of SO$_2$ Calibration Readings

Concentration (ppm)	% Variation
2.0	19
4.0	13
6.0	6
8.0	6

Ion chromatographic analysis requires the conversion of sulfur dioxide to sulfate ion in aquæous solution. Replicate sulfate spikes run during these analyses were found to vary from the target value by no more than 4.4 percent. Blanks were always within 0.1 µg/mL of one another. The latter value was used as the method detection limit.

Table 6: Precision of SO$_4$ Ion Chromatography Data

Run	Mean conc. by run. (µg/mL)	Co-efficient of Variation (%) by run.	% Variation from mean of all spiked samples.	% Variation from target value.
1	9.8	0.4	1.3	2.1
2	9.6	0.1	4.4	4.4
3	10.0	1.4	0.4	0.4
4	10.6	0.6	6.3	3.6
Overall	10.0	4.4	0.0	0.0

3.4 Formaldehyde Results

Table 7: Summary of Formaldehyde Results

# above the LOD[*]	15
Min (ppm)	<0.012[*]
Max (ppm)	0.102

*see limits of detection in the table 'Non Metal Area Data', Appendix.

Measurable formaldehyde was detected at 15 of the 50 sampled sites. The highest value detected was 0.102 ppm. Because 70% of all sites had values below detection limits, other summary statistics are not reported. The machine limit of detection for formaldehyde was established as 1 μg (1/2 of the lowest calibration standard). Site specific limits of detection, calculated from flow volumes and the machine LOD, can be found in the table 'Non Metal Area Data' in the Appendix.

Reliability/Precision of Formaldehyde Results

No zero drift was noted during any of the ion chromatography (IC) runs. Replicate lab spikes of 1.0, 5.0, and 10.0 μg/mL yielded values of 1.0, 5.5, and 11.6 μg/mL respectively. Concentrations in the 5.0 μg/mL range were positively biased by 10% with a 9% coefficient of variation. Concentrations in the 10.0 μg/mL range were found to exceed spike values by 16% with a coefficient of variation of 8%.

3.5 Other Aldehydes

Aldehyde data were re-analyzed using a single spike of mixed aldehyde standard to determine the presence of aldehydes other than formaldehyde. Acetaldehyde was identified at 11 sites. Acrolein peaks noted for 3 sites are potentially confounded by acetone, which co-elutes from the HPLC column.

Table 8: Other Measured Aldehydes

Site Designation	acetaldehyde ppm	acrolein (acetone?) ppm
P1	0.020	not detected
P3	0.040	not detected
P6	0.120	0.070
P7	0.004	not detected
P10	0.026	not detected
H3	0.021	not detected
H4	0.012	not detected
H6	0.024	not detected
H7	0.261	not detected
H10	0.054	not detected
S2	not detected	0.028
S7	not detected	0.109
C1	0.004	not detected

The highest acetaldehyde exposure was 0.261 ppm. The highest acrolein exposure was 0.109 ppm. Detection limits were not quantified.

Reliability/precision of Aldehyde results

The above aldehyde values were determined from a single standard. Improved confidence in aldehyde values would require more precise analysis than was undertaken in this study. Concentrations of formaldehyde, run as part of the mixed aldehyde standard, varied from known concentrations of 1, 10, and 20 μg/mL by 81%, 19% and 15% respectively.

3.6 Fluoride Results

Table 9: Summary of Fluoride Results

# above the LOD[*]	2
Min (ppm)	<0.001[*]
Max (ppm)	0.152

*see limits of detection in the table 'Non Metal Area Data', Appendix.

Fluoride was only detectable at 2 sites. Concentrations at these sites were 0.152 ppm and 0.127 ppm.

Reliability/precision of Fluoride results

Output data from replicate fluoride lab spikes varied from target values by percentages ranging from 1.6 to 14.4 %. Three of four runs were positively biased. Because no detectable levels of fluoride were reported for any of the samples in run 4, the potential 14.4% overestimate had no impact on any reported sample concentrations. Of the remaining runs, the maximum variation was never greater than 4.2%.

Table 10: Precision of Fluoride Results

Run	Mean conc. by run. (μg/mL)	Co-efficient of Variation (%)	% Variation from mean of all spiked samples.	% Bias
1	10.42	0.3	0.1	+4.2
2	10.16	0.5	2.7	+1.6
3	9.63	14.9	7.4	-3.7
4	11.44	2.2	10.0	+14.4
Overall	10.11	9.4	0.0	+1.1

3.7 Metals Results

Area metal samples were collected from each of the 50 selected sites. Personal metal samples or surrogates were collected from 24. Table 11 reports maximum and minimum measured values, along with the number of samples with detectable levels for each metal.

Table 11: Detectable Concentrations and Ranges for Each Metal.

	Area Metal			Personal Metal		
	# above LOD*	min (µg/m3)	max (µg/m3)	# above LOD*	min (µg/m3)	max (µg/m3)
Al	34	<0.076	15.561	23	<0.178	62.778
Sb	5	<0.002	0.010	1	<0.002	<0.021
As	0	<0.320	<2.340	0	<0.400	<2.350
Ba	21	<0.002	0.091	11	<0.002	0.368
Be	2	<0.006	0.002	5	<0.001	<0.010
B	31	<0.022	5.252	18	<0.023	3.890
Cd	23	<0.002	0.114	10	<0.003	0.999
Cr	7	<0.051	0.431	5	<0.089	0.306
Co	13	<0.001	0.169	15	<0.002	0.863
Cu	22	<0.002	3.750	20	<0.002	0.312
Au	0	<0.001	<0.005	0	<0.001	<0.005
Fe	25	<0.110	4.042	18	<0.180	26.952
Pb	3	<0.007	0.208	6	<0.008	0.788
Li	1	<0.005	0.015	1	<0.008	<0.125
Mg	18	<0.022	4.248	17	<0.031	9.566
Mn	36	<0.001	0.094	22	<0.002	0.174
Hg	3	<0.004	0.017	0	<0.005	<0.013
Ni	8	<0.005	0.291	9	<0.008	0.175
Se	2	<0.110	0.249	0	<0.140	<0.420
Ag	4	<0.001	0.003	3	<0.001	1.755
V	1	<1.050	5.220	0	<1.330	<4.150
Zn	19	<0.017	1.502	15	<0.017	3.583

*see limits of detection in the table 'Area Metal Data', Appendix.

Frequency distributions were plotted for those metals with more than half their reported values above detection limits. Both area and personal metal distributions appeared to be approximately log normal.

The most commonly detected area metals, manganese, aluminum, boron, and iron, were each found in at least 25 area samples. Barium analysis was inadvertently omitted from 13 samples, but detectable levels were found in 21 of 37 analyzed samples. Summary statistics for these 5 metals appears in table 12 below.

Table 12: Distribution Data for Area Metals Detected at > 50% of Sites

	Al	Ba	B	Fe	Mn
Mean (μg/m^3)	1.128	0.015	0.534	0.549	0.013
S.D. (μg/m^3)	2.441	0.023	0.906	0.737	0.018
Median (μg/m^3)	0.487	0.003	0.139	0.281	0.003
Geometric Mean (μg/m^3)	0.455	0.005	0.175	0.326	0.005
Geometric S.D.	4	5	5	3	4

*see limits of detection in the table 'Personal (or Surrogate) Metal Exposures', Appendix.

Eight metals were found in more than half of all personal samples. These were aluminum, manganese, copper, boron, iron, magnesium, cobalt and zinc. Barium was found in 11 of 12 analyzed samples. Descriptive statistics for these 9 metals appear in the table below.

Table 13: Average Values for Personal Metal Samples

	Al	Ba	B	Co	Cu	Fe	Mg	Mn	Zn
Mean(μg/m3)	7.820	0.085	0.655	0.069	0.075	2.506	1.868	0.056	0.359
S.D. (μg/m3)	15.945	0.120	0.860	0.194	0.095	5.598	2.472	0.049	0.806
Median(μg/m3)	3.348	0.008	0.379	0.006	0.037	1.083	1.153	0.039	0.052
Geometric Mean (μg/m3)	2.424	0.018	0.272	0.008	0.024	0.917	0.481	0.034	0.086
Geometric S.D.	5	8	5	6	6	4	8	4	5

*see limits of detection in the table 'Personal (or Surrogate) Metal Exposures', Appendix.

Differences between Paired Area and Personal Metal Samples

For all five metals found in more than 50% of both area and personal samples, the geometric means for personal samples exceeded those for area samples.

Table 14: A Comparison of Personal vs. Area Geometric Means

Measurement	Al	Ba	B	Fe	Mn
Area Geometric Mean (μg/m3)	0.455	0.005	0.175	0.326	0.005
Personal Geometric Mean (μg/m3)	2.424	0.018	0.272	0.917	0.034
Personal:Area Ratio	5.3	3.6	1.6	2.8	6.8

Paired personal/area samples are compared in table 15 below. There was at least one usable pair for eighteen of twenty-two metals.

Table 15: Differences between Paired Area and Personal Metal Samples

Metal	Usable Pairs	Pairs where Personal > Area	Wilcoxon Results
aluminum	23	20	p<0.002
antimony	2	0	n/p
arsenic	0		n/p
barium	11	9	p=0.062
beryllium	4	4	n/p
boron	17	9	p=0.733
cadmium	10	8	p=0.025
chromium	6	3	p=0.211
cobalt	13	11	p=0.020
copper	21	14	p=0.078
gold	0		n/p
iron	21	13	p=0.028
lead	5	5	n/p
lithium	0		n/p
magnesium	19	14	p=0.019
manganese	22	19	p<0.001
mercury	2	0	n/p
nickel	13	9	p=0.084
selenium	0		n/p
silver	3	2	n/p
vanadium	1	0	n/p
zinc	18	9	p=0.372

n/p = not performed.

For beryllium and lead, personal exposures consistently exceeded area exposures. For 13 of the remaining metals, personal exposures were greater than or equal to area exposures at a majority of sites. Statistically significant differences between area and personal exposures (P<0.05) were noted for aluminum, cadmium, cobalt, iron, magnesium and manganese.

Reliability/precision of Metal results

Table 16: Variation in Paired Metal Samples by Site

Site	Median Variation %	$\dfrac{\text{sum of absolute differences}}{\text{sum of means}}$ %	
		when pairs of <LOD values assumed equal	when pairs of <LOD values assumed to differ by LOD/2.83
1	10.5	21	28
2	0.0	9	18
3	4.0	19	25
4	0.0	42	46
5	0.0	13	20
6	0.0	13	20
7	8.5	19	24
8	0.0	18	23
Overall	0.0	20	26

Median variation %, reflecting any systematic difference between paired samples indicates no bias for 5 of 8 sites. Values at the other 3 sites are all less than 11%.

Percent variation by site was expressed as $\dfrac{\text{sum of absolute differences}}{\text{sum of means}}$. Assuming pairs of values below the detection limit to be equal, this variation ranged from 9% to 42% with a mean value of 20%.

Assuming pairs of values below the detection limit to be unequal, with an average value of LOD/2.83 (LOD/2√2), variation between side by side metal samples by site would range from 18 to 46% with a mean value of 26%.

These calculations are affected by two major sources of error:

1. The estimated total error may be inflated by variations within pairs of large values. The table below demonstrates the contribution of each of 4 quartiles (by

average mass) to the total error. As can be seen, the 2 pairs (2.3 % of all pairs) whose mean mass is between 6 and 8 μg account for 27.5% of the total variation.

Table 17: The Effects of Metal Mass on Calculated Variation

Range of mean values	<2 μg	2 - 4 μg	4 - 6 μg	6 - 8 μg
# of pairs	77	2	6	2
sum of differences (ng)	6689	1120	2850	4050
% contribution to total variation	45.5	7.6	19.4	27.5
average contribution (ng) per pair	87	560	475	2025

While this source of error tempts one to use non parametric (median) values to represent variation, this option is subject to the second source of error.

2. Differences between pairs of censored values are not known. Because 53% of all pairs contain censored values, the use of median values to represent variation within censored and uncensored pairs would result in variation being described by an assigned value (LOD/2.83). Taking the median of known values only yields an average 42% variation between paired samples, but is only known to represent less than half the replicates.

The following intra class correlations reflect the variation by metal across all 8 sites. Score is an inclusion criterion. ICCs calculated for concentrations, ln concentrations, and rank are included for comparison. As can be seen, assumptions about distributions have little effect on ICC values for Mn, Al, Cu, Co, or Fe. Because the ICCs for rank are free from distribution assumptions, one can be confident that they do not underestimate the magnitude of the ICC values. However, because they only deal with rank, and do not take the magnitude of individual differences into account, they may be somewhat low.

Table 18: Intra Class Correlations for Duplicate Metal Samples

Metal	ICC			Uncensored values per pair			Score
	value	ln value	rank	both	one	none	
Ba.	0.24	0.40	0.62	8	0	0	16
Mn	0.72	0.72	0.67	8	0	0	16
Al	0.69	0.69	0.74	8	0	0	16
Cu	0.82	0.78	0.83	8	0	0	16
Mg	0.54	0.62	0.67	8	0	0	16
Co	0.00	0.00	0.00	5	3	0	13
B	0.90	0.97	0.59	4	2	2	10
Fe	0.32	0.26	0.28	2	5	1	9
Cd	0.92	0.70	0.45	1	3	4	5

ICC's above 0.40 indicate general agreement between replicate pairs. Using rank values, six of the eight metals show reasonable levels of correlation. Cobalt and iron are the only exceptions.

3.8 Additive Exposures

While concentrations of individual contaminants were found to be low, it was of interest to determine whether exposure to the mixture of kiln emissions was also within an acceptable range (i.e. exposure ("E") was less than 1). Excluding the one site where acrolein may have been above permissible levels, combined area exposures for all substances ("E") ranged from 0.02 to 0.44.

3.9 Strategies Employed to Minimize Exposure by Site Category

Professional: Half the professional potters whose sites were measured relied on passive ventilation. Of the remaining 5, one used direct venting, one used a window fan, two fired raku kilns outdoors, and the last fired a gas kiln in a separate building.

Recreation Centres: Four of the ten recreation centres had separate, single use kiln rooms. Three of these employed engineered room exhaust systems and the fourth relied on a window fan. Three sites had mixed use

kiln/storage rooms. Two of these used direct venting while the third relied on a domestic wall exhaust. The three remaining sites fired in mixed use pottery studios. Kilns at these three sites all had local exhaust ventilation. At one of these sites, the kiln was routinely fired after hours when the studio was unoccupied.

Elementary Schools: The general trend in elementary schools was to separate students from kiln firings. Four of ten elementary schools fired their kilns, unventilated, in the school's boiler room. In another, the kiln was removed from the classroom and placed in a sporadically used faculty office. At two sites, ventilated kilns were fired after hours. Of the 3 kilns fired in the classroom during school hours, two had direct venting systems and the third was fired under a vented hood.

Secondary Schools: In five secondary schools, kilns were fired in low use areas adjacent to classrooms. Two of these sites were directly vented, two used vented hoods, and the last used slot exhausts around the kiln lids. Of the five sites where kilns were fired in the classroom, two used vented hoods, two depended on window exhaust fans, and the last (which relied on general room exhaust) was generally fired after hours.

Post Secondary: Three of the site measurements in this category were in single use kiln rooms. Two of these sites, one with an indoor gas kiln, fired under vented hoods while the third employed a room exhaust. Four of the kilns measured, two of which were gas fired, were in dual use firing/storage rooms. The two gas kilns were fired under exhaust hoods (one active and one passive). One of the electric kilns one used an active hood while the other relied on the hood over an adjacent kiln for room exhaust. At three sites where gas kilns were being monitored, kilns were

fired in partially enclosed outdoor spaces. Two of these gas kilns had chimneys and the third used a passive hood vented through a roof.

3.10 Explanatory Variables

Relationships between explanatory variables and those contaminants found at more than 50% of all sites (NO_2, CO, Al, Ba, B, Fe, and Mn) were explored.

3.10.1 Variations by Site Category

Analysis of Variance (ANOVA) was carried out to determine whether emission concentrations for electric kiln firings varied between the five site categories (professional, hobby, elementary schools, secondary schools, post secondary institutions). ANOVA table means and P-values appear in tables 19 and 20 below. Log values were used for substances whose concentrations between sites were distributed log normally. Similar results were found with the non-parametric Kruskall Wallis test.

Table 19: ANOVA Table Means for NO_2 and CO Concs by Site Category

	Ln Peak NO2	Average NO2	Ln Peak CO	Ln CO
Professional	3.543	23.03	1.581	0.294
Hobby	4.084	21.24	1.796	0.497
Elementary	3.642	20.46	0.333	-0.224
Secondary	3.741	22.81	0.393	-0.342
Post Secondary	3.702	23.82	-0.054	-0.342
P-Value	0.7584	0.9883	0.0171	0.0051

Nitrogen dioxide concentrations were not found to vary significantly by site category. Carbon monoxide concentrations, on the other hand, did vary significantly. Highest concentrations were found at recreation facilities. Lowest values were found in the public schools.

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Table 20: ANOVA Table Means for Area Metal Concs by Site Category

	Ln Al	Ln Ba	Ln B	Ln Fe	Ln Mn
Professional	6.823	2.029	5.816	6.029	1.935
Recreation	6.884	2.191	7.131	6.260	2.349
Elementary	5.520	0.858	4.085	5.395	0.618
Secondary	5.366	1.299	4.264	5.417	1.364
Post Secondary	6.008	2.482	4.536	5.837	1.435
P-Value	<0.008	0.136	<0.0001	0.168	0.076

There were, however, 3 metals whose variation was significant at the $P<0.10$ level: aluminum ($P<0.008$), boron ($P<0.0001$), and manganese ($P=0.076$). Metal concentrations were highest in recreation centres, lowest in public schools.

3.10.2 Variations by Ventilation

Eight ventilation strategies were identified for the 41 electric kilns fired indoors: HVAC systems; exhaust hoods; custom designed a) overhead and b) wall mounted room exhausts; custom exhaust slots adjacent to the kiln lid; direct kiln exhausts at the base of the kiln; domestic wall and window fans; and passive ventilation.

Table 21 below shows mean rank values (Kruskall-Wallis) and rank order averaged across the 7 contaminants (NO_2, CO, Al, Ba, B, Fe, and Mn) found at more than 50% of all sites. Mean rank value refers to the 41 sites. Rank order refers to the eight ventilation strategies.

Table 21: Ventilation Strategies
Ordered from Most to Least Efficient

Ventilation	Mean Rank Value	Rank Order
hvac	14.9	2.6
hood	16.5	2.6
wall	17.7	3.0
direct	20.4	5.1
overhead	20.9	5.0
passive	21.1	5.0
domfan	22.2	5.4
slot	29.1	7.3

Detailed output from the Kruskall-Wallis analysis is found in table 22 below.

Table 22: Ranking of Ventilation Strategies by Contaminant.

Ventilation Strategy	Count	peak NO2	NO2	Count	peak CO	CO	Al	Ba	B	Fe	Mn
		mean rank			mean rank						
passive	8	20.1	18.8	9	24.8	21.5	25.3	15.4	16.8	25.7	24.3
domfan	5	27.0	22.4	5	30.8	33.5	20.6	19.0	25.1	17.3	17.4
overhead	5	12.2	10.8	5	16.7	14.6	27.4	15.5	30.6	19.4	28.2
slot	3	35.2	32.0	3	28.0	17.8	30.7	25.5	28.7	34.7	34.3
direct	7	23.3	23.0	7	20.1	23.4	16.4	18.7	19.9	21.1	20.7
hood	9	16.1	21.2	9	13.6	17.5	13.2	14.3	16.4	16.9	16.1
hvac	2	7.8	9.0	2	21.8	17.5	24.5	13.0	22.5	14.0	4.0
wall	1	35.0	38.0	1	10.5	17.5	18.0	9.5	13.5	14.5	13.0
p-values		0.044	0.131		0.116	0.091	0.212	0.780	0.339	0.341	0.073

HVAC Systems

Contaminant concentrations at the two sites relying on air dilution by HVAC systems tended to be low. In cases where local exhaust was used along with general ventilation, emission levels were assumed to be due to the local exhaust system for this analysis.

Exhaust Hoods

Smoke tube observations indicated that strong convection currents were likely to ensure the effectiveness of passive hoods at higher temperatures, but that low temperature emissions were less likely to be captured.

Unlike custom exhaust hoods commercially available hoods were observed to have the fan motor at the hood end. One such hood in an elementary school picked up emissions on one side of the hood and spilled them into the room on the other. In this particular case, the flexible hose that connected the hood to the wall outlet was looped and twisted.

Room Exhausts

Wall and overhead exhaust vents were in common use. Some of the highest measurements taken around electric kilns were in small, isolated kiln rooms serviced by such room exhausts. Observation of smoke tube results indicated that wall exhaust systems were often less effective during the later part of a firing when higher temperatures generated strong convection currents.

Slot Exhaust Systems

While smoke tubes demonstrated that exhaust slots adjacent to the perimeter of the kiln lid were effective at lower temperatures, their effectiveness was reduced later in the firing as the heat of the firing causes emissions to rise. Cool, fresh replacement air was seen to rise from the floor to be directly exhausted by exhaust slots while kiln emissions hovered in the breathing zone above the exhaust slots.

Directly Vented Kilns

Measurable emissions were evident at some sites with direct kiln exhaust systems in place. In some instances, potters had failed to adapt to the new ventilation strategy, leaving lids ajar or peep holes open. In other cases kilns were old and leaky with ill fitting lids.

Domestic Wall/Window Fans

Contaminant concentrations recorded at sites using domestic exhaust fans were among the highest recorded. The ability of these fans to capture smoke released around the kiln lid was limited.

3.10.3 Variations by Clay

An analysis of variance using firing temperature in 100 degree Celsius intervals as a surrogate for clay type failed to demonstrate a significant relationship between emissions levels and clay type.

Table 23: ANOVA Table Means for Concentrations vs Clay Type

Temp °C	Ln Peak NO2	NO2	Ln Peak CO	Ln CO	Ln Al	Ln Ba	Ln B	Ln Fe	Ln Mn
600	3.091	14.40	1.792	-0.342	5.146	0.347	3.944	5.175	0.347
800	1.792	1.60	-0.342	-0.342	5.872	•	7.080	4.533	3.807
900	5.247	40.90	2.833	0.405	5.130	0.347	3.930	5.134	1.609
1000	3.834	20.71	0.691	0.015	6.229	1.199	5.403	5.705	1.337
1100	3.880	23.89	1.441	-0.030	6.599	2.718	5.684	6.103	2.028
1200	3.498	20.09	0.689	-0.017	6.040	1.287	4.925	5.799	1.289
1300	3.941	20.71	1.750	0.273	5.760	2.647	4.332	6.022	1.475
P-Value	0.1051	0.5484	0.4107	0.9379	0.7914	0.1055	0.3734	0.6781	0.5805

Similar results were found with the non-parametric Kruskall Wallis test.

3.10.4 Variations by Glaze Composition and Quantity

It proved extremely difficult to consistently characterize glaze materials, and impossible to quantify them. Most commonly, especially in categories where the numbers of users and glazes tended to be large (eg. educational institutions and some recreation centres), information on glazes available to users was readily available, but identification and quantification of glazes in the kiln could not be done. Even where users could identify which glazes were being fired, they were unable to provide estimates of quantities used. It was impossible to define a surrogate for measured glaze use that would prove particularly useful. The best information available on quantities related to how many pieces (surface area and thickness of application unknown) had some of a particular glaze on their surface. Even measured volumes of glaze, were they available, could prove unreliable. Individually mixed glazes are suspensions of glaze materials and settling of suspended materials results in dilution over time.

This inability to adequately characterize or quantify glaze materials (see methods) precluded any assessment of the relationship between these variables and measured exposures.

3.10.5 Variations by Firing Type

Variations between emission levels from the firing of greenware (the bisque firing) and the firing of glazed bisque ware (the glaze or glost firing) were analyzed. Only firings of electric kilns that could be readily distinguished as either bisque (20) or glaze (12) firings were included in the analysis.

NO_2 was detected at all bisque sites and 11 of 12 glaze sites. The Mann Whitney test demonstrated that both peak and average NO_2 concentrations were significantly higher at bisque than at glost firings ($P<.04$). Regression analysis of the relationship between NO_2 concentrations and clay mass failed to demonstrate an association ($P=0.359$ for bisque sites, $P>0.74$ for bisque and glaze sites combined).

CO was detected at 10 of 20 bisque sites and 5 of 12 glaze sites. With a mean rank of 17.9 for bisque sites and 14.2 for glaze sites, the Mann Whitney test failed to demonstrate that CO emissions from the firing of greenware were higher than those from glaze firings ($p=.132$). Simple linear regression demonstrated a relationship between CO concentrations and clay mass for bisque sites ($p=0.135$, adj $R^2=.071$) that was stronger than the relationship between CO concentrations and clay mass at glaze sites ($p=0.891$, $R^2=.002$), but was not statistically significant.

Table 24: The Number of Bisque and Glaze Sites where Metals Were Detected

	Li	Ba	Be	B	Mg	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Au	Hg	Pb
bisque	1	8	1	8	5	10	0	2	12	7	6	2	6	6	0	1	1	8	1	0	1	0
glaze	0	3	0	10	7	9	1	2	10	7	3	3	8	5	0	1	0	9	1	0	1	2

While it was initially expected that metal concentrations would be significantly higher during the glost firing than during the firing of greenware, this was not demonstrated by the Mann-Whitney non-parametric test. Only aluminum concentrations were found to vary significantly. Concentrations were higher when greenware was fired ($p = 0.011$, one sided).

3.10.6 Variations by Fuel Type

Of all emissions, only cadmium ($p=0.075$,) and barium ($p=0.047$) were shown to vary by fuel type (Mann-Whitney test, $p<0.10$). Both were found in higher concentrations around electric kilns. When only glaze firings were considered, cadmium and boron concentrations were found to be higher around electric kilns ($P=.061$ for both). No other substances appeared to vary significantly ($p<0.10$) with fuel type.

3.10.7 Variations by Room Size

Third order polynomial regression analyses demonstrated an inverse correlation between boron exposures and room volume ($p=.0259$, adj $R^2=0.152$). No other substances appeared to vary significantly with room volume ($p<0.10$).

3.10.8 Raku

Metals in use by the two raku potters sampled were aluminum, boron, cobalt, copper, iron, lithium, and silver. Personal metal exposures for these raku potters did not obviously differ from exposures experienced by other potters. Neither of them had exposures in the top 10% for any of the seven

metals. Copper (of particular concern to raku potters) and iron exposures were both below median values.

4. DISCUSSION

Nitrogen oxides, carbon monoxide, sulfur dioxide, formaldehyde, other aldehydes, fluorine, and metal fumes have all been identified as common emissions from pottery kilns (Rossol 1996). The extent to which potters in south western British Columbia are exposed to these pollutants is discussed below.

4.1 Nitrogen Dioxide

The WCB Permissible (8 hour time weighted average) Concentration for NO_2 is 1 ppm, more than 16 times higher than the highest measured firing duration average. While nitrogen dioxide has been shown to cause changes in pulmonary resistance at concentrations of 2 - 3 ppm in healthy adults, concentrations of 1 ppm or less for periods of up to 4 hours have produced no consistent effects on pulmonary function (Amdur, Doull et al. 1991). In asthmatics, however, similar changes would be expected at lower concentrations (Gilman, Rall et al. 1990).

Known to be a product of gas combustion, NO_2 emissions are a concern for anyone firing a gas fuelled pottery kiln. However, this study found no statistical difference between NO_2 emissions from electric kiln firings and those attributable to gas fired kilns. The two highest peak values were attributable to electric kilns in the hobby and professional categories. The two highest averaged values were measured around electric kilns in professional studios.

While significantly higher concentrations during the firing of greenware tend to support the idea that NO_2 is emitted from the clay body, the fact that average NO_2 concentrations did not vary with clay mass suggests that the oxidation of nitrogen in the air may be an important source of NO_2 emissions.

NO_2 concentrations measured around kilns appear to give no cause for concern. NO_2 is, however, an exhaust product of gas combustion and one must be aware of the potential for high exposures associated with poorly adjusted burners or improperly ventilated exhaust.

4.2 Carbon Monoxide

The highest firing duration average for carbon monoxide was 6.9 ppm, 3.6 times lower than the PC of 25 ppm. This level would pose no serious health threat to adult potters. The highest individual spikes (95 and 68 ppm) occurred at post secondary institutions when the flow of exhaust from gas kilns was reduced to balance internal temperature and create a chemically reducing environment. Fifteen minute average concentrations around these peaks were 82 and 66 ppm respectively (the 15 minute permissible concentration for CO is 100 ppm). In one instance, the kiln was re-adjusted after increasing carbon monoxide levels became apparent. While the 15 minute PC was never exceeded, there appears to be a very real potential for short term exposures that exceed the 15 minute limit of 100 ppm when firing gas kilns in enclosed or partially enclosed spaces.

The exposure limit of 25 ppm was implemented to keep blood carbon monoxide levels below 3.5% (ACGIH 1991). Symptoms have, however, been noted below this level. Reduced performance of psychomotor tasks is evident at levels between 2% and 5% (ACGIH 1991). Amdur et al note that blood carboxyhæmoglobin levels in adults exposed to concentrations of 10 ppm for 4 to 12 hours do not exceed 2% and that this level has not been shown to cause health problems in normally healthy human adults (Amdur, Doull et al. 1991). This may not be true for higher risk individuals. People with a higher metabolic rate (e.g. children) tend to have more severe symptoms and those with significant cardiovascular disease are more vulnerable because they cannot compensate for

reductions in blood oxygen (Gilman, Rall et al. 1990). Elevation of COHb from 0.6% to 2% aggravated symptoms of myocardial ischemia and angina in men with stable angina pectoris (ACGIH). Even the relatively low levels of carbon monoxide measured in this study may have effects on a more susceptible population. These concentrations would certainly be capable of further elevating the already high blood levels of carboxyhæmoglobin often found in smokers.

The highest average and peak values associated with electric kilns were 5.7 and 33 ppm respectively. These were measured at a site where two kilns were being fired simultaneously in a room with a domestic wall exhaust fan. In fact, the four highest average CO values were measured at locations where such fans were in use. It should be noted that two sites with measurable CO were using direct ventilation systems, one in conjunction with a wall fan. While Reist found carbon monoxide concentrations over 100 ppm at a location 1.5 m above the floor and 0.6 m from unventilated 0.1 and 0.2 m^3 kilns (Reist 1984), this study failed to find comparable values.

Average carbon monoxide concentrations were not found to vary significantly between gas and electric firings. This is an anomalous outcome for the following reasons. In the presence of adequate oxygen, one would expect carbon oxidation to proceed to the dioxide form. The electric firing is generally considered to be an oxidation firing. In contrast, one would expect considerable CO to be generated during the reduction phase of a gas firing. It may be that these expectations were not realized for the following reasons.

There is considerable awareness and concern regarding the potential for noxious emissions from gas burners, and installation of appropriate exhaust ventilation is regulated. Potters are therefore likely to ensure professional installation and inspection of gas and ventilation systems. Emissions are always vented to the outdoors, away from the potter.

The presence of carbon monoxide around electric kilns suggests that there is insufficient oxygen, at least in some firings, to complete the oxidation process. Improvements in glaze quality have been associated with direct ventilation systems (Skutt 1994). This could well result from the provision of additional oxygen as fresh air is drawn directly into the kiln. The fact that kiln gases can be measured in the kiln environment is a reflection of the adequacy of kiln ventilation. Electric kilns are usually installed by the potter and levels of ventilation similar to that used with gas kilns are not usually considered necessary.

While it was originally expected that carbon monoxide would only be detected as an emission product of the clay body during the firing of greenware, this proved not to be the case. CO was also detected where glazed bisque ware was being fired.

Measurable quantities of carbon monoxide were emitted at calculated temperatures ranging from 150°C to 750°C. While this temperature range is similar to that reported by Reist (Reist 1984), there are a number of reasons why recorded temperatures may not precisely reflect clay temperatures at which CO is emitted: 1.) The assumption of linearity between time and temperature may be somewhat bold: a.) it is based on data from 8 kilns, only 4 of which were monitored from the time they were first turned on; b.) more ideal curves, which some potters try to achieve, begin and end with more gentle temperature increases; and c.) potters who use pyrometers may fire differently than those who do not. 2.) A number of potters reported considerable variation between values displayed by different pyrometers, or variations between values displayed by pyrometers and temperatures indicated by pyrometric cones. 3.) Temperatures may vary with location in the kiln and the position of the temperature probe may not represent temperatures throughout. 4.) Air

temperatures are likely to increase more quickly than clay temperatures. Because pyrometers reflect air temperatures at the site of the probe, displayed temperatures (assuming the pyrometer is accurate) are likely to systematically overestimate clay temperatures at which carbon monoxide is emitted. 5.) Periods of emission are likely related to object mass as the heat takes time to penetrate the clay.

4.3 Sulfur Dioxide

The strong odour during the early part of the bisque firing has been attributed by some to the presence of SO_2, however, data suggest that this is not the case. The TMX410 consistently failed to find concentrations of SO_2 above the detection limit of 1.1 ppm during this time period. Given that personal odour thresholds range from 0.3 to 3.2 ppm (Ruth 1986), it is improbable that early concentrations exceeded odour thresholds for most people.

Emissions from electric kilns were only of a magnitude and duration sufficient to provide continuous data above the detection limit for one site. Data from this site indicated that SO_2 was given off during the latter part of the firing, beginning when temperatures exceeded 800°C and continuing through to the end of the firing at 1230°C. This range is somewhat wider than the 1000°C to 1100°C parameters noted by McCann (McCann 1992). There was the only electric kiln site where continuous measurement indicated any values above the limit of detection. The 2 other sites where SO_2 was known to exceed the odour threshold were both firing with gas.

While it has been claimed that SO_2 will be released from almost all clays (Rossol 1982), this study was unable to substantiate that claim. SO_2 was only detected at 6 electric kiln sites and 3 sites where gas kilns were being fired. The 15 minute permissible concentration of 5.0 was not exceeded at any of the 9 sites.

Average SO_2 concentrations were below 0.014 ppm (more than 140x lower than the Workers Compensation Board Permissible Concentration of 2.0 ppm) around 5 of the electric and 2 of the gas kilns. At the remaining electric kiln site, a concentration of 0.508 ppm was calculated from ion chromatography (IC) data. At the last gas site, the electrochemical gas analyzer estimated the average concentration to be 1.2 ppm. However, other experience with this analyzer indicates that this value may be somewhat high. No ion chromatography (IC) data were available for this site.

There was a 3 fold discrepancy between IC data and those generated by the electrochemical gas analyzer for the same site. Calibration problems may have biased readings. If SO_2 emissions were of short duration, average concentrations calculated by substituting $LOD/\sqrt{2}$ for values below the LOD could be falsely elevated by as much as 0.4 ppm. Some inaccuracy may be attributed to the TMX 410 itself. The SO_2 sensor may have responded to unidentified interferents in the kiln environment. Loss of SO_2 on the surfaces of sampling cassettes or tubing may have reduced the quantity available for IC analysis.

The inability of this study to detect short SO_2 peaks of less that 1.1 ppm is a shortcoming. Humans can show reduced pulmonary flow in response to a few deep breaths of sulfur dioxide at concentrations of 1 to 5 ppm. In asthmatics, bronchoconstriction may occur at 0.25 ppm (Gilman, Rall et al. 1990). Concentrations below these levels have no effect on individuals with chronic bronchitis (Amdur, Doull et al. 1991).

4.4 Formaldehyde

Measurable formaldehyde was detected at 30% of the sampled sites. The highest average value detected was 0.102 ppm, nearly 20 times lower than the

Workers' Compensation Board Permissible Concentration of 2.0 ppm. Since this PC equals the level at which irritation begins (Amdur, Doull et al. 1991), it may not provide adequate protection. The Health Protection Branch of the Canadian Environmental Health Directorate recommends concentrations be reduced below a 0.05 ppm (Federal-Provincial Advisory Committee on Environmental and Occupational Health 1987).

Upper airway irritation and increased nasal airway resistance have been seen with concentrations as low as 0.08 ppm. Neurophysiologic health effects and eye irritation have been reported at concentrations down to 0.04 ppm. White male workers exposed to concentrations greater than 0.1 ppm appear to be at risk for an increased incidence of respiratory cancers(ACGIH 1991). Formaldehyde is a known sensitizer and there is no information regarding levels at which sensitization could occur (ACGIH 1991). Occupational exposure has been linked to asthma (Amdur, Doull et al. 1991; Gilman, Rall et al. 1990). The National Institute for Occupational Hygiene in the United States (NIOSH) has established a TWA of 0.016 ppm and a 15 minute ceiling of 0.1 ppm. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRÆ) has also established a similar ceiling. The 0.016 ppm NIOSH TWA is barely above the level generally seen in ambient outdoor air. At these levels, many of the kiln sites measured would not be in compliance. Five professional sites, four recreation sites, two elementary schools, one secondary school had concentrations above 0.016 ppm. At four professional sites, four recreation centres, six elementary schools, five secondary schools and five post secondary institutions, detection limits were such that one could not be certain exposures were below 0.016 ppm. While organic materials in commercially prepared clays and glazes may decompose to form formaldehyde (Rossol 1982), one cannot be certain whether the formaldehyde levels measured above can be directly attributable to pottery

kiln emissions, or whether they represent other sources (e.g. building materials, furnishings, or other art supplies). Continuous monitoring could provide the level of information necessary to distinguish formaldehyde concentrations in kiln emissions from ambient levels emitted by other sources.

4.5 Other Aldehydes

Acetaldehyde was identified at eleven sites. Acrolein and/or acetone were measured at three. The highest acetaldehyde exposure was 380x lower than the PC of 100 ppm. This compound appears to be of no concern.

The method of analysis used for aldehydes could not distinguish between acetone and acrolein, hence one cannot determine whether the referent chromatographic peak represents acetone, acrolein, or a mixture of the two. Assuming all three values were acetone only, potential exposures were nearly 4 orders of magnitude below the P.C. of 1000 ppm and should be of little concern. Should they be acrolein only, one measured value exceeded the PC of 0.1 ppm and all 3 measured values exceeded Canadian indoor air quality guideline of 0.02 ppm (Federal-Provincial Advisory Committee on Environmental and Occupational Health 1987).

While it was thought that characteristic odours notable during the early stages of the bisque firing might be due to aldehyde emissions, this link was not demonstrated. Aldehydes were not consistently present at sites where odours were obvious, nor were odours always obvious when aldehydes were present. There was no consistent evidence linking measurable aldehyde to clay type or firing type.

4.6 Fluoride

Fluoride was only detectable at 2 sites. Concentrations at these sites were more than 8 times lower than the WCB Permissible Concentration of 1.9 ppm. In both instances, the detectable fraction was of gaseous, not particulate origin. There was no evidence to support the suggestion by Luxon that fluorides are emitted in the form of ammonium fluosilicates (Luxon 1963).

4.7 Metals

4.7.1 Area Metals

Geometric means for those metals found at more than 50% of all sites (aluminum, barium, boron, iron, and manganese) were very low.

Table 25: Geometric Means of Area Metals and Permissible Concentrations

Metal	Conc. (mg/m^3)	PC (mg/m^3)
Aluminum	4.6×10^{-4}	
Barium	5.3×10^{-6}	0.5
Boron	1.8×10^{-4}	1.0
Manganese	4.7×10^{-6}	5.0
Iron	3.3×10^{-4}	1.0

Aluminum is not regulated by the Workers Compensation Board of B.C. Of the three regulated metals, all geometric means were more than 3 orders of magnitude below Permissible Concentrations. When compared to the ACGIH threshold limit value of 10 mg/m^3, aluminum is similarly low. Because clay is an aluminum silicate, one cannot be certain what proportion of the aluminum measured in this study was emitted from the kiln as aluminum metal and what proportion might be in the silicate form. The

TLV for aluminum refers to metal dust. One would expect the bio-availability of the silicate form to be limited, hence the TLV may not apply.

4.7.2 Personal Metals

Concentrations of aluminum, manganese, copper, boron, iron, magnesium, cobalt, and zinc were all very low. Of the seven regulated metals, all geometric means were 3 orders of magnitude or more below WCB Permissible Concentrations. Aluminum is similarly 3 orders of magnitude below the ACGIH threshold limit value of 10 mg/m^3.

Table 26: Geometric Means of Personal Metals and Permissible Concentrations

Metal	Conc. (mg/m^3)	PC (mg/m^3)
Aluminum	2.4×10^{-3}	
Barium	1.8×10^{-5}	0.5
Boron	2.7×10^{-4}	1.0
Cobalt	8.5×10^{-6}	0.1
Copper	2.4×10^{-5}	0.2
Iron	9.2×10^{-4}	1.0
Magnesium	4.8×10^{-4}	10.0
Manganese	3.4×10^{-5}	5.0
Zinc	8.6×10^{-5}	5.0

4.7.3 Highest Metal Concentrations

The highest concentrations of individual metals in area and personal samples are compared to Workers Compensation Board Permissible Concentrations in table 27 below. All area metal concentrations were at least 2 orders of magnitude below PC's with the exception of Vanadium which was detected at only one site. Among the personal samples, all metals were at least 2 orders of magnitude below PC's, except lead, cadmium, iron, cobalt, and silver.

Table 27: Highest Recorded Metals (both area and personal), Protection Factors, and Permissible Concentrations.

Metal	Permissible Concentration	Area Sample		Personal Sample	
		Highest Concentration	Protection Factor	Highest Concentration	Protection Factor
	(µg/m3)	(µg/m3)		(µg/m3)	
Al		15.561		62.778	
Sb	500	0.010	50,000	<0.021	>23,809
As	500	<2.340	>213	<2.350	>212
Ba	500	0.091	5,515	0.368	1,358
Be	2	0.002	1,000	<0.010	>200
B	1000	5.252	190	3.890	257
Cd	50	0.114	437	0.999	50
Cr	50	0.431	116	0.306	379
Co	20	0.169	119	0.863	23
Cu	200	3.750	53	0.312	640
Au		<0.005		<0.005	
Fe	1000	4.042	247	26.952	37
Pb	50	0.208	240	0.788	63
Li	25	0.015	1,667	<0.125	>200
Mg	10000	4.248	2,354	9.566	1,045
Mn	5000	0.094	53,237	0.174	28,730
Hg	50	0.017	3,002	<0.013	>3846
Ni	50	0.291	172	0.175	286
Se	200	0.249	803	<0.420	>476
Ag	10	0.003	3,223	1.755	6
V	50	5.220	10	<4.150	>12
Zn	5000	1.502	3,328	3.583	1,396

4.7.4 Area vs. Personal Metal Samples

While the differences between personal and area exposures were somewhat variable between sites, data suggest that sources other than kiln emissions pose a greater risk of metal exposures. Personal to area ratios comparing geometric means for metals present at more half the sampling sites (Al, B, Fe, Mn) all demonstrate higher personal exposures. Data from paired samples indicate significantly higher personal than area exposures to aluminum, cobalt, iron, magnesium and manganese.

Future studies should focus on elucidating specific practices that lead to increased metal exposure, with an eye to reducing these exposures.

4.7.5 Metals with Reported Effects below the Permissible Concentration

Molten aluminum has been has been shown to cause asthmatic symptoms in refinery workers. It has also been linked to pulmonary fibrosis, with much greater risks associated with mixed aluminum/silica environments (Rom 1992). Despite this information, no exposure limit has been assigned to aluminum by the WCB. The ACGIH TLV is 10 mg/m^3. The McIntyre Foundation has noted no adverse health effects with aluminum oxide exposures equivalent to 2 mg/m^3 (ACGIH 1991). The highest personal exposures measured in this study were 32x lower than this value.

Cobalt, in the tungsten carbide industry, has been shown to cause respiratory irritation at air concentrations of 0.002 to 0.01 mg/m^3 and may be a cause of hard metal pneumoconiosis (Amdur, Doull et al. 1991). Previously unexposed healthy young males developed cough, expectoration and sore throat in response to hard metal mixtures with cobalt

concentrations as low as 0.014 mg/m^3, and cobalt at unspecified concentrations below 0.1 mg/m^3 has been linked to asthma. (ACGIH 1991)

Copper has been shown to alter taste at concentrations between 0.02 and 0.4 mg/m^3, but no negative health effects have been demonstrated at this level.

Chronic manganese exposure, in the early stages, has been shown to increase somnolence, impair speech, and lead to a lack of co-ordination which can be manifest as difficulty walking. With continued exposure, postural instability, bradykinesis, tremor, and emotional lability develop. In the later stages, Parkinson's like symptoms become apparent (Amdur, Doull et al. 1991)(Amdur, Doull et al. 1991; Rom 1992). One industrial study has shown chronic manganese poisoning in miners exposed to concentrations, two thirds of which were below 5.0 mg/m^3. However, other studies have failed to replicate these results (ACGIH 1991).

4.7.6 Metals that are Linked to Cancer

Six metals used in pottery glazes have been linked to cancer (IARC 1987). Three of these: arsenic, nickel, and chromium (in the hexavalent form) are classified as known human carcinogens. Beryllium and cadmium have been designated probable human carcinogens and lead is considered to be possibly carcinogenic in humans. Epidemiological evidence for human carcinogenicity comes from studies in industrial settings where concentrations are considerably higher than those found in this study.

4.7.7 Variations in Metal Exposure by Site Category

Area measurements found high concentrations of aluminum in professional and hobby categories and low concentrations in elementary schools. The highest concentrations of boron were found in recreation

centres, followed by professional studios then the educational institutions. While chromium was measured in 30% of both professional studios and secondary schools, there were no levels above limits of detection from elementary school sites or post secondary institutions. Cadmium levels were highest amongst recreation centre potters with no measurable levels found in the secondary school category.

4.7.8 Variations in Metal Exposure by Firing Type

While it was originally assumed that metals concentrations would be significantly higher around kilns firing glazed bisque ware than around kilns firing greenware, this was not generally found to be the case. Metal concentrations were generally very low. This is consistent with Reist's thought that a kiln brought slowly to the proper temperature then allowed to cool will keep vapour pressures low, minimize boiling and spattering of the glaze, and keep emissions to a minimum (Reist 1984). However, this outcome was not a certainty because metals exert a vapour pressure at temperatures below the boiling point and "Complex reactions which occur during glaze firing make it difficult to predict precisely at what temperature metals will volatize and oxidize to form a fume " (Rossol 1996).

4.8 Ventilation

Ventilation is generally recommended to control emissions from kilns (Rossol 1982; McCann 1992). Unfortunately, in this study certain strategies such as slot hoods around the perimeter of the kiln lid, overhead room exhausts, domestic wall/window fans, and direct venting showed no noticeable improvement over unventilated kilns. A failure to match exhaust flow rates,

available replacement air, and air flow patterns to specific kiln needs may account for the higher concentrations found under some conditions. It must also be born in mind that the kilns which are unventilated may remain so because users do not perceive a need for ventilation (emissions may be minimal or, in larger studios, dilution volumes may be large).

Despite these caveats, specific concerns remain about certain ventilation strategies. Domestic wall/window fans, for example, which were never designed for industrial ventilation appeared to have minimal impact on contaminant concentrations. Slot exhausts around the perimeter of the kiln lid were limited in their ability to capture rapidly rising contaminants at higher kiln temperatures.

Despite the hope that direct kiln exhaust systems would keep fumes out of the kiln room, measurable contamination was evident at some sites with these systems in place. Direct venting systems remove air directly through the bottom of the kiln. Where kilns were old and leaky, lids left ajar or peep holes open, direct venting was unable to prevent the escape of emissions into the kiln room. For negative pressure (direct venting) systems to be effective, it has been recommended that the fan should be near the exhaust end (Rossol 1996). Whether exhaust efficiency at measured sites was compromised by fan placement is not certain.

While contaminant concentrations at sites relying on air dilution by HVAC systems tended to be low, it was difficult to separate the performance of such systems from other factors such as larger room dimensions. Similarly, the effectiveness of other exhaust ventilation strategies may be confounded by the presence of HVAC systems.

Despite the fact that exhaust hoods ranked among the most effective ventilation strategies, some variation related to hood design and placement were noted. In some cases, kilns were not positioned correctly under hoods. Some

hoods were apparently too small for the kilns they were servicing. The effect of size became increasingly evident as the distance from the kiln to the hood increased.

Smoke tubes indicated that passive hoods were less effective than those with fans. Among powered hoods, some variation may be related to fan placement and the appropriateness ductwork. Rossol recommends that for canopy hoods, fans should be at the exhaust end of the ductwork (Rossol 1996). While this tends to be the case for hoods in institutional settings, some commercially available hoods have the fan motor attached to the hood itself. Poor performance may result from increased back pressure when flexible hose is used to connect the hood to the wall outlet.

In many cases, it is difficult to separate the effects of ventilation from other variables such as room dimensions or true differences in emission levels. With limited numbers of kiln sites in each ventilation category, this study was limited in its ability to demonstrate the true potential of the above mentioned strategies.

Despite the above reservations, this study indicates that having a well ventilated kiln room with a custom designed exhaust hood is the most effective way to minimize air contamination and potential exposure to kiln emissions.

4.9 Study Limitations

While this study provides a reasonable cross sectional snapshot of exposures to kiln emission, it has fallen short of characterizing the determinants of these exposures. The results of this study illustrate the diversity in equipment, methods, and materials commonly used by potters in southwestern British Columbia. The fifty potters measured used 48 clays, a wide range of glazes and other colorants that defied enumeration, and 8 or more different ventilation strategies with variations in flow rates and replacement air. There were wide

variations in room size, kiln size, and kiln pack density. Quantification of clay depended on rough estimates made by as many different observers as there were sites. Kilns were fired indoors, outdoors, and in partially enclosed environments. Kilns were fired to thirteen different temperature maxima over durations that ranged from 5 to 24 hours (including an overnight pre soak).

Emission measurements were not taken in small, poorly equipped hobby studios with poorly ventilated kilns in living areas.

4.10 Further Health Considerations

While none of the measured indoor pollutants were found in concentrations known to have a negative impact on health, these substances were not emitted in isolation. Contaminants in the pottery environment may work synergistically, or one may potentiate the effects of another.

All kiln emissions occur in an environment where clay dust is present. The silica in clay dust poses a well substantiated health risk for industrial potters (Davies 1968). Unfortunately, the levels of silica exposure among potters in southwestern British Columbia are unknown. Future studies looking at these exposures could add important information to our growing knowledge of potters' exposures.

Formaldehyde and three of the metals, chromium, cobalt and nickel, are known sensitizers. Responses from exposed, sensitized individuals can occur at levels far below thresholds recognized for a healthy adult population.

Heat is an added stressor in many kiln environments. Kiln room temperatures at a number of sites measured during this study rose above 30°C during the latter stages of a firing.

Pottery is an activity undertaken by a diverse group which includes children, seniors, pregnant women, and individuals with pre-existing health

conditions (e.g. asthma). Many individuals may have elevated susceptibilities to kiln emissions. Concentrations of contaminants must be kept low enough to ensure an adequate margin of safety for all participants.

5. CONCLUSION

From the results of this study, one may conclude that the health of British Columbia potters in small professional potteries, recreation centres, and educational institutions does not appear to be at risk from kiln emissions. There were a number of contributing factors that helped minimize that risk. In most cases, some type of ventilation was in place. Many studios were sizable rooms offering a large dilution volume. Kiln loads fired in the elementary schools tended to be small, presumably emitting proportionally lower levels of emissions. Some potters employed firing practices designed to minimize exposure: kilns were left overnight on a low setting to drive off organic gases while kiln rooms or buildings were unoccupied; or firings were done in isolated or little used rooms.

The potential for higher levels of contamination was made evident at a number of recreation centres where contaminant levels in small kiln rooms ranked among the highest measured, despite ventilation. It is possible that exposures for people working adjacent to kilns in confined, unventilated areas may be excessive. The author strongly encourages all potters firing under such conditions to consider an industrial grade exhaust hood large enough for the kiln to sit completely under it. The use of rigid ductwork when connecting the hood to the outdoors can help minimize back pressure and ensure proper flow. It is generally recommended that the exhaust motor be located close to where the ductwork exits the building. The proper operation of all exhaust systems requires a source of fresh air to replace that exhausted from the kiln room.

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APPENDIX:

INDIVIDUAL MEASUREMENTS

Site	B/G	E/G	Temp	Peak			Average					
Category	(Bisque/glost)	(elect/gas)	(°C)	NO2	CO	SO2	NO2	CO	SO2	SO2	Formaldehyde	Fluoride
				(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	TMX (ppm)	IC (ppm)	(ppm)	(ppm)
Professional												
P1	G	E	1015	n/a	<1	<1.1	n/a	<1.0	<1.1	<0.002	0.023	<0.001
P2	B/G	E	1060	0.241	31	<1.1	0.060	4.5	<1.1	<0.002	0.102	<0.001
P3	Raku	G	1120	0.040	5	<1.1	<0.003	<1.0	<1.1	<0.003	<0.019	<0.001
P4	B	E	1204	0.173	19	<1.1	0.053	2.2	<1.1	<0.003	<0.025	<0.001
P5	B	E	1230	0.009	9	<1.1	<0.003	3.1	<1.1	0.005	0.059	<0.001
P6	G	E	800	0.006	<1	<1.1	0.002	<1.0	<1.1	<0.044	<0.029	<0.040
P7	G	G	1305	0.039	10	<1.1	0.017	1.1	<1.1	<0.002	<0.013	<0.001
P8	Raku	G	1000	0.011	<1	<1.1	0.003	<1.0	<1.1	<0.003	<0.026	<0.001
P9	G	E	1060, 1230	0.040	8	<1.1	0.013	<1.0	<1.1	<0.030	0.027	<0.033
P10	G	E	1060	0.019	3	<1.1	0.010	<1.0	<1.1	<0.029	0.035	<0.026
Hobby												
H1	B	E	1015	0.190	2	<1.1	0.039	<1.0	<1.1	<0.004	<0.029	<0.002
H2	B	E	990	0.047	33	5.0	0.023	5.7	1.6	0.508	0.057	<0.004
	G	E	1230									
H3	G	E	1115	0.031	8	<1.1	0.012	1.2	<1.1	<0.036	0.022	<0.003
H4	B	E	1015	0.079	16	<1.1	0.015	3.0	<1.1	<0.023	0.027	<0.020
H5	B	E	1015	0.042	2	<1.1	0.021	<1.0	<1.1	0.004	<0.014	<0.001
H6	G	E	1230	0.044	<1	<1.1	0.021	<1.0	<1.1	0.014	<0.014	<0.004
H7	B	E	1015	0.311	22	<1.1	0.031	1.7	<1.1	n/a	<0.053	<0.010
H8	B	E	1015	0.013	<1	<1.1	0.009	<1.0	<1.1	<0.002	<0.018	<0.001
H9	B/G	E	1015	0.068	16	<1.1	0.026	3.3	<1.1	<0.002	0.059	<0.001
H10	B	E	1015	0.049	21	<1.1	0.016	4.9	<1.1	<0.026	<0.019	<0.024
	G	E	1230									
Elementary												
E1	B	E	875	0.190	17	<1.1	0.041	1.5	<1.1	<0.005	<0.023	<0.003
E2	B	E	1190	0.038	<1	<1.1	0.024	<1.0	<1.1	<0.004	<0.020	<0.002
E3	B	E	1230	0.018	<1	<1.1	0.010	<1.0	<1.1	<0.006	<0.033	<0.001
E4	G	E	1015	0.041	<1	<1.1	0.027	<1.0	<1.1	<0.005	<0.038	<0.002
E5	G	E	1015	0.025	<1	<1.1	0.012	<1.0	<1.1	<0.003	0.032	<0.001
E6	G	E	1015	0.015	2	<1.1	0.001	<1.0	<1.1	<0.003	0.024	<0.001
E7	B	E	1060	0.070	9	<1.1	0.025	1.1	<1.1	<0.002	<0.016	0.127
E8	B	E	1170	0.023	<1	<1.1	0.017	<1.0	<1.1	<0.005	<0.024	<0.003
E9	B	E	1015	0.060	<1	<1.1	0.027	<1.0	<1.1	<0.003	<0.014	<0.002
E10	B	E	1015	0.034	<1	<1.1	0.021	<1.0	<1.1	<0.011	<0.022	<0.004
Secondary												
S1	B	E	presoak	0.022	6	<1.1	0.014	<1.0	<1.1	<0.005	<0.024	<0.003
S2	B/G	E	1015	0.033	<1	<1.1	0.018	<1.0	<1.1	<0.003	0.018	<0.002
S3	B	E	1015	0.081	<1	<1.1	0.028	<1.0	<1.1	<0.004	<0.020	<0.003
S4	G	E	1230	0.033	<1	<1.1	0.023	<1.0	<1.1	<0.002	0.013	<0.001
S5	B	E	1015	0.098	<1	<1.1	0.014	<1.0	<1.1	0.008	0.013	<0.002
S6	B/G	E	1015	0.038	<1	<1.1	0.028	<1.0	<1.1	0.004	<0.016	<0.002
S7	G	E	1060	0.057	2	<1.1	0.025	<1.0	<1.1	<0.003	<0.017	<0.002
S8	B/G	E	1015	0.015	11	<1.1	0.009	<1.0	<1.1	<0.002	<0.015	0.152
S9	B	E	1060	0.056	3	<1.1	0.041	<1.0	<1.1	<0.003	<0.020	<0.002
S10	B/G	E		0.051	<1	<1.1	0.027	<1.0	<1.1	<0.004	<0.018	<0.002
	G	E	1888									
Post Secondary												
C1	B	E	990, 1115	0.040	3	<1.1	0.025	<1.0	<1.1	<0.002	<0.016	<0.001
	G	E	1230, 1305									
C2	G	G	1305	0.061	68	6.6	0.010	3.5	<1.1	0.004	<0.011	<0.001
C3	B	E	950	0.037	<1	<1.1	0.024	<1.0	<1.1	<0.003	<0.014	<0.002
C4	G	G	1305	0.191	95	5.0	0.044	6.9	1.2	n/a	0.016	n/a
C5	G	G	1305	0.021	<1	<1.1	0.010	<1.0	<1.1	<0.004	<0.022	<0.003
	B	E	1060									
C6	B	E	990	0.121	<1	<1.1	0.043	<1.0	<1.1	<0.004	<0.023	<0.003
C7	G	G	1305	0.037	<1	<1.1	0.018	<1.0	<1.1	<0.006	<0.039	<0.002
C8	G	G	1305	0.082	9	<1.1	0.021	1.3	<1.1	n/a	<0.026	n/a
	B	E	930									
	G	E	1305									
C9	G	E	1060	0.029	<1	<1.1	0.016	<1.0	<1.1	<0.002	<0.014	<0.001
C10	G	G	1305	0.033	<1	<1.1	0.025	<1.0	<1.1	0.003	<0.012	<0.003

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	Li	Ba	Be	B	Mg	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Au	Hg	Pb
	(ng/m3)																					
Professional																						
P1	<50	<2	<5.0	127	1265	2334	<1660	<166	94	876	<3	<8	2	194	<500	<160	<0.9	9.8	<9	<2.0	<5	57
P2	<8	17	<0.8	733	33	841	<1670	<167	<2	192	<2	<17	<2	<17	<500	<170	2.5	21.2	<2	<0.2	<5	208
P3	<60	n/a	<6.0	851	40	811	<2000	<199	<2	<300	<4	<20	<2	<40	<600	<200	<1.0	<4.0	<10	<2.0	<6	<10
P4	<13	15	<1.3	102	<51	<256	<2560	<256	3	<520	<3	<13	<3	<26	<770	<260	<1.3	35.1	<3	<0.3	<8	<13
P5	<8	50	<0.8	226	<32	1316	<1620	<162	5	671	8	<8	<2	<17	<490	<170	<0.9	23.8	<2	<0.2	<5	<9
P6	<100	n/a	<10.0	1188	3438	355	<3330	431	45	93	169	<33	104	<67	<1000	249	<1.7	43.0	<17	<4.0	17	<17
P7	<38	<2	<3.8	72	<25	<127	<1270	<127	<1	<200	<3	<13	3750	<26	<390	<130	<0.7	<2.6	<7	<2.0	<4	<7
P8	<79	n/a	<7.9	149	<53	2126	<2640	341	<3	<400	<6	57	<3	<53	<800	<270	<1.4	<5.3	<14	<3.0	<8	<14
P9	<66	n/a	<6.6	944	801	8418	<2210	286	37	4042	<4	291	25	413	<670	<230	<1.2	17.5	<12	<3.0	<7	<12
P10	<66	n/a	<6.6	826	1385	1987	<2190	<219	36	1157	<4	25	24	585	<660	<220	<1.2	<4.4	<12	<3.0	<7	<12
Hobby																						
H1	<14	4	<1.4	1679	458	542	<2655	<265	6	<535	<3	<14	7	<27	<800	<270	<1.4	51.0	<3	<0.3	<9	<14
H2	<6	19	<0.6	2183	95	519	<1280	<128	17	533	<1	<6	70	202	<390	<130	<0.7	26.6	6	<0.1	<4	<7
H3	<44	n/a	<4.4	302	3705	1766	<1460	<146	39	1943	<3	<15	<2	317	<440	<150	<0.8	26.2	<8	<2.0	<5	29
H4	<48	n/a	<4.8	2015	1334	1293	<1600	368	30	1327	<3	67	18	1502	<490	<160	<0.8	4.6	<8	<2.0	8	<8
H5	15.0	13	2.0	933.0	102	642	<1200	<120	5	295	<2	<7	<2	35	<260	85.0	1.0	27.9	<2	<0.1	<4	<6
H6	<40	n/a	<4.0	1637	216	1076	<1330	<133	9	<200	<3	<14	<2	<27	<400	<140	<0.7	3.9	<7	<2.0	<4	<7
H7	<52	n/a	<5.2	706	1967	2269	<1740	<174	41	2654	<3	<18	<2	<35	<530	<180	<0.9	114.5	<9	<2.0	<6	<9
H8	<9	<2	<0.9	347	<35	719	<1740	<174	<2	347	<2	<9	<2	<18	<530	<180	<0.9	42.9	<2	<0.2	<6	<9
H9	<7	41	<0.7	2124	<28	593	<1400	<140	17	280	<1	<7	16	136	<420	<140	3.1	35.9	<2	<0.1	<5	<8
H10	<55	n/a	<5.5	5252	<37	1838	<1830	<183	3	274	<4	<19	<2	67	<550	<190	<1.0	32.7	<10	<2.0	9	<10
Elementary																						
E1	<72	<2	<2.4	<72	<48	<239	<2400	<239	5	<240	1	<24	5	61	<720	<240	<1.2	12.2	10	<3.0	<8	<12
E2	<61	<2	<2.0	<61	<40	<202	<2020	<202	<2	<210	<2	<21	16	113	<610	<210	<1.1	<4.1	<11	<3.0	<7	<11
E3	<100	<3	<3.3	<100	<66	<332	<3320	<332	3	<340	2	<33	<4	518	<1000	<340	<1.7	<5.4	<17	<4.0	<10	<17
E4	<19	<4	<1.9	229	<77	<383	<3830	<383	4	<770	20	<19	44	<39	<1150	<390	<2.0	29.5	<4	<0.4	<12	<20
E5	<11	<2	<1.1	<22	<44	15561	<2190	<220	<2	<440	<2	<11	106	<22	<660	<220	<1.1	21.2	<3	<0.2	<7	<11
E6	<9	6	<0.9	368	<37	<184	<1840	<184	<2	<370	<2	<10	<2	<19	<560	<190	<1.0	19.7	9	<0.2	<6	<10
E7	<48	2	<1.6	<48	<32	<159	<1590	<159	<2	<240	<1	<8	<2	<32	<480	<160	<0.9	<3.2	<8	<2.0	<5	<9
E8	<74	<2	<2.5	<74	<49	<247	<2470	<247	<2	360	<2	<25	<3	<50	<740	<250	<1.3	<5.0	<13	<3.1	<8	<13
E9	<43	13	<1.4	<47	<28	<142	<1420	<142	1	<150	<1	<14	<2	<29	<530	<150	<0.8	<2.9	<8	<2.0	<5	<8
E10	<65	<2	<2.2	<65	<44	<218	<2180	<210	<2	<220	1	50	<3	144	<760	<220	<1.1	<4.4	<11	<3.0	<7	<11
Secondary																						
S1	<73	<2	<2.4	<73	<49	<243	<2430	<243	<2	<250	1	<24	7	<49	<730	<250	<1.3	<4.9	<13	<3.0	<8	<13
S2	<49	<1	<1.6	<49	<33	<76	<1650	<165	1	<170	<2	<17	<2	<33	<500	<170	<0.9	<3.3	<9	<2.0	<5	<9
S3	<62	<2	<2.1	<62	<41	<206	<2070	<206	<2	<210	40	<21	<3	<42	<620	<210	<1.1	<1.3	<11	<3.0	<7	<8
S4	<32	<1	<1.1	<32	<22	<108	<1080	<108	1	<110	<1	<11	<2	<22	<330	<110	<0.6	<2.2	<6	<2.0	<4	<6
S5	<34	<1	<1.1	<34	<23	212	<1140	<114	1	<120	<1	<12	<2	<23	<350	<120	<0.6	<2.3	<6	<2.0	<4	<6
S6	<46	31	<1.5	1152	<31	717	<1540	<154	29	532	58	<16	54	40	<470	<160	<0.8	<3.1	<8	<2.0	<5	<9
S7	<61	87	<2.1	129	732	1097	<2030	<202	40	1143	7	18	30	<41	<610	<205	<1.1	<2.1	<11	<2.6	<7	<9
S8	<7	<1	<0.7	89	<30	454	<1490	149	<2	<300	<1	37	<2	85	<450	<150	<0.8	<3.0	7	<0.1	<5	<8
S9	<59	18	<2.0	156	2771	210	<1980	198	19	486	<1	<20	38	<40	<600	<200	<1.0	<4.0	<10	<2.0	<6	<10
S10	<53	18	<1.8	<53	<35	<175	<1750	175	19	256	<1	<18	37	<36	<530	<180	<0.9	<3.5	<9	<2.0	<6	<9
Post Secondary																						
C1	<45	n/a	<4.5	313	<31	1220	<1513	<51	28	496	<3	63	<2	<31	<460	<160	<0.8	<3.1	<8	<2.0	<5	<8
C2	<5	8	<0.5	25	47	255	<1050	<105	4	295	<1	<5	<2	56	<320	<110	1.8	1.3	3	<0.1	<4	<6
C3	<7	3	<1.4	<43	<28	142	<1420	<142	1	<150	<1	<15	<2	<29	<430	<150	<0.8	<2.9	<8	<2.0	<5	<8
C4	<47	67	<1.6	294	2310	1568	<1560	<156	15	539	<1	<16	17	<32	<570	<160	<0.8	<3.2	<8	<2.0	<5	<9
C5	<68	30	<2.3	<68	<46	82	5220	<227	6	1470	1	<23	16	173	<690	<230	<1.2	<4.6	<12	<3.0	<7	<13
C6	<73	<2	<2.4	<73	<49	243	<2430	<243	<2	<250	<2	<25	<3	<49	<730	<250	<1.3	<4.9	<13	<3.0	<8	<13
C7	<122	<4	<4.1	<122	4248	799	<4080	<408	40	1818	2	<41	41	<82	<2340	<410	2.1	<8.2	<21	<5.0	<13	<21
C8	<13	91	<1.3	258	<52	1125	<2590	<259	3	<520	<3	<13	<3	96	<780	<260	<1.3	7.0	<3	<0.3	<8	<14
C9	<44	15	<0.7	494	<29	820	<1450	<145	1	167	<1	<8	42	83	<440	<150	<0.8	6.8	<8	<0.1	<5	<8
C10	<37	19	<1.2	<37	<24	122	<1220	<122	1	<130	2	<13	<2	<25	<370	<130	<0.7	<2.5	<7	<2.0	<4	<7

Personal (or Surrogate) Metal Exposures

Site	Sample	Li	Ba	Be	B	Mg	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Au	Hg	Pb
		concentration (ng/m3)																					
P1	personal	<52	<2	<5.2	184	2601	11191	<1720	<172	101	2628	<3	20	19	115	<520	<180	<0.9	27.3	<9	<2.0	<6	295
P3	personal	<62	n/a	<6.2	937	476	5349	<2050	<205	38	673	22	<21	23	240	<620	<210	<1.1	6.0	<11	<3.0	<7	<11
P6	personal	<98	n/a	<9.8	742	5668	3621	<3270	96	169	1727	<7	<33	4	55	<990	<330	1755.2	35.7	<17	<4.0	<10	<17
P7	personal	<40	276	<4.0	236	2350	49347	<1330	306	62	3771	154	122	135	3583	<400	<140	<1.0	21.2	<7	<2.0	<7	53
P8	personal	<83	n/a	<8.3	762	2375	293	<2760	<276	37	903	<6	<28	3	<56	<830	<280	<1.4	<5.6	<14	<3.0	<9	<14
P9	personal	<68	n/a	<6.8	806	<45	2274	<2260	<226	71	3001	24	<23	48	761	<680	<231	<1.2	24.6	<12	<3.0	<7	33
P10	personal	<68	n/a	<6.8	807	1204	4992	<2260	66	42	4587	8	<23	<3	264	<680	<230	<1.2	<4.6	<12	<3.0	<7	<12
R2	personal	<8	101	<0.8	1563	<33	2552	<1660	<166	28	<340	17	30	<2	<17	<500	<170	<0.9	36.1	<2	<0.2	<5	<9
R3	personal	<72	n/a	<7.2	1212	2301	3364	<2390	<239	40	1262	<5	<24	27	88	<720	<240	1.7	999.5	<12	<3.0	<8	788
R6	personal	<73	n/a	<7.3	992	274	3676	<2440	<244	82	800	<5	175	296	163	<740	<250	<1.3	<4.9	<13	<3.0	<8	<13
R10	glaze room	<63	n/a	<6.3	1100	1843	2102	<2090	<209	35	58	8	24	2	<42	<630	<210	<1.1	<4.2	<11	<3.0	<7	<11
S2	personal	<67	3	<2.2	6524	1455	1455	<2220	<222	28	1654	1	<22	47	<45	<660	<230	<1.2	<4.5	<12	<3.0	<7	<12
S3	personal	<72	8	5.5	<72	9566	1435	<2410	<241	40	1315	28	<24	48	<49	<730	<150	<1.2	<4.9	<12	<3.0	<8	42
S6	glaze bench	<46	48	<1.5	3890	<31	3332	<1540	<154	21	686	356	<16	312	9	<470	<160	<0.8	<3.1	<8	<2.0	<5	<10
S8	teachers desk	<8	5	<8	95	<32	483	<1590	159	<2	<320	<2	<8	139	<16	<480	<160	<0.8	<3.2	<2	<0.2	<5	<8
S10	work bench	<53	2	<1.8	<53	<36	<178	<1780	178	23	<180	<2	<18	9	<36	<540	<180	<0.9	<3.6	<9	<2.0	<6	<9
C1	personal	<57	n/a	<5.7	297	1102	4178	<1890	<89	45	1567	863	116	172	1585	<570	<190	<1.0	<3.8	<10	<2.0	<6	<10
C2	personal	<57	n/a	<5.7	1102	1102	4178	<1890	<89	45	1567	863	116	172	1585	<570	<190	<1.0	<3.8	<10	<2.0	<6	<10
C3	personal	<9	368	2.4	35	2008	5326	<1840	<184	36	2108	8	<19	70	48	<560	<190	<1.0	<3.7	<10	<2.0	<6	<10
C5	personal	<72	<2	<2.4	<72	<48	241	<2410	<241	<2	<250	1	<24	<3	<49	<730	<250	<1.2	<4.9	<12	<3.0	<8	<12
C7	personal	<125	5	<4.2	<125	<83	232	<4150	<415	7	<420	6	<42	<5	565	<2350	<420	<2.1	<8.3	<21	<5.0	<13	<21
C8	personal	<13	159	2.8	462	318	3683	<2570	<257	141	<520	<3	<13	91	<26	<770	<260	<1.3	9.5	<3	<0.3	<8	<13
C9	personal	<12	123	2.6	<23	2260	62778	<2320	<232	174	26952	<2	83	192	179	<700	<240	<1.2	13.2	<3	<0.2	<7	<12