University of Alberta

Workplace Air Contaminant Exposures of Specialty-Area Pig Barn Workers

by

Irene Isabel Wenger ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

Medical Sciences - Public Health Sciences

Edmonton, Alberta
Spring 2004

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Abstract

Purpose: To measure the full workshift and activity-specific air contaminant exposures of specialty-area pig barn workers (Dry Sow/Breeding, Farrowing, and Nursery/Grower-Finisher).

Methods: From 20 large confinement pig barns throughout Alberta, Canada, which met inclusion criteria, 10 were randomly selected. Forty-three volunteer specialty workers (winter) and 37 (summer) were randomly recruited (16, 12, 15 in winter, and 13, 10 and 14 in summer, for Dry Sow/Breeding, Farrowing, and Nursery/Grower-Finisher workers, respectively). The mean age of study participants was 33.6 ± 9.5 years, and 64% were male. Personal air contaminant exposures were continuously monitored over three consecutive shifts using a custom-made, study-specific, Personal Environmental Sampling Backpack (PESB II) strapped to the worker's back. The PESB II was portable, met stringent biosecurity requirements dictated by the study barns *a priori*, and captured personal exposures to respirable dust, endotoxin, CO_2, NH_3, and H_2S simultaneously in the worker's breathing zone. Investigators followed workers to record workplace tasks conducted.

Results: Over 25% of all specialty-area workers had respirable dust mass exposures exceeding a proposed guideline of 0.28 mg/m^3. Nursery/Grower-Finisher workers had the highest respirable dust mass and endotoxin exposures, compared to Farrowing workers, and the highest respirable dust count exposures during dry feeding and barn checking tasks. Farrowing workers were 3 times more likely to be exposed to high dust counts when conducting general workplace activities. There was a trend to higher respirable dust exposures during pig moving activities. Peak H_2S exposures ($\geq$15 ppm)

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occurred during pit work activities. Workers conducting these tasks were 21 times more likely to be exposed to H_2S concentrations exceeding the Government of Alberta's proposed 15 ppm ceiling limit.

Conclusions: Personal monitoring allowed for the continuous capture of actual worker exposures throughout multiple areas of modern pig barns. Full workshift and activity-specific air contaminant exposures differed by specialty, indicating that pig barn workers should be enrolled in studies on the basis of area-specialty. The presence of solid flooring was found to be predictive of higher endotoxin and lower H_2S exposures. Observer-recorded time activity diaries are essential to reliably and accurately link to real-time continuous workplace air contaminant exposures.

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Dedication

This dissertation is dedicated to Christopher Ouellette, the love of my life, without whom this project would not have been possible. Your ability to take an idea for an instrumentation backpack and make it a reality, your computer programming expertise for the assembly of an activity-exposure data set, and your tremendous support and encouragement of me throughout my PhD program, are only some of the important contributions you made to the success of my project.

This dissertation is also dedicated to my parents, Dr. Heinz H. and Mrs. Elfriede Wenger, for their continued love, support and encouragement.

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Acknowledgments

For development of the project instrumentation, the author is deeply indebted to Chris A Ouellette for the design and development of the Personal Environmental Sampling Backpack (PESB II) and its precursor the PESB. The author also thanks the Glenrose Rehabilitation Hospital, which allocated space and equipment for the assembly of the equipment, Narcisse Ouellette who designed the complex electronics in the PESB II equipment and programmed the data logger, and Juan Carlos Segura who assisted in equipment assembly. In addition, the author would also like to thank Ernie Barber, U of S, and the Institute of Agricultural, Rural and Environmental Health, U of S, for providing sampling pumps and monitoring equipment which were incorporated into the original PESB. Dycor Industrial Research Limited is acknowledged for use of an in-house dust chamber for equipment calibration.

For the field component of the study, the author would like to thank Michelle Colangelo and Amanda Whelan, for their commitment to the project and for their conscientious attention to detail during data collection. Alberta Agriculture, Food and Rural Development are acknowledged for seconding Michelle and Amanda to this project. The author would also like to thank the rural hospitals across Alberta which allocated space for a field equipment calibration and maintenance office, and Dr. John Feddes and Dr. Lynn Elmes from the Department of Agriculture, Food and Nutritional Sciences, U of A, for allocating space for equipment disinfection and storage of project supplies. Span Gas Safety Services Ltd. (loan of H_2S units), Edmonton Garrison (loan of a Dry Cal unit), Capital Health (loan of a Dry Cal unit), and Prairie Swine Centre Inc.,

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U of S (loan of an Abacus dust particle counter) are gratefully acknowledged. The author would also like to acknowledge the following individuals and companies: Janes Goller, swine unit, U of A (allowing the study team to shadow his work activities in order to design activity diaries); Larry Serbin; Darryl Bilan; Enviro-Test Laboratories (endotoxin cassette storage/shipment); Robert Borg; Marshall Eliason, Alberta Agriculture, Food and Rural Development (weather station and data logger); McDonald's Restaurants (project watches); Koch Ford Lincoln Sales Ltd. (disposable floor mats); Chuck Humphrey, Rutherford library, U of A (assistance with organization of the activity diary data); Annamarie Ouellette (supplier of baking ingredients); and Stacy Ouellette (the official project baker, who baked all the goodies as a thank you to pig barn staff). The author would also like to thank Crystal Molnar for her commitment to the project and for her attention to detail in coding and entering the diary data.

The author is indebted to the barn owners and managers who allowed the study team access to their barns and the career pig barn workers who participated in this study. A big thank you as well to the supervisory committee and to the many friends and colleagues who provided guidance and support throughout the PhD program.

Financial support by the Canada-Alberta Hog Industry Development Fund (Wenger and Hrudey), Alberta Agriculture, Food and Rural Development (Wenger), Alberta Health and Wellness (Environmental Health Sciences Laboratory), and National Sciences and Engineering Research Council of Canada Discovery Grant (Hrudey) are also acknowledged.

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Glossary

Boar: A male breeding pig.

Dry Sow/Breeding area: This area houses sows, boars and maiden and bred gilts in stalls and pens. In this area, sows and gilts are bred (via natural mating to boars or artificial insemination), and housed for approximately 110 days until they are moved to the Farrowing area.

Farrowing area: Gilts and sows give birth to their offspring in farrowing crates in this area. Pigs reside here for approximately 21 days following which sows are moved back to the Dry Sow/Breeding area and piglets are moved to the Nursery area.

Farrow-to-Wean pig farm: This type of pig farm has both the Dry Sow/Breeding and Farrowing areas on one site.

Farrow-to-Finish pig farm: This type of pig farm has all four areas (Dry Sow/Breeding, Farrowing, Nursery and Grower/Finisher) typically on one site.

Gilt: A young female pig of reproductive age.

Grower/Finisher area: This area houses grower and finisher pigs for approximately 8 weeks in each growth phase.

Nursery area: This area houses weaner pigs for approximately 5 to 6 weeks.

Piglet: A newborn pig.

Sow: A female pig, of reproductive age, who has given birth to offspring.

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Chapter One

1.0 Overview

Occupational exposures among pig farmers, and more recently the workers in the pig barns, have been studied since the mid-1970s beginning with the work of Donham et al. (1977). An impetus for such studies was that pig herd sizes were becoming much larger, with a move towards housing larger numbers of pigs exclusively indoors at higher stocking densities. This raised a concern about higher concentrations of contaminants in the pig barn environment. With the growth in herd size, there was a move away from owner-operated barns, to the hiring of full-time employees to work in these facilities. The increase in the number of hours worked per day by career pig barn workers, along with demonstrated levels of airborne particulate and gases inside these facilities, has resulted in net increases in daily exposures for workers to air contaminants. This further heightened concerns about the respiratory health of workers, not just the health of the pigs (Donham et al., 1977). Since that time, there has been a lot of literature on this topic.

Investigations into the health hazards of career pig barn workers have identified a number of air contaminants in the pig barn environment that could affect lung health. They include dust, ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2) gases, and endotoxin (Curtis et al., 1975; Donham et al., 1977; Thedell et al., 1980, Donham et al., 1986; Barber et al., 1991). Dust in pig barns originates from many sources including: pig dandruff, dried fecal material and urine, feed, microorganisms and dust mites. Studies suggest that exposure to pig barn dust reduces lung function (Donham et al.,

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1995; Takai et al., 1995; Reynolds et al., 1996). CO_2 is a normal byproduct of pig respiration. NH_3 is produced mainly from decomposition of urine on floor surfaces. It is a gas that is highly soluble in water and, at high concentrations, can irritate the mucous membranes of the eyes, nose, throat and upper respiratory system. Researchers speculate that NH_3 gas can adhere to respirable dust particles, which are subsequently carried deep into the lungs (Schwartz et al., 1992), and may add to ammonia's potential toxic effects. H_2S is a by-product of the anaerobic breakdown of manure. At low concentrations H_2S can cause eye irritation. The inhalation of H_2S at or above concentrations of 150 ppm can cause olfactory nerve paralysis, with fatalities occurring with concentrations approaching 1000 ppm (ATSDR, 1999). Endotoxins are inherent components of the cell wall of gram negative bacteria and are biologically active, whether they are still a part of, or independent of, the bacterial cell (Preller et al., 1995a). Studies suggest that endotoxins may induce conditions such as broncho-constriction, organic dust toxic syndrome, or mucous membrane irritation (Olenchock, 1997). Endotoxins may be responsible for changes in lung function and bronchial reactivity and are emerging as one of the more important classes of contaminants in pig barn environments (Donham et al., 1989; Rylander et al., 1989; Zejda et al., 1994; Schwartz et al., 1995; Vogelzang et al., 1998a).

Pig barn workers are highly specialized with specific job responsibilities in each of the distinct areas within the barns. A modern pig barn is typically constructed as a number of isolated specialty areas interconnected by a common hallway (Figure 1.1).

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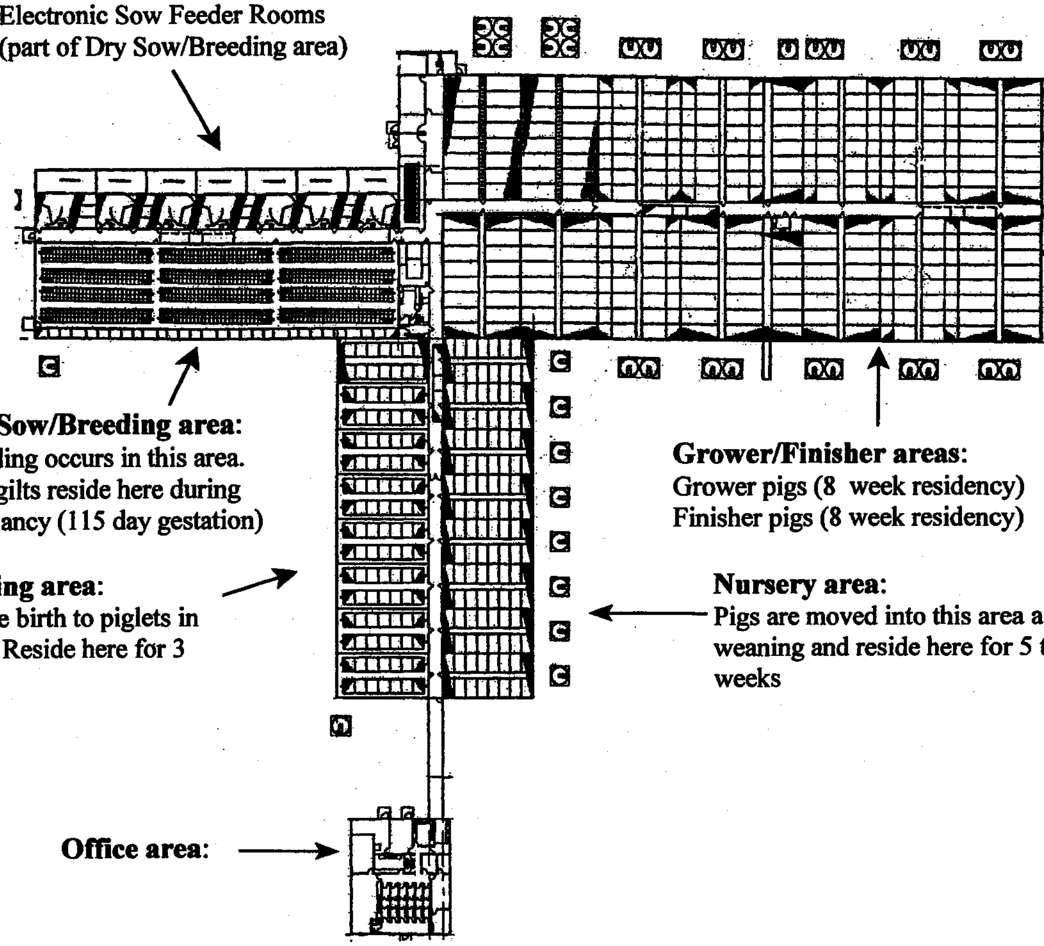

Figure 1.1. Layout of a 600-Sow Farrow to Finish Unit (Source: Praire Swine Centre Inc., University of Saskatchewan)

Each specialty area within this complex consists of a number of animal rooms, separated by walls and doors. These areas house individual classes and ages of pigs. Each individual animal room has its own unique airspace, with an individually controlled ventilation system that meets the requirements of the animals housed within the room. The Dry Sow/Breeding area houses sows, boars and maiden and bred gilts in stalls and pens. In this area, sows and gilts are bred (via natural mating to boars or artificial insemination), and housed for approximately 110 days until they are moved to the Farrowing area. The Farrowing area, where sows give birth, houses sows and their piglets, in farrowing crates, for approximately 21 days. The Nursery area houses weaner pigs for approximately 5 to 6 weeks. The Grower/Finisher areas of barns house grower and finisher pigs, for approximately 8 weeks in each growth phase.

Previous pig barn worker health and exposure studies assigned exposure on the basis of "working in a pig barn", not on the specific barn area in which work was conducted. Area monitoring studies, which have evaluated contaminant concentration within the individual pig barn specialty areas, found that: CO_2 concentrations tended to be highest in the Dry Sow/Breeding and Nursery areas (Barber et al., 1991); respirable dust concentrations were highest in the Farrowing and Nursery areas (Meyer and Manbeck, 1986; Barber et al., 1991; Takai et al., 1996); NH_3 concentrations tended to be the highest in the Nursery area (Meyer and Manbeck, 1986); and total dust concentrations were highest in the Nursery and Grower/Finisher areas (Meyer and Manbeck, 1986). Given these demonstrated exposure differences in specialty areas, it seems likely that individual workers, who conduct the majority of their tasks in higher contaminant areas,

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will exhibit higher personal-monitored contaminant exposures than counterpart workers who spend less time in these areas.

The purpose of this research was to evaluate full workshift and activity-specific air contaminant exposures of specialty-area pig barn workers. A key feature of this research is the extensive use of personal monitoring equipment to measure contaminant exposure in the individual worker's breathing zone rather than an area-wide measurement made by a fixed monitoring station. The combination of this monitoring approach and a detailed time-activity record is unique to the study of exposures among this occupational cohort.

This dissertation was prepared following the paper-based format. Each chapter was written as a stand-alone document with an introduction, discussion and reference section. Chapter one presents the literature on contaminant concentrations and worker exposures in pig barns. Time activity diaries and their role in assessing exposures of pig barn workers are described. Activity-specific breathing zone H_2S exposures of pig barn workers are discussed. Chapter two describes the equipment developed specifically for this study to monitor the personal exposures of career pig barn workers recruited to the study. Chapters three (seasonal workplace exposure of specialty career pig barn workers), four (contaminant exposure during workplace activities in modern pig barns) and five (activity-related H_2S exposures of career pig barn workers) were prepared as stand-alone papers, with the intent to submit them, in a revised format, for publication. Chapter six presents an overall conclusion of the findings and implications of this research.

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LITERATURE REVIEW

This literature review concentrates on three major topics, each corresponding to the three research papers (chapters 3, 4 and 5) presented in this dissertation. The first section presents literature on contaminant concentrations and workplace exposures in pig barns. The second focuses on the use of time activity diaries in social science research and agriculture. The third section presents literature on activity-specific H_2S exposures.

1.1. Literature Review: Contaminant concentrations and workplace exposures

This section was prepared as a systematic review of pig barn workplace and worker contaminant exposures. This review includes studies identified through several sources: 1) an electronic database search of Medline (1966 to 2003), confined to English language studies, for papers in the occupational, industrial health and agriculture literature. Search terms included: 'indoor and air pollutants', 'pig or swine or hog', 'occupational exposure or occupational health', 'dust or hydrogen sulfide gas or carbon dioxide gas or ammonia gas or endotoxin'; 2) Published papers were obtained from colleagues in public health, agricultural engineering, industrial hygiene, and animal science; 3) Reference lists of review articles and all included papers were searched for additional studies. The author also collected studies from scientific conferences and through on-going inspection of newly published articles in occupational and industrial hygiene journals. The search is considered up-to-date to September, 2003.

Studies were included if they involved the monitoring of air contaminants inside pig barns, or the personal exposures of pig barn farmers or workers. Studies were

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excluded if they evaluated the effects of airborne contaminants on livestock health; if they primarily evaluated exposure monitoring equipment or the comparison of such equipment for air quality measurement assessments; if the study compared sampling methodologies or laboratory assays; if they mainly described study methodology; if they were studies dealing strictly with contaminant emissions; if they were review articles; or if they were primarily pig barn worker health outcomes studies where air contaminant concentrations or worker exposures were not measured.

Fifty-six studies were selected for inclusion in this literature review. Fourteen were conducted in the United States (Table 1.1; studies A1 through A14), 20 in Canada (Table 1.2; studies C1 through C20) and 22 in Europe, including Belgium, Britain, Denmark, Finland, Germany, the Netherlands, and Sweden (Table 1.3; studies E1 through E22).

1.1.1. Description of studies

1.1.1.1 Types of pig barns

All studies were conducted in swine confinement units, meaning that the pigs were reared solely indoors. The majority of barns were mechanically ventilated. Four studies involved barns that were naturally ventilated (A2, A7, C12, C14). Some research sites involved either University or experimental facilities (A2, A8, A11, C3-4, C6, C8, C10, C12-13, C15-19, E16); however, most studies (42 of 56) examined farmer-owned commercial pig barns.

1.1.1.2 Number of participating farms and worker cohorts

While the majority (73%) of studies included 15 or fewer cooperating farms, 4

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involved 16 to 30 farms (A4-5, E4-5), and 5 consisted of 40 to 60 farms (C1-2, C7, E2, E13). Several studies used the same pig barns. Donham and Popendorf (1985) and Donham et al. (1986) studied the same 21 confinement operations. Barber et al. (1991) and Barber et al. (1993) studied 173 pig buildings on 50 farms. Several studies used the same pig barn worker cohorts. Donham et al. (1995), Reynolds et al. (1996), and Schwartz et al. (1995), studied 207 male workers from 108 swine farms. Preller et al. (1995a), Vogelzang et al. (1998b), and Vogelzang et al. (2000), studied 198 male owners of pig farms.

1.1.1.3 **Sampling seasons**

Thirty-eight per cent of the studies did not report sampling season. Eight studies reported winter sampling (A4-5, C4, C7, C15-16, C19, E3), and twelve sampled during winter and summer (A2-3, A9, C1-3, C5, C14, C20, E12, E20-21). The remainder (14 of 56 studies) reported contaminant sampling during various other times of the year including over more than two seasons.

1.1.1.4 **Sampling Strategies**

The common types of workplace monitoring are area monitoring, and personal monitoring. In area monitoring, sampling equipment is positioned in a representative, fixed-site location within a room or airspace. While such monitoring provides an estimate of contaminant concentrations within an airspace, it "does not provide a good estimate of worker exposure" (Olishifski and Kerwin, 1988). Personal air contaminant monitoring means that sampling equipment is worn by the workers themselves, with air contaminants being monitored within the breathing space of the worker. This "is the

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preferred method of evaluating workers' exposure to air contaminants ... (because it) closely approximates the concentration inhaled" (Olishifski and Kerwin, 1988).

Area monitoring

Sixty one per cent (34 of 56) of the studies used area monitoring alone to measure contaminant concentrations. One of these collected concentration measurements at pig height only (C9), while five positioned monitors at heights of 0.8 to 1.0 m, corresponding to table top height or a height that a worker would be at when bending over to pull the manure pit plug (A11, C3, C5, C11, E14).

Nineteen studies reported positioning the monitoring equipment at a height coinciding with a worker's breathing zone. Three of these did not specifically define the measurement height (A9, E10, E17), while fifteen defined this height to range from 1.2 to 1.6 m (A1, A4-5, A8, C1-2, C10, C12, C14, C17-18, E1-3, E17). Two studies monitoring exposures at a height coinciding with a worker's breathing zone, did so using a systematic sampling approach whereby contaminants were monitored following a carefully established grid pattern, representing areas in which workers were most likely to conduct workplace activities (Donham and Popendorf, 1985; Donham et al., 1986).

Personal monitoring

Eighteen per cent (10 of 56) of the studies used personal exposure monitoring for contaminant exposure assessment, while 21% (12 of 56) used a combination of personal and area monitoring. Personal monitoring typically referred to workers wearing the monitoring equipment themselves. In one study, however, personal exposure monitoring referred to the collection of an air sample within the worker's breathing zone using

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colorimetric detector tubes (Donham et al., 1977).

1.1.2. Contaminants monitored

1.1.2.1 Total, inhalable and respirable dust

Studies used both area and personal sampling for total, inhalable and respirable dust. The term "total dust" (all airborne particles) is used quite inconsistently to describe large dust particle sizes. Rarely are sampling systems designed to actually capture all of the dust in the air sample. It is difficult to actually sample total dust. Many total dust reports are more likely closer to inhalable dust. Inhalable dust particles, particles contained within total dust, have a collection efficiency of 50% at 100 μm in aerodynamic diameter (50% cut-point) (Lippmann, 2001). Particulates of this size can be inhaled through the nose and mouth (ACGIH, 2001). Some of the airborne particles in the inhalable size fraction are trapped in the mucous of the nose and pharynx and are therefore prevented from traveling deeper into the lungs. Particulates in the thoracic dust fraction (mentioned here for completeness), have a 50% cut-point at 10 μm (Lippmann, 2001). Respirable dust particles have a 50% cut-point at 4 μm in aerodynamic diameter (ACGIH, 2001) and are easily trapped in the upper and lower airways. Mid-sized respirable particles (1 to 5 μm) are more likely to settle in the small airways (West, 1998).

Area monitoring

Those studies that sampled for airborne dust concentrations using area monitoring measured total dust (A2, A7, A14, C4-5, C8, E3, E10); total and respirable dust (A3, A5-6, A8-9, A11, C1, C10, C14-16, C20, E1-2, E4, E15-17); inhalable and respirable dust (C2, C18, E14, E17); and respirable dust only (C9, C12-13, C17, C19, E11).

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Total dust mass concentrations (means) ranged from 1.3 mg/m^3, for an average 6-h sampling duration in which there were 96 hand-fed finisher pigs in the room (Attwood et al., 1986), to 3.5 mg/m^3 for a study in which a 4-h sample was collected 1 m above the floor (Duchaine et al., 2000). The highest time-weighted average total dust concentration reported was 9.4 mg/m^3 for a 4-h sample collected at 1 m in a Farrow-to-Finish facility (Duchaine et al., 2000).

Four studies reported ***inhalable dust*** area measurement concentrations (C2, C18, E14, E17). Mean dust concentrations varied from 1.8 mg/m^3 in summer (Takai et al., 1998) to 2.8 mg/m^3 during winter ventilation (Smith et al., 1993). The lowest inhalable dust concentration (0.9 mg/m^3) was monitored during an overnight dust collection period (Takai et al., 1998).

Respirable dust concentrations (means) varied from a minimum of 0.13 mg/m^3 (Zejda et al., 1994) to a maximum of 0.37 mg/m^3 (Attwood et al., 1986).

Personal monitoring

A number of studies sampled for airborne dust concentrations using personal monitoring for total dust only (A13, C4, C15, C19, E6-7, E13, E16); inhalable dust only (E8, E12, E18, E20-22); total and respirable dust (A6, A12, C7, E4-5, E19); and inhalable and respirable dust (E9).

Personal ***total dust*** concentrations ranged from 1.2 mg/m^3, where a filter was used to collect dust when workers were conducting activities, for an average of 190 min far from animals (Vinzents and Nielsen, 1992) to 13.5 mg/m^3 for a mean time-weighted-average (2 to 5-h) exposure of study participants to a specific pig barn worker activity

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(pig weighing) (Larsson et al., 1994).

Personal ***inhalable dust*** concentrations ranged from 0.9 mg/m^3 in a study where participants were exposed for 3 h within 2 to 5 m of a pressure washing activity (Larsson et al., 2002), to 23.3 mg/m^3, for a study in which study participants were exposed for 3 hours to a pig weighing activity (Larsson et al., 1994).

Personal ***respirable dust*** exposures varied from 0.13 mg/m^3 in a study of 19 part-time workers (Haglind and Rylander, 1987) to 0.56 mg/m^3 for 16 study participants who were exposed to within 2 to 5 m during a particular pig barn work activity (pressure washing) (Larsson et al., 2002).

Pig barn specialty area contaminant concentrations

As seen in Figure 1.1, a typical pig barn has 4 specialty areas: Dry Sow/Breeding, Farrowing, Nursery and Grower/Finisher. Seventeen studies evaluated differences in contaminant concentrations by specialty area (A1-2, A4-5, A9, C1-3, C12-13, C20, E2, E10-11, E15-17). Only five of these evaluated the contaminant concentrations in all specialty areas of the participating pig barns (Meyer and Manbeck, 1986; Barber et al., 1991; Barber et al., 1993; Takai et al., 1998; Chénard et al., 2003).

Dust concentrations (area monitoring): Results reported by Meyer and Manbeck (1986), showed that time-weighted average area-sampled *total dust* concentrations varied by specialty area, and were lowest in the Dry Sow/Breeding area (0.8 mg/m^3), and the highest in the Nursery areas (2.7 mg/m^3). For area-sampled *inhalable dust*, the Nursery area was shown to have the highest concentrations of 3.6 mg/m^3 (Takai et al., 1998). Only three studies reported specialty area-specific *respirable*

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dust concentrations (A9, C1, E16). Concentrations were found to be the highest in the Nursery area (0.27 mg/m^3) (Takai et al., 1996), the Nursery and Grower/Finisher areas (0.21 mg/m^3) (Barber et al., 1991), and the Farrowing area (0.78 mg/m^3) (Meyer and Manbeck, 1986). Depending on the study, either the Dry Sow/Breeding area (Meyer and Manbeck, 1986), the Finisher area (Takai et al., 1996), or the Farrowing area (Barber et al., 1991) had the lowest respirable dust concentrations.

Dust concentrations (personal monitoring): Only one study conducted time-weighted-average personal *total dust* specialty area measurements (E16). Total dust concentrations for the Nursery area were reported to be 3.6 mg/m^3, and those for the Finisher area, 2.0 mg/m^3 (Takai et al., 1996). None of the studies located for this review evaluated personal inhalable or respirable dust exposures in the different specialty areas of the pig barn.

1.1.3. **Endotoxin**

The analysis of endotoxin concentrations were conducted on both area-sampled and personal-sampled dust, for all dust size fractions (total, inhalable, and respirable). Depending on the study, endotoxin results were reported as ng endotoxin/mg dust (E19), μg endotoxin/m^3 air (E3-5, E7-8), ng endotoxin/m^3 air (E1, E6, E9, E12-13, E20-21), or endotoxin units (EU)/m^3 air (A12-13, C4-5, C15). Given that differences exist among U.S. reference standard endotoxin, conversion factors are required to properly convert ng to EU (Reynolds et al., 2002; Reynolds and Milton, 1993). In order for proper comparisons of studies to be made, it is important that results be reported in either EU, or ng. As well, it is necessary to provide the conversion factor to convert ng to EU specific

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to the endotoxin standard used in the analysis (Reynolds et al., 2002; Reynolds and Milton, 1993). Only one study in this review that reported results in ng, provided the necessary conversion factor: 1 ng = 8 EU (Radon et al., 2001).

Of the studies in which the units were reported as EU/m^3 (including Radon et al., 2001), endotoxin concentrations from personal-sampled total dust, ranged from 203 EU/m^3, where the exposures of 207 workers from 108 pig farms were monitored (Reynolds et al., 1996), to 4035 EU/m^3, where study participants were exposed (for 4 h) to a Grower/Finisher room at a research facility, while riding a stationary bike for 3 km at 18 km/hour to simulate exertion during typical pig barn work (Dosman et al., 2000). Only one study, reported endotoxin concentrations in EU/m^3 for personal-sampled respirable dust. Reynolds et al. (1996) found an overall mean concentration of 17 EU/m^3 among the 207 workers from 108 pig barns.

1.1.4. **Barn gases**

The majority of gas sampling was conducted via area monitoring, with the exception of three studies in which only NH_3 gas (A12, E21) or CO_2, NH_3 and H_2S gases (A3) were monitored within the breathing zone of the worker using colorimetric tubes or low volume samplers.

1.1.4.1 ***Carbon Dioxide (CO_2)***

Two studies (A4, C1) reported CO_2 concentrations by specialty area. Donham and Popendorf (1985) reported that the Farrowing area had the highest mean concentrations (1838 to 2452 ppm), followed by the Nursery/Grower (1745 to 1819 ppm) and Finisher areas (1000 to 1338 ppm). Barber et al. (1991) reported the highest CO_2

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concentration in the Nursery area in winter (4524 ppm), followed by the Dry Sow/Breeding area (4286 ppm) and the Farrowing and Grower/Finisher areas (3987 and 3954 ppm, respectively). Summer CO_2 concentrations were consistently lower than winter concentrations for all specialty areas monitored (Barber et al., 1991). CO_2 concentrations measured in the breathing zone, were higher in the winter (7877 ppm) than in the summer (1705 ppm) (Donham et al., 1977).

1.1.4.2 **Ammonia (NH_3)**

In the studies in which NH_3 concentrations were determined via area monitoring, concentrations varied between < 1 ppm during periods of high ventilation (Maghirang et al., 1997) to 26 ppm in Grower/Finisher rooms in an experimental facility (Senthilselvan et al., 1997; Zhang et al., 1998). Three studies evaluated the NH_3 concentrations in various specialty areas in the pigs barns (A4, A8, C1). In two of these studies, the Farrowing area had the highest concentration (19 to 42 ppm), followed by the Nursery and Nursery/Grower areas (17 to 39 ppm), Dry Sow/Breeding area (15 ppm), with the Grower/Finisher area having the lowest NH_3 concentration (15 ppm) (Donham and Popendorf, 1985; Barber et al., 1991). The third study found the highest NH_3 concentrations to be in the Nursery area (105 ppm) (Meyer and Manbeck, 1986). Barber et al. (1991) showed lower NH_3 concentrations in summer than in winter. Personal monitored NH_3 concentrations ranged between 6 ppm (Reynolds et al., 1996) to 21 ppm (in summer) and 84 ppm (in winter) (Donham et al., 1977).

1.1.4.3 ***Hydrogen Sulfide (H_2S)***

H_2S concentrations were monitored in 7 studies (A3, A8, C3, C11, C15, C19, E7).

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With the exception of two, all studies reported area-monitored H_2S concentrations of ≤ 1 ppm. Donham and Popendorf (1985) reported H_2S concentrations ranging from 0.4 to 1.7 ppm in the Farrowing area and 0.5 to 1.3 ppm in the Nursery/Grower area. In a study which specifically evaluated H_2S concentrations following manure agitation and removal workplace activities, a maximum concentration of 1000 ppm was observed (Chénard et al., 2003).

1.1.5. **Summary**

The 56 studies included in this review provided some useful information on air contaminant concentrations in pig barn environments. These assessments were primarily made by area-sampling. Relatively few studies conducted personal sampling and where this was done, generally only dust concentrations were monitored. Area-monitored respirable dust concentrations varied from 0.13 mg/m^3 to 0.37 mg/m^3, while personal respirable dust exposures ranged from 0.13 mg/m^3 to 0.56 mg/m^3. Area-monitored CO_2 concentrations ranged from 3736 ppm to 7877 ppm, in winter and summer respectively. NH_3 concentrations ranged from < 1 ppm to 26 ppm. H_2S concentrations were typically found to be below 3 ppm. While studies showed that the different areas of the pig barns do not have the same contaminant concentrations, no study provided a complete picture of where air contaminants might be the highest in pig barn environments. Depending on the study, area-monitored respirable dust concentrations were found to be the highest in the Farrowing, Nursery or Grower/Finisher areas, and lowest in the Dry Sow/Breeding, Farrowing or Finisher areas. Area-monitored CO_2 and NH_3 concentrations were found to be the highest in the Farrowing and Nursery areas, while the Grower/Finish areas were

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found to have the lowest concentrations of these barn gases. Levels of contaminants in specific specialty areas of pig barns should be of concern to specialty-area full time workers. However, no studies have been conducted where a personal sampling exposure assessment methodology was utilized for all important contaminants (respirable dust, respirable endotoxin, CO_2, NH_3 and H_2S) for the exposures of specialty-area career pig barn workers.

1.2. **Literature review: Time Activity Diaries**

Personal workplace air contaminant monitoring would be more valuable if this data could be linked with how much time workers spent in specific pig barn areas and what activities were being conducted there. The best way to document this information is to use a time activity diary. A literature review was conducted to determine if these diaries had been utilized in studies assessing pig barn worker exposures.

Time activity diaries are chronological recordings of activities conducted over the day and usually include information on start and stop times, the location where the activity was conducted, and whether other people were present in the area or involved with the activity itself (Robinson, 1988; Sexton and Ryan, 1988; Robinson and Thomas, 1991). Data are typically recorded by the study participants themselves, using open-ended diaries (Robinson, 1988). The benefits to such an approach include the potential to capture information on new and sometimes unanticipated activities (Robinson and Godbey, 1997), and the ability to collect data at a low cost. However, Robinson and Godbey (1997) highlight some important limitations to an open-ended diary format.

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These include: data quality issues related to the honesty and willingness of study participants to share accurate activity information; data recording consistency issues where some people may record more information than others; and self-reporting may be subject to recording or recall bias. To combat some of these issues, researchers have used a more structured diary format in which study participants record each activity conducted, in 15-min time blocks over the entire workday, selecting from a list of pre-determined activities (Kains, 1994; Preller et al., 1995b; Vogelzang et al., 1998a). While such a revised diary format may result in greater data recording compliance, there is a chance that not all activities conducted during the day will be captured. This is especially true if more than one activity is conducted during a 15-minute time interval. Direct observational methods (where observers shadow study participants and record all activities conducted by these individuals over specified time periods) are an alternative to self-reporting (Robinson and Godbey, 1997). While direct observation results in more objective and unbiased activity data recording, their use results in substantially increased study costs.

1.2.1. **Activity-specific workplace exposures**

Time-activity diaries are used to gain an understanding of how and where people spend their day (Robinson, 1988; Robinson and Godbey, 1997; Klepeis, et al., 2001). Time-activity studies allow researchers to predict when people are likely to have the greatest potential for exposure to known contaminants (Gephart et al., 1994; Alberta Health and Wellness, 2000).

While the focus of this research was to evaluate the real-time personal exposures

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of pig barn workers, real-time and full workshift personal exposure monitoring has been used to monitor occupational exposures in other industries. Walsh et al. (2000), used real-time monitoring to evaluate worker exposures to tetrachloroethylene in dry cleaning businesses. Personal exposures were directly linked to activities conducted using a video camera and a portable video cassette recorder. Other larger scale studies have also linked exposure data collected with time activity diaries. The Total Exposure Assessment Methodology (TEAM) studies conducted in the U.S., linked personal exposures to carbon monoxide (CO), volatile organic compounds (VOC), particulates, and pesticides, to activities conducted by study participants both inside and outside the home (Zartarian et al., 1997). The Health Surveillance Branch of Alberta Health and Wellness has also conducted a number of community exposure and health effects assessment studies. The Alberta Oil Sands (Alberta Health and Wellness, 2000), Grande Prairie and area (Alberta Health and Wellness, 2002), and Fort Saskatchewan and area (Alberta Health and Wellness, 2003) studies, each monitored the personal exposures of area residents to a number of air contaminants including nitrogen dioxide, sulfur dioxide, and ozone, both inside and outside the home. The exposures in these studies were then linked to proportion of time study participants spent indoors, outdoors, at work, traveling, and other activities.

More pertinent to this dissertation, a time activity diary was developed by Kains (1993) for use by Ontario pig farmers. The highly-structured types of workplace tasks conducted on pig farms made it possible for Kains (1993) to develop an activity logbook. A 2-digit activity code was developed that could be recorded easily and accurately by the

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workers in a logbook. Workers were asked to record activity data every 15 minutes over the workday for a 2-week period. Kains (1994) found that those pork producers who were keen to improve labour efficiency were keen to participate in this study. However, some farmers were reluctant to record the data, even though participation would have only meant 1 h of time commitment over the 2 week period (Kains, 1994).

The results of the Kains (1994) time use of pig farmers study from seven farms showed that, on a weekly basis, per 100 sows, the participating farmers spent their time as follows:

33.9% feeding pigs and preparing feed

12.1% conducting health checks

15% conducting cleaning and washing activities

12.1 % moving pigs (includes shipping pigs)

9.3% breeding sows and gilts

4.6% conducting repair and maintenance activities

5.7% on management activities including recording keeping

7.3% other activities including selling breeding stock

Slightly more time was spent by these workers feeding sows, conducting health checks, on washing activities, and moving nursery pigs in the Farrowing and Nursery areas (Kains, 1994), when compared to tasks in other areas.

The linkage of activity diary data with personal exposure monitoring data is important for comparing the exposures of workers in one area or for one task to the exposures of others. Such a linkage is also important for a number of reasons: it allows

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for exposures across studies to be compared; it allows for data to be incorporated into exposure modeling processes; and it allows for the evaluation of unacceptable exposures and the tasks that may have contributed to them (Duan and Mage, 1997).

In a study of 96 veterinarians, specializing predominantly in either swine, cattle, poultry or companion animals (Elbers et al., 1996), study participants were asked to select from a list of pre-determined activities and record all professional activities conducted in 15 min time blocks over 7 consecutive days in 2 seasons (Autumn and Spring). In addition, the concentration of personal respirable dust and respirable endotoxin exposures were monitored twice for each study participant, once during the first day of each season. The time activity diary results indicated that duration of activities were not similar across veterinary specialties, and that veterinarians who worked with livestock were found to have higher total dust and endotoxin exposures than companion animal veterinarians.

While the majority of studies involving pig barn workers have only reported the overall daily workshift exposures, a number of studies have evaluated activity-specific exposures (Vinzents and Nielsen, 1992; Larsson et al., 2002; Haglind and Rylander, 1987; Perkins et al., 1997).

A small study was conducted to monitor the total dust exposures of 4 workers from large intensive (400 to 500-sow) pig barns in the Netherlands for activities conducted close to and far away from the pigs (Vinzents and Nielsen, 1992). Exposures were monitored for four consecutive days, with one dust collection cassette used in the worker's breathing zones for the > 2 h they spent conducting activities close to the pigs ("insemination, castration, cutting teeth and tails, and moving animals"), and a different

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cassette for the > 2 h they spent conducting workplace tasks far away from pigs (“feeding and other work”). No differences were found in total dust or endotoxin exposures for workers working close to, or far from animals.

A study by Larsson et al. (2002), was conducted to evaluate the inhalable and respirable dust and endotoxin exposures of naïve study participants to a pressure washing activity conducted in a pig barn. Sixteen study participants, who had no previous exposures to pig barn environments, were enrolled in this study. Groups of two to six study participants, were exposed for 3 h over 4 consecutive days to a pressure washing activity, conducted by a pig farmer who was 2 to 5 m away from them during the duration of the exposure.

Haglind and Rylander (1987), evaluated the contaminant exposures of 29 part-time pig barn workers. Personal total and respirable dust samples were collected, for which endotoxin concentrations were also determined. Data analysis was used to determine those variables that were predictive of specific workplace exposures involving feeding, straw spreading, sweeping, manure removal, and weighing activities.

The review of the literature showed that only a limited number of studies have been published on the activity-specific workplace exposures of pig barn workers for which time activity diaries were utilized. In the studies using the same occupational cohort, pig barn workers were asked to record daily activities for 21 pre-determined activities, in 15-minute intervals, for 7 days during winter and again in summer (Preller et al., 1995a; Preller et al., 1995b; Vogelzang et al., 1998a; Vogelzang et al., 1998b; Vogelzang et al., 2000). Duration of time spent conducting activities in different

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"compartments" of the barns "Farrowing, Sow, Piglets and Finishing" (Preller et al., 1995a) were calculated using the diary data. Using empirical modeling, associations between activities conducted by the workers and the personal inhalable dust and endotoxin exposures sampled over two workshifts, one in winter and one in summer, were calculated. The results of these studies showed that barn cleanliness and feeding method were predictive of inhalable dust exposure, and that floor type and feeding method were predictive of workplace endotoxin exposure. As well, activities involving higher levels of animal activity, were predictive of inhalable dust and endotoxin exposures.

1.2.2. **Summary**

Time activity diaries have been used to a limited extent to evaluate the types and duration of activities conducted by workers in pig barns. However, these diaries have never been used to link real-time continuous air contaminant exposures of workers to the specific workplace tasks undertaken. Given that workers conduct a number of activities during the workday, there is merit in utilizing time activity diaries to link specific air contaminant exposures to specific activities.

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1.3. Literature review: Activity-specific H_2S exposures

Hydrogen sulfide (H_2S), is a colorless, flammable, toxic gas which is denser than air, and at low concentrations (< 1 ppm) (O'Donoghue, 1961) smells like rotten eggs (Lewis, 1997; Fuller and Suruda, 2000; ACGIH, 2001). At higher concentrations (150 to 200 ppm) its distinctive smell is no longer discernable due to paralysis of the olfactory nerve, thereby making the presence/absence of smell unreliable as an early warning detection system (ACGIH, 2001). An exposure of 500 to 1000 ppm of H_2S, with as little as one breath, can result in a condition referred to as "knockdown", meaning "a sudden loss of consciousness" (Guidotti, 1994). During the study, pig barn workers confided to the author about knockdown situations they themselves, and other pig barn workers across Canada had experienced. At concentrations approaching 1000 ppm H_2S is quickly fatal (Costigan, 2003).

In modern pig barns, manure is stored in underfloor pits in a liquid form (Janni et al., 1981). Feces, urine, spilled feed, and wastewater from pig waterers and room/floor washing are added on a continual basis to the liquid slurry (Zhang et al., 1990). Anaerobic decomposition of the manure results in the formation of H_2S (Arogo et al., 2000), which is released when the manure is agitated (Zhang et al., 1990). In many pits, a solid "crust" layer forms on the surface, which together with other solids in the manure, necessitates manure agitation prior to removal to outdoor storage lagoons.

Pig barn workers are typically exposed to low concentrations of H_2S during workshifts. However, during selected activities such as manure agitation and pit plug pulling, H_2S concentrations can reach 1000 ppm or higher (Chénard et al., 2003;

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Costigan, 2003). Therefore, workers who conduct liquid manure-related activities, such as draining pits, repairing the manure pump, or working inside a manure transfer room, may be subject to exposures exceeding the occupational exposure guidelines for H_2S. In Alberta, occupational exposure ceiling limits (a concentration above which workers cannot be exposed for *any* length of time) for H_2S have recently been lowered from 20 ppm to 15 ppm (Alberta Human Resources and Employment, 2002).

1.3.1. Summary

Because of the potential health risks that can be caused by exposures to H_2S, particularly at levels that exceed established ceiling limits, it is important to determine for any workplace the exposure risks when performing common workplace activities. As well, it is important to identify those activities most likely to require intervention to prevent excessive exposures. For acute hazards, personal alarm monitors are warranted.

1.4. Rationale for the present study

The literature reviews highlight the research that has been conducted to evaluate the air contaminant exposures of pig barn workers and some useful information emerged from these studies. The reviews however, also identified that the picture is still incomplete and there are gaps in our understanding of personal air contaminant exposures among career pig barn workers. Three main areas where improved methodology could provide more complete exposure data emerged: 1) better designed monitoring equipment that could be transported into modern pig barns; 2) a method of personal monitoring that would capture actual worker exposures; and 3) linking barn location with worker activity

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and duration of exposure.

In summary, though some studies conducted personal monitoring for selected contaminants, none performed simultaneous personal monitoring for the major air contaminants likely to contribute to potential health effects (dust, endotoxin, CO_2, NH_3, H_2S, RH, barn temperature). Prior to designing the Personal Environmental Sampling Backpack (PESB II) system (Chapter two), workers would have been burdened with at least 4 separate pieces of monitoring equipment to monitor relevant contaminants. In addition to being cumbersome to the degree that worker behaviour is likely to be modified, it is unlikely that this equipment could be adequately cleaned and sterilized to conform to the rigorous biosafety protocols of modern pig barns.

While some studies did identify the potential for exposures to be greater in certain pig barn specialty areas, these assessments were based primarily on area monitoring. The area-monitoring evidence does not provide evidence on individual worker exposure, and should be considered hypothesis-generating. Personal exposure monitoring for breathing zone air is needed to validate the area-monitored exposures of workers. As well, most of the published studies confined monitoring to a selected room within a particular specialty area (which could have been only 1 room out of a possible 27 rooms), but were not conducted on a scale that captured exposures in all rooms within an area, or different areas of a barn. Some workplace areas may have higher air contaminant levels than others. It is therefore important to monitor the personal exposure of the worker in all areas of the barn.

In addition, the studies to date have only evaluated exposures based on an overall

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time-weighted-average. No study conducted real-time monitoring of personal exposures on a continuous basis, a step that is necessary to deal with possible health impacts associated with peak exposures. Finally, exposure data needs to be linked to activity data collected through the use of time activity diaries.

This research was designed to address these deficiencies. The first two deficiencies were addressed by developing a Personal Environmental Sampling Backpack (PESB II) monitoring system that could be adequately cleaned and disinfected between pig barn visits. This equipment was designed to be worn by specialty-area workers and to monitor all personal air contaminant exposures on a real-time basis over full workshifts. The third deficiency was addressed by utilizing observer-recorded time activity diaries to record type and duration of workplace activities conducted. These data could then be linked to real-time contaminant concentrations monitored by the PESB II system.

Incorporating these improvements into this research project allowed the development of a more complete picture of not only personal contaminant exposures but also activity-specific exposures of specialty-area career pig barn workers.

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Table 1.1. Summary of American contaminant assessment studies in confinement pig barns

Study Authors / publication year	Study ID	Study setting	Sampling strategy and Contaminants monitored
Avery et al., 1975	A1	2 Farrowing and 4 Finisher units	**Area monitoring.** *Sampling height*: 1.2 m. *Sampling frequency*: 14 to 30 minutes (8 samples in a 24 hour period). *Contaminant(s)*: H_2S. *Sampling season(s)*: not reported
Curtis et al., 1975	A2	Study 3: 5 university Gestation and Farrowing rooms; Study 4: 12 rooms in 5 commercial operations (Farrowing, Nursery, Finisher). Farms were either totally enclosed or had modified open fronts.	**Area monitoring.** Study 3: *Sampling height*: Floor level. *Sampling frequency*: weekly measurements (10 minute sampling) over 15 months. *Contaminant(s)*: total dust (gravimetric). *Sampling season*: warmer weather. Study 4: *Sampling height*: floor level. *Sampling frequency*: 1 to 6 times. *Contaminant(s)*: total dust (gravimetric). *Sampling season(s)*: cooler weather.
Donham et al., 1977	A3	13 confinement units with similar design and function.	**Personal monitoring.** *Sampling height*: farmer's breathing zone. *Sampling frequency*: not reported. *Contaminant(s)*: CO_2, H_2S, NH_3 (break tip tube or low volume personal air sampler). *Sampling season(s)*: summer and winter **Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: 15 min. *Contaminant(s)*: total and respirable dust (gravimetric). *Sampling season(s)*: summer and winter.
Donham and Popendorf, 1985	A4	21 confinement operations. Specialty areas monitored: Farrowing, Nursery/Grower, Finisher.	**Area monitoring.** *Sampling height*: 1.5 m. *Sampling frequency*: grab sampling at 1.5 h intervals and integrated sampling for 3.5 to 4 h, both following grid pattern covering working area. *Contaminant(s)*: NH_3, H_2S, CO_2 and CO. *Sampling season(s)*: December to February
Donham et al., 1986	A5	21 confinement operations. Specialty areas monitored: Farrowing, Nursery/Grower, Finisher.	**Area monitoring.** *Sampling height*: 1.5 m. *Sampling frequency*: 3.5 to 4 h following grid pattern covering working area. *Contaminant(s)*: total and respirable dust (gravimetric), NH_3. *Sampling season(s)*: December to February.

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Table 1.1. Summary of American contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Study setting	Sampling strategy and Contaminants monitored
Donham et al., 1995	A6	207 male workers from 108 farms.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: 2 to 6 h. *Contaminant(s)*: total and respirable dust (gravimetric), total and respirable endotoxin. *Sampling season(s)*: spring, autumn, winter. **Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: 2 to 6 h. *Contaminant(s)*: total and respirable dust (gravimetric), total and respirable endotoxin, NH_3, CO_2, H_2S, CO (passive dosimeters and colimetric tubes. *Sampling season(s)*: spring, autumn, winter.
Heber et al., 1988	A7	11 commercial Finisher buildings. 7 buildings naturally ventilated, 4 mechanically ventilated.	**Area monitoring.** *Sampling height*: not reported (service alley). *Sampling frequency*: monthly for 8 months. *Contaminant(s)*: total dust (gravimetric), barn temperature, RH. *Sampling season(s)*: July to March.
Maghirang et al., 1997	A8	Mechanically ventilated experimental nursery building.	**Area monitoring.** *Sampling height*: 0.5 m (service alley) and 1.5 m (pen). *Sampling frequency*: 13 sampling days (twice weekly) during one 6-week production cycle. 24 h (dust), 10 min (temp and CO_2), hourly (RH), once/day (NH_3) . *Contaminant(s)*: total and respirable dust (gravimetric), barn temperature, RH, CO_2, NH_3. *Sampling season(s)*: warm outside temperatures.
Meyer and Manbeck, 1986	A9	8 commercial farms. Specialty areas evaluated: 16 nursery rooms, 7 Farrowing rooms, 10 Grower/Finisher rooms, 8 Dry Sow/Breeding rooms.	**Area monitoring.** *Sampling height*: human breathing height. *Sampling frequency*: 244 min (115 to 342 minutes). *Contaminant(s)*: total dust (gravimetric), respirable dust (in Nursery facility only), NH_3, RH, barn temperature. *Sampling season(s)*: March, May, November.
Ni et al., 2000	A10	2, 1000-head curtained Finisher buildings on one commercial farm.	**Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: prior to and following room heating, conducted at night. *Contaminant(s)*: H_2S, NH_3, CO_2. *Sampling season(s)*: June.

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Table 1.1. Summary of American contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Study setting	Sampling strategy and Contaminants monitored
Pickrell et al., 1995	A11	2 Nursery/Grower confinement facilities at research Institute.	**Area monitoring.** *Sampling height*: 0.8 to 0.9 m. *Sampling frequency*: not reported. *Contaminant(s)*: total and respirable dust (gravimetric), total and respirable endotoxin, NH_3. *Sampling season(s)*: summer.
Reynolds et al., 1996	A12	207 workers from 108 farms.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: full workshift, twice over 5-yr period. *Contaminant(s)*: total and respirable dust (gravimetric), total and respirable endotoxin, NH_3 (passive dosimeters). *Sampling season(s)*: autumn, winter, spring. **Area monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: not reported. *Contaminant(s)*: NH_3 (colorimetric detector tubes). *Sampling season(s)*: autumn, winter, spring.
Schwartz et al., 1995	A13	207 workers from 108 farms.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: full workshift. *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: autumn, winter, spring.
Thedell et al., 1980	A14	2 confinement units.	**Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: not reported. *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: not reported.

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Table 1.2. Summary of Canadian contaminant assessment studies in confinement pig barns

Study Authors / publication year	Study ID	Study setting	Sampling strategy and Contaminants monitored
Barber et al., 1991	C1	173 buildings on 50 farms, primarily Farrow to Finish, a few Grow/Finish only. One room from each of Dry Sow/Breeding, Farrowing, Nursery, Grow/Finish. Information collected on building cleanliness, heating/ventilation systems, feeding type and method, stocking density.	**Area monitoring.** *Sampling height*: 1.5 m (operator walkway). *Sampling frequency*: 8 h per monitoring event (dust and temp), 1 hour sample (gases), once per 8 h period (RH). *Contaminant(s)*: total and respirable dust (gravimetric), total and respirable endotoxin, barn temperature, RH, NH_3, CO_2. *Sampling season(s)*: once visit during winter (November to March) and summer (May to September).
Barber et al., 1993	C2	Study A: 3 Grow/Finish buildings monitored in each of 3 successive years. Study B: 173 buildings on 50 farms, primarily Farrow to Finish (refer to Study C1 above)	**Area monitoring.** Study A: *Sampling height*: not reported. *Sampling frequency*: 8-h samples in each of 3 successive years. *Contaminant(s)*: inhalable and respirable dust, inhalable and respirable endotoxin, CO_2, NH_3, barn temperature, RH. *Sampling season(s)*: not reported. Study B: As for Study C1 above.
Chénard et al., 2003	C3	4 production sites: 2 at Prairie Swine Centre (U of S), 2 at independent Corporation. 4 production areas: Dry Sow/Breeding, Farrowing, Nursery, Grow/Finish.	**Area monitoring.** *Sampling height*: 1 m. *Sampling frequency*: continuous monitoring at 20-s intervals, 4 times in each production sector. *Contaminant(s)*: H_2S. *Sampling season(s)*: once in summer/fall, once in winter.
Dosman et al., 2000	C4	Grow/Finish rooms at Prairie Swine Centre (U of S). 21 study participants rode a stationary bike for 3 km @ 18 km/hr for each hour spent in the room.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: continuous monitoring for 4 hours. *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: March. **Area monitoring.** *Sampling height*: 1 m. *Sampling frequency*: 1 h sample (gases), 4 measurements during 4 hours (environmental parameters, dust), 1 min dust count measurements. *Contaminant(s)*: total dust (gravimetric), NH_3, CO_2, barn temperature, RH, respirable dust (particle counting). *Sampling season(s)*: March.

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Table 1.2. Summary of Canadian contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Study setting	Sampling strategy and Contaminants monitored
Duchaine et al., 2000	C5	8 Finisher units. Information gathered on number of ventilation fans, type of feed, number of pigs, building dimensions, pit emptying schedule, and visual cleanliness.	**Area monitoring.** *Sampling height*: 1 m. *Sampling frequency*: continuous over 4-h (NH_3, dust), beginning, middle and end of 4 h (Temp, RH, CO_2). *Contaminant(s)*: total dust (gravimetric), barn temperature, RH, NH_3, CO_2, endotoxin. *Sampling season(s)*: winter and summer.
Feddes et al., 1984	C6	4 Finisher rooms at Ellerslie Research Station (U of A).	**Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: over 1 or 2-days in each room. *Contaminant(s)*: Temp, RH, CO_2 (exhaust air). *Sampling season(s)*: not reported.
Holness et al., 1987	C7	54 farms with > 500 pigs marketed.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: full workshift (mean 9 hours). *Contaminant(s)*: total and respirable dust (gravimetric). *Sampling season(s)*: late March early April.
Honey and McQuitty, 1979	C8	4 Finisher rooms at Ellerslie Research Station (U of A).	**Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: 3-6 min. *Contaminant(s)*: Dust concentration (6-stage Andersen Sampler), barn temperature, RH. *Sampling season(s)*: not reported.
Lau et al., 1996	C9	1 Grow/Finish barn (annual production 3000 pigs).	**Area monitoring.** *Sampling height*: pig level. *Sampling frequency*: two measurements at 20 min intervals (after operator finished morning chores and pigs' activity levels declined), once per week over 18 mon. *Contaminant(s)*: respirable dust (MiniRAM), NH_3, barn temperature, RH. *Sampling season(s)*: across all seasons.
Lemay et al., 2000	C10	2 Grow/Finish rooms at Prairie Swine Centre (U of S).	**Area monitoring.** *Sampling height*: 1.6 m (operator walkway). *Sampling frequency*: twice daily (10 AM, 3:30 PM), Monday, Wednesday, Friday (particle counting). 48 to 72 h (total dust, CO_2, NH_3). *Contaminant(s)*: total dust (gravimetric), respirable dust (particle counting), temp; CO_2 and NH_3. *Sampling season(s)*: October through November.

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Table 1.2. Summary of Canadian contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Study setting	Sampling strategy and Contaminants monitored
Patni and Clarke, 1991	C11	3 Grow/Finish barns.	**Area monitoring.** *Sampling height*: floor level and 1 m. *Sampling frequency*: prior to, during, and following manure mixing at 3 to 6 monitoring sites. *Contaminant(s)*: H_2S, NH_3, CO_2. *Sampling season(s)*: autumn and spring.
Perkins and Feddes, 1996	C12	3 Farrowing rooms, U of A research farm. Positive pressure ventilation system.	**Area monitoring.** *Sampling height*: 0.9 m (dust), 1.6 m (temp). *Sampling frequency*: 36-s intervals, over 24 h. *Contaminant(s)*: respirable dust (particle counts). *Sampling season(s)*: not reported.
Perkins et al., 1997	C13	1 Farrowing room, U of A research farm.	**Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: 3 h monitoring. *Contaminant(s)*: respirable dust (particle counting). *Sampling season(s)*: not reported.
Phillips, 1986	C14	3 barns, with natural and mechanically ventilated areas.	**Area monitoring.** *Sampling height*: 1.3 m (over pens). *Sampling frequency*: 10 to 12 h periods (2 to 3 sites per room). *Contaminant(s)*: total and respirable dust (gravimetric), NH_3. *Sampling season(s)*: winter and summer.
Senthilselvan et al., 1997	C15	2 Grow/Finish rooms at Prairie Swine Centre (U of S). 20 male study participants rode a stationary bike for 3 km at 18 km/h.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: continuous (5 h). *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: November and December. **Area monitoring.** *Sampling height*: 1.6 m (particle counting), others not reported. *Sampling frequency*: continuous (dust, H_2S), 1 h sample (NH_3, CO_2), 5 to 20-s measurements at 8 AM and 12:30 PM (particle counting). *Contaminant(s)*: total dust (gravimetric), total endotoxin, respirable dust (particle counting), H_2S, NH_3, CO_2, barn temperature, RH. *Sampling season(s)*: November and December.

Table 1.2. Summary of Canadian contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Study setting	Sampling strategy and Contaminants monitored
Welford et al., 1990	C16	Finisher rooms at U of A Research Station, with partially and fully slatted flooring.	**Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: 5 min out of every 30 min (dust), 15 min intervals (temp). *Contaminant(s)*: total dust (gravimetric), respirable dust (particle counting), barn temperature. Sampling season(s): November to March.
Zhang et al., 1994	C17	Grow/Finish rooms at Prairie Swine Centre (U of S).	**Area monitoring.** *Sampling height*: 1.6 m (6 locations). *Sampling frequency*: 20-s intervals twice daily (8:30 AM, 1:00 PM), after technician walked around room for 3 min to simulate animal activity consistent with presence of worker in room. *Contaminant(s)*: respirable dust (particle counting). *Sampling season(s)*: May to July.
Zhang et al., 1996	C18	2 Grow/Finish rooms at Prairie Swine Centre (U of S).	**Area monitoring.** *Sampling height*: 0.2, 1.6, 2.4 m (above walkway). *Sampling frequency*: 100-s intervals twice daily (9:00 AM and 4:00 PM) after technician walked through room (as described in C17) over 11 weeks. *Contaminant(s)*: inhalable dust (gravimetric), respirable dust (particle counting), temp, RH, CO_2 (colorimetric tubes). *Sampling season(s)*: not reported.
Zhang et al., 1998	C19	2 Grow/Finish rooms at Prairie Swine Centre (U of S). 20 male study participants rode a stationary bike for 3 km at 18 km/h.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: continuous (5 h). *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: December. **Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: not reported (dust), continuous (H_2S), 1 hour (NH_3, CO_2). *Contaminant(s)*: respirable dust (particle counting), H_2S, NH_3, CO_2, barn temperature. *Sampling season(s)*: December.

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Table 1.2. Summary of Canadian contaminant assessment studies in confinement pig barns (continued)

Study Authors/ publication year	Study ID	Study setting	Sampling strategy and Contaminants monitored
Zejda et al., 1994	C20	50 buildings on selected farms. 4 production areas monitored: Farrowing, Nursery, Grower, Finisher.	**Area monitoring.** *Sampling height*: mid building height (service alley). *Sampling frequency*: 3.5 to 4 h. *Contaminant(s)*: total and respirable dust (gravimetric), total endotoxin, CO_2, NH_3. *Sampling season(s)*: winter and summer.

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Table 1.3. Summary of European contaminant assessment studies in confinement pig barns

Study Authors / publication year	Study ID	Country / Study setting	Sampling strategy and Contaminants monitored
Attwood et al., 1986	E1	The Netherlands. 4 Grow/Finish buildings.	**Area monitoring.** *Sampling height*: 1.5 m. *Sampling frequency*: 6-hour samples collected monthly over 4-months. *Contaminant(s)*: Total and respirable dust (gravimetric), total and respirable endotoxin. *Sampling season(s)*: not reported.
Attwood et al., 1987	E2	The Netherlands. 171 Farrowing, Nursery and Grow/Finish buildings, both mechanically and naturally ventilated. Information collected on age of pigs, heating/ventilation systems, feeding methods, cleaning practices.	**Area monitoring.** *Sampling height*: 1.5 m (above passageway). *Sampling frequency*: 6-hour monitoring. *Contaminant(s)*: total and respirable dust (gravimetric), CO_2, NH_3, barn temperature, RH. *Sampling season(s)*: October to January.
Clark et al., 1983	E3	Sweden. 8 swine confinement buildings on 6 farms.	**Area monitoring.** *Sampling height*: 1.5 m. *Sampling frequency*: 1 h. *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: early winter.
Donham et al., 1989	E4	Sweden. 30 confinement buildings on 28 farms.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: 2 to 8 h. *Contaminant(s)*: Total and respirable dust (gravimetric), total endotoxin. *Sampling period*: not reported. **Area monitoring.** *Sampling height*: 1.2 m. *Sampling frequency*: 2 to 3 h (NH_3), not reported (rest of contaminants). *Contaminant(s)*: Total and respirable dust (gravimetric), total and respirable endotoxin, NH_3, CO_2, H_2S. *Sampling period*: not reported.

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Table 1.3. Summary of European contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Country / Study setting	Sampling strategy and Contaminants monitored
Haglind and Rylander, 1987	E5	Sweden. 29 part-time farmers from 19 confinement operations.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: during work in barn. *Contaminant(s)*: total and respirable dust (gravimetric), total and respirable endotoxin. *Sampling season(s)*: not reported. **Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: not reported. *Contaminant(s)*: NH_3. *Sampling season(s)*: not reported.
Heederick et al., 1990	E6	The Netherlands. 2 operations with 33 employees in total.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: full workshift. *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: spring. **Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: not reported. *Contaminant(s)*: NH_3. *Sampling season(s)*: spring.
Larsson et al., 1994	E7	Sweden. 14 healthy study participants, no previous exposure to barn dust. Exposed during pig weighing activity each day on 7 days.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: continuous (2 to 5 hours). *Contaminant(s)*: total dust, total endotoxin. *Sampling season(s)*: not reported. **Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: mid exposure time. *Contaminant(s)*: CO_2, NH_3, H_2S. *Sampling season(s)*: not reported.
Larsson et al., 1997	E8	Sweden. 31 healthy study participants, no previous exposure to barn dust. Assisted with pig weighing activity.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: continuous (3 h). *Contaminant(s)*: inhalable dust, inhalable endotoxin. *Sampling season(s)*: not reported.

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Table 1.3. Summary of European contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Country / Study setting	Sampling strategy and Contaminants monitored
Larsson et al., 2002	E9	Sweden. 16 healthy study participants, no previous exposure to barn dust. Exposed during pressure washing activity (2 to 5 m from farmer conducting task) each day on 4 days.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: continuous (3 h). *Contaminant(s)*: inhalable and respirable dust (gravimetric), inhalable and respirable endotoxin. *Sampling season(s)*: not reported.
Louhelainen et al., 1987	E10	Finland. 15 farms. 4 Farrow to wean, 8 Finisher, 3 Farrow to Finish. Herd sizes averaged 30 sows (10 to 55), Finisher pigs 200 (90 to 470).	**Area monitoring.** *Sampling height*: breathing zone (pen and center walkway). *Sampling frequency*: during tending of pigs. *Contaminant(s)*: total dust. *Sampling season(s)*: summer.
Nicks et al., 1993	E11	Belgium. Study 1: 7 Farrowing and 2 Nursery buildings. Study 2: 5 Farrowing and 7 Finisher buildings.	**Area monitoring.** Study 1. *Sampling height*: not reported. *Sampling frequency*: every 20 min over 7 days (RH, temp), 8 h (CO_2, NH_3). *Contaminant(s)*: RH, barn temperature, CO_2, NH_3. *Sampling season(s)*: not reported. Study 2. *Sampling height*: not reported. *Sampling frequency*: hourly over 3 days. *Contaminant(s)*: respirable dust (particle counting). *Sampling season(s)*: not reported.
Preller et al., 1995	E12	The Netherlands. 198 male farmers. Information collected on number of pigs, feed method, heat/ventilation system, type of flooring, use of bedding, cleanliness of barns.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: full workshift, mean 8.3 h (5.2 to 10.4 h). *Contaminant(s)*: inhalable dust (gravimetric), inhalable endotoxin. Farmers completed a diary for 7 days each season on activities conducted in 15 minute intervals (selected from 21 pre-determined activities). *Sampling season*: 1 day winter, 1 day summer (Monday through Thursday).

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Table 1.3. Summary of European contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Country / Study setting	Sampling strategy and Contaminants monitored
Radon et al., 2001	E13	Denmark. 40 farmers. Information collected on number of animals, heat/ventilation system, type of flooring, frequency of cleaning.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: median sampling time 118 minutes, while conducting activities and moving from room to room. *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: not reported. **Area monitoring.** *Sampling height*: not reported. *Sampling frequency*: not reported. *Contaminant(s)*: NH_3, CO_2, barn temperature, RH. *Sampling season(s)*: not reported.
Smith et al., 1993	E14	Britain. 1 Grow/Finish room.	**Area monitoring.** *Sampling height*: 1.0 and 1.9 m. *Sampling frequency*: 3 d of sampling over 5 weeks, at 10 locations in the room; conducted over 4 periods of different activity level each day: (1) morning feeding and cleaning; (2) midday; (3) afternoon feeding; and (4) overnight. *Contaminant(s)*: inhalable and respirable dust (gravimetric). *Sampling season(s)*: not reported.
Takai et al., 1995	E15	Denmark. Commercial farm with 300 sows. Farrowing, Nursery, Grow-Finish buildings.	**Area monitoring.** *Sampling height*: 1.7 m. *Sampling frequency*: 24 hours, once weekly. *Contaminant(s)*: total and respirable dust (gravimetric), barn temperature, RH, CO_2, NH_3. *Sampling season(s)*: not reported.
Takai et al., 1996	E16	Denmark. Nursery and Grow/Finish rooms at the Institute's experimental farm.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: one sampling cassette used for 5 d, when working in a specific room. *Contaminant(s)*: Total dust (gravimetric). *Sampling season(s)*: not reported. **Area monitoring.** *Sampling height*: 1.5 m (2 locations walkway, pen). *Sampling frequency*: 24 hours. *Contaminant(s)*: Total and respirable dust (gravimetric), barn temperature, RH. *Sampling season(s)*: not reported.

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Table 1.3. Summary of European contaminant assessment studies in confinement pig barns (continued)

Study Authors / publication year	Study ID	Country / Study setting	Sampling strategy and Contaminants monitored
Takai et al., 1998	E17	Britain, the Netherlands, Denmark, Germany. Different housing systems: Dry Sow/Breeding (litter, slats), Nursery (slats), Finisher (litter, slats).	**Area monitoring.** *Sampling height*: pig and worker breathing zones. *Sampling frequency*: not reported, at 6 locations in areas. *Contaminant(s)*: inhalable and respirable dust (gravimetric). *Sampling season(s)*: not reported.
Vinzents, 1994	E18	Denmark. 3 workers on 2 farms, 100 and 200 sows, respectively.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: full workshift (6.5 h). *Contaminant(s)*: inhalable dust (gravimetric). *Sampling season(s)*: not reported.
Vinzents and Nielsen, 1992	E19	Denmark. Survey A: 2 farms with 2 employees per farm. Survey B: 11 farms with 23 employees total; average herd size 380 sows.	**Personal monitoring.** Survey A: *Sampling height*: breathing zone. *Sampling frequency*: over 4 consecutive days; one filter cassette used when worker close to animals (artificial insemination, castrating, cutting teeth/tails, and moving pigs) and another cassette used when worker conducting tasks far from animals (other activities including feeding). *Contaminant(s)*: total dust (gravimetric), total endotoxin. *Sampling season(s)*: May. Survey B: *Sampling height*: breathing zone. *Sampling frequency*: full workshift (6 to 7 h). *Contaminant(s)*: total and respirable dust, total and respirable endotoxin. *Sampling season(s)*: October and November.
Vogelzang et al., 1998	E20	The Netherlands. 198 male pig farmers. Information collected on number of pigs, feed method, heat/ventilation system, type of flooring, use of bedding, cleanliness of barns.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: full workshift, mean 8.3 h (5.2-10.4 h). *Contaminant(s)*: inhalable dust (gravimetric), inhalable endotoxin. Farmers completed a diary for 7 days each season on activities conducted in 15 minute intervals (selected from 21 pre-determined activities). *Sampling season(s)*: 1 day winter and 1 day summer.

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Table 1.3. Summary of European contaminant assessment studies in confinement pig barns (continued)

Study Authors/ publication year	Study ID	Country / Study setting	Sampling strategy and Contaminants monitored
Vogelzang et al., 2000	E21	The Netherlands. 198 male pig farmers. Information collected on number of pigs, feed method, heat/ventilation system, type of flooring; use of bedding, cleanliness of barns.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: full workshift, mean 8.3 h (5.2-10.4 h). *Contaminant(s)*: inhalable dust (gravimetric), inhalable endotoxin, NH_3 (personal passive monitoring). Farmers completed a diary for 7 days each season on activities conducted in 15 minute intervals (selected from 21 pre-determined activities). *Sampling season(s)*: 1 day winter and 1 day summer.
Zhiping et al., 1996	E22	Sweden. 38 healthy volunteers not previously exposed to barn dust. Exposed during pig weighing activity.	**Personal monitoring.** *Sampling height*: breathing zone. *Sampling frequency*: 3 to 4 hours. *Contaminant(s)*: inhalable dust (gravimetric), inhalable endotoxin. *Sampling season(s)*: not reported.

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Chapter Two

Development of a Personal Environmental Sampling Backpack System for the Exposure Assessment of Career Pig Barn Workers

2.1. Introduction

To accurately assess continuous, personal, airborne contaminant exposures of career pig barn workers over full work-shifts, it was first necessary to develop a monitoring system that was portable (reasonable weight and size for workers to wear over full workshifts), easily disinfected (able to meet stringent biosecurity requirements of modern barns), and capable of capturing potential contaminants of interest simultaneously in the breathing zone of the worker. The original version of the Personal Environmental Sampling Backpack (PESB) was designed and built over the course of 3 months. It was tested in a pilot study conducted by this author (Wenger, 1999) to monitor exposures of career pig barn workers. The equipment was then used in a second study to evaluate the exposures of poultry workers (Ouellette et al., 1999). Though the original PESB system captured the intended air contaminant exposure data, investigators noted a number of limitations (Ouellette et al., 1999). To improve the capture of the full range of real-time personal exposures of the full workshift, two major modifications were made. First, the weight and dimensions of the system were reduced to make it more acceptable to workers; and second, additional sensors and improved monitoring technology were incorporated.

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2.2. *Biosecurity*

As herd size and stocking density have increased in enclosed barns, biosecurity protocols have become much more stringent. Persons who need to travel between large independent pig operations, are subject to a 48-hour "pig free" time and must shower and change clothes before entering the barns. In fact, most modern pig barns do not permit equipment or paperwork that has previously been in other pig barns to enter their barns. These stringent measures are in place to decrease the risk of transmitting highly contagious diseases that could be detrimental to the herd and potentially lead to enormous economic losses. All current research within the confines of today's pork producing facilities must incorporate biosecurity protocols to properly wash and disinfect equipment (Barber et al., 1987; Barber et al., 1991).

The original PESB was purposefully designed to be a single piece of equipment that could be easily disinfected between barn visits. By designing such a system that would meet the higher biosecurity requirements of the pig industry meant that the system would also be suitable for the biosecurity standards of other agricultural industries. The author followed a biosecurity protocol that was developed specifically for the pilot study in 1997. Following the pilot study, the biosecurity protocol was revised to meet even higher requirements demanded by the participating barns and their herd veterinarians (Appendix 3.3 and 3.4) to enable the study team to conduct the present study in 2000. Ethics approval was obtained for the present study from the Health Research Ethics Board (B: Health Research) of the Faculty of Medicine, University of Alberta.

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2.3. *Personal monitoring*

The PESB was also designed to monitor personal exposures to all contaminants of interest in the breathing zone of the workers (Ouellette et al., 1999). Workers are known to conduct tasks in as many as 27 separate pig rooms (Chapter three), in addition to time spent in coffee rooms, medicine rooms, and shop areas. The PESB was strapped onto the back of a willing worker for an entire workshift, and monitored exposures on a real-time basis as workplace tasks were conducted in the barn, regardless of area.

2.4. **Limitations of the original PESB system**

Following the pilot study, the PESB system was evaluated and a number of limitations were noted. Ouellette et al. (1999) noted that size and weight were a problem, that it had limited data storage capability, that the maximum CO_2 exposures were not being monitored, and that it could be improved by adding a sensor to monitor H_2S exposures.

(1) **Size and weight**. The first iteration of the PESB equipment was too bulky and did not allow workers to maneuver through narrow spaces. One example was when a worker was moving pigs into a weigh scale. The observer assigned to this worker was required to wear the monitoring equipment during the work task, but this made it impossible to monitor the actual breathing zone exposure of the worker. In addition, workers complained about the weight of the PESB of 8.4 kg (19 lbs). Given that the protocol for the current study mandated that workers wear the PESB for 3 consecutive days per season, for 8+ hours per day, it was believed that the original system would deter workers from participating in the study for more than one day.

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(2) **Limited data storage capability**. The dust counter in the PESB system, permitted the storage of 500 data readings. This meant that exposure monitoring at 1-min intervals was limited to 8 hours and 20 min. However, pilot study data showed workshift lengths of up to 10 hours (data not shown). Therefore several hours of personal exposure measurements were not being captured.

(3) **Peak CO_2 monitoring.** The CO_2 unit in the PESB system was able to monitor exposures up to 5000 ppm. However, in the pig barn pilot study, CO_2 exposures reached this exposure level and possibly exceeded it. Therefore it was unclear what the actual peak CO_2 exposures were in this occupational cohort, especially during winter, when barn ventilation rates are lower.

(4) **No H_2S monitoring capability**. H_2S is an important and potentially fatal occupational exposure hazard in pig barn environments, and the author noted that the PESB system did not allow for the real-time continuous monitoring of this contaminant.

2.5. Modifications to the PESB instrumentation:

To address these limitations, a company in Edmonton, under the direction of CA Ouellette, the agricultural engineer who designed and built the PESB instrumentation, and the author, spent 4 months experimenting and making the necessary modifications.

(1) **Improved data logging capability**. To increase storage capability, a single data logger unit with a large memory replaced multiple loggers. Now exposures over an entire workshift could be monitored. The storage of respirable dust counts, CO_2, RH and barn temperature data in a single logger (the H_2S and NH_3 data were independently

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logged) also allowed for quicker data downloading.

(2) **Reduced Sampling interval.** With improved data logging capability, it was possible to reduce the sampling interval of respirable dust counts, CO_2, RH and barn temperature to 10 s (except for H_2S and NH_3 at 20-s intervals), allowing for changes in exposures to be captured as workers moved from pen to pen, or from room to room.

(3) **Reduced weight and size.** The weight of the PESB II was reduced to 4.5 kg (10 lbs) by removing on-board loggers and by incorporating monitoring equipment with the same principle of detection (diode laser dust counter, and NDIR non-dispersive infrared CO_2 monitor), but smaller in size. Such changes also reduced the overall dimensions of the PESB II making the equipment more portable.

(4) **Improved CO_2 monitoring capability.** A newer model of the Young Environmental System's (Vancouver, BC) CO_2 monitor was incorporated into the PESB II to increase the upper detection limit of exposures to 10,000 ppm.

(5) **Addition of a hydrogen sulfide (H_2S) sensor.** An H_2S sensor was incorporated into the PESB II system to enable the monitoring of personal activity-specific H_2S exposures.

2.6. The Personal Environmental Sampling Backpack version 2 (PESB II) instrumentation:

The smaller lighter PESB II system has become an important tool not only for our research group but to others. Research groups in Saskatchewan and Alberta are presently using this newly modified equipment for poultry barn worker exposure and respiratory health studies.

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Table 2.1 presents the environmental parameters and specifications of the monitoring equipment contained in the PESB II. Figure 2.1 presents the overall layout of the environmental sensors and airflow paths in the PESB II equipment. Figure 2.2 presents pictures of the PESB II instrumentation, while Figure 2.3 depicts a worker wearing the PESB II.

2.7. Error analysis of the gas monitoring equipment in the PESB II

To assess the margin of error associated with the PESB II exposure data, Table 2.3 was prepared. Such information is important to ensure a high degree of confidence in the exposure readings presented in Chapters three, four and five. Calculations were based on the specifications of the monitoring equipment (Table 2.1) and the analytical accuracy of the gases used in the calibration of the PESB II monitoring equipment (Table 2.2).

2.8. NH_3 sensors' cross-sensitivity to H_2S

During the course of this study, the quality of the NH_3 sensor, its response time following exposure and its cross-sensitivity to other in-barn gases, most notably H_2S, were questioned. A major concern challenging data validity was the discovery of a cross-sensitivity reaction between the background levels of H_2S present in the pig barn and the NH_3 sensors. This led to erroneous NH_3 readings especially during higher H_2S exposure activities. Laboratory tests (Appendix 2.1) conducted by this research group found the level of this cross-sensitivity to range between 1 to 5 ppm for every 1 ppm of H_2S exposure, and was highly dependent on individual sensors.

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Table 2.1. Environmental parameters measured by, and specifications of, the monitoring equipment contained in the Personal Environmental Sampling Backpack (PESB II) as well as the air flow meter equipment used for calibration of the personal pumps

Contaminant	Model	Manufacturer	Principle of detection	Range & accuracy	Response times
Respirable dust counts	ABACUS™ 301	Particle Measuring Systems Inc., Boulder, CO	Diode laser, 780nm	>0.3, >0.5, >1.0, and >5μm; background counts < 1 count/ft^3; maximum particle concentration @ 10% coincidence loss =10^6/ft^3; counting efficiency=50%± 10% for 0.3μm particles; and capture efficiency of 115% ± 10% for 0.5μm particles	Sampling period (10-s intervals)
NH_3	Toxi-Ultra	Biosystems Inc., Middletown, CT	Electrochemical (3-electrode)	0 to 50 ppm; ± 5% or 1 ppm, whichever is greater	$T_{90} \leq 150$ s
H_2S	Toxi-Ultra	Biosystems Inc., Middletown, CT	Electrochemical (3-electrode)	0 to 100 ppm; ± 5% or 1 ppm, whichever is greater	$T_{90} \leq 30$ s
CO_2	YES-206 Falcon	Young Environmental Systems Inc., Vancouver, BC	NDIR non-dispersive infrared	0 to 9,999 ppm; ±5% or 50 ppm, whichever is greater	$T_{90} < 60$ s
RH	HIH-3602-A	MICRO SWITCH Honeywell Inc., Freeport, IL	Thermoset Polymer Capacitance	0 to 100%; ± 2%	$T_{40} = 50$ s in slowly moving air at 25 °C
Dry-bulb temperature	HOBO® H8 External Temperature	Hoskin Scientific, Vancouver, BC	Thermistor	-40° to 100°C; ±0.5 °C at 20 °C	Response time in air: 4.5 min
Data logger (sensor inputs)	TFX11	Onset Computer Corporation, Bourne, MA	12 bit, switched capacitor, successive approximation, analog to digital converter	11 channels; 0-5V ± 1 least significant bit (LSB)	
Personal Pump	Gilian BDX II Abatement Air Sampler	Sensidyne, Clearwater, FL	Constant voltage	500 cc/min - 3,000 cc/min ± 5% setpoint, with no more than 2 adjustments in an 8-h period	
Personal Pump	GilAir II	Sensidyne, Clearwater, FL	Constant rotations per min (RPM)	1,000 cc/min - 5,000 cc/min ± 5% setpoint	
Air Flow Meter	DryCal® DC-Lite	BIOS International, Butler, NJ	Dry Piston and infrared sensors	50 mL/min - 2 L/min ± 1%; > 2 L/min - 5 L/min ± 3.5%	

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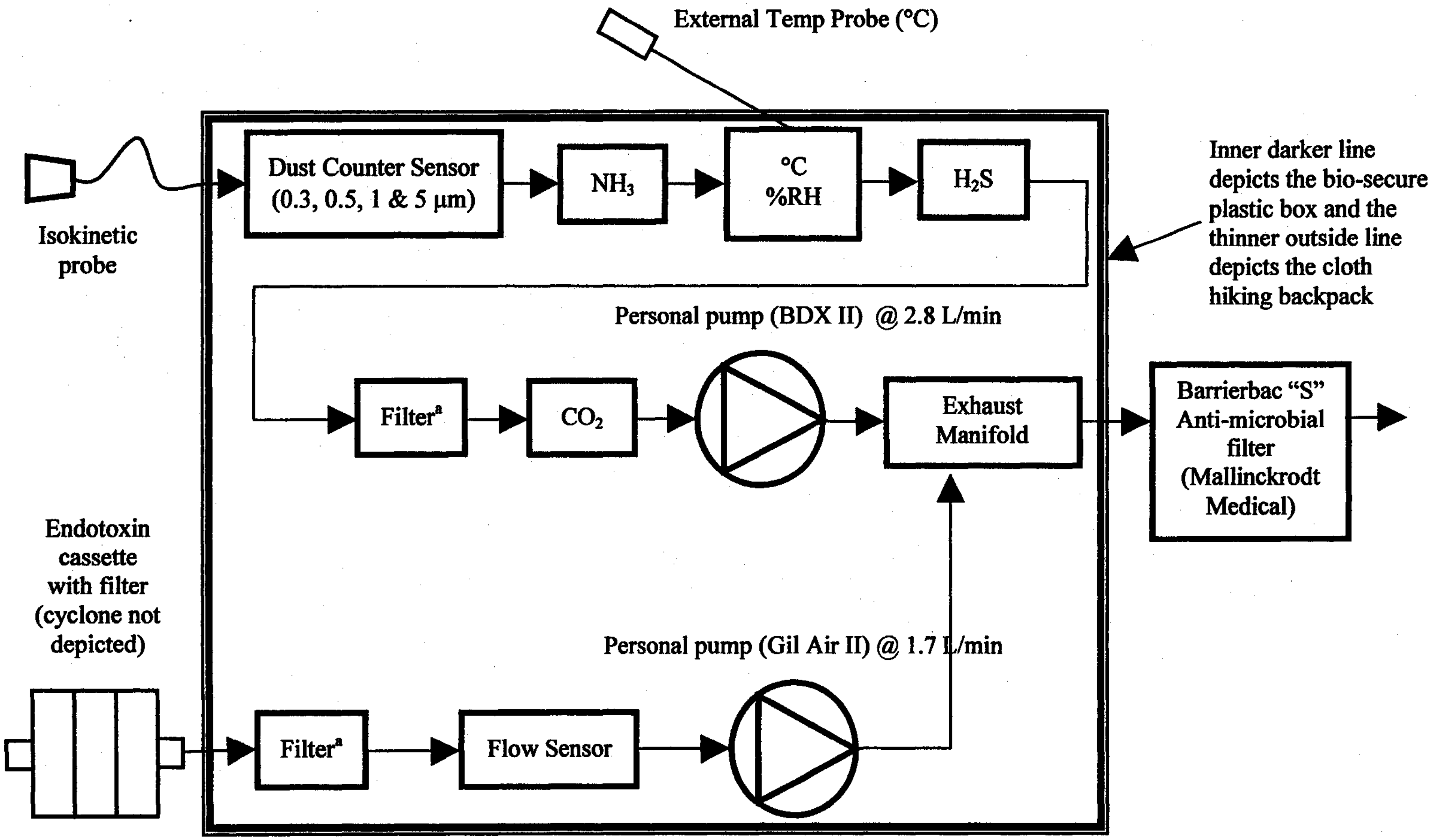

[a] In-line filters removed particulates to prevent damage to downstream equipment, sensors, and pumps

Figure 2.1. PESB II: Overall layout of the environmental sensors and airflow paths

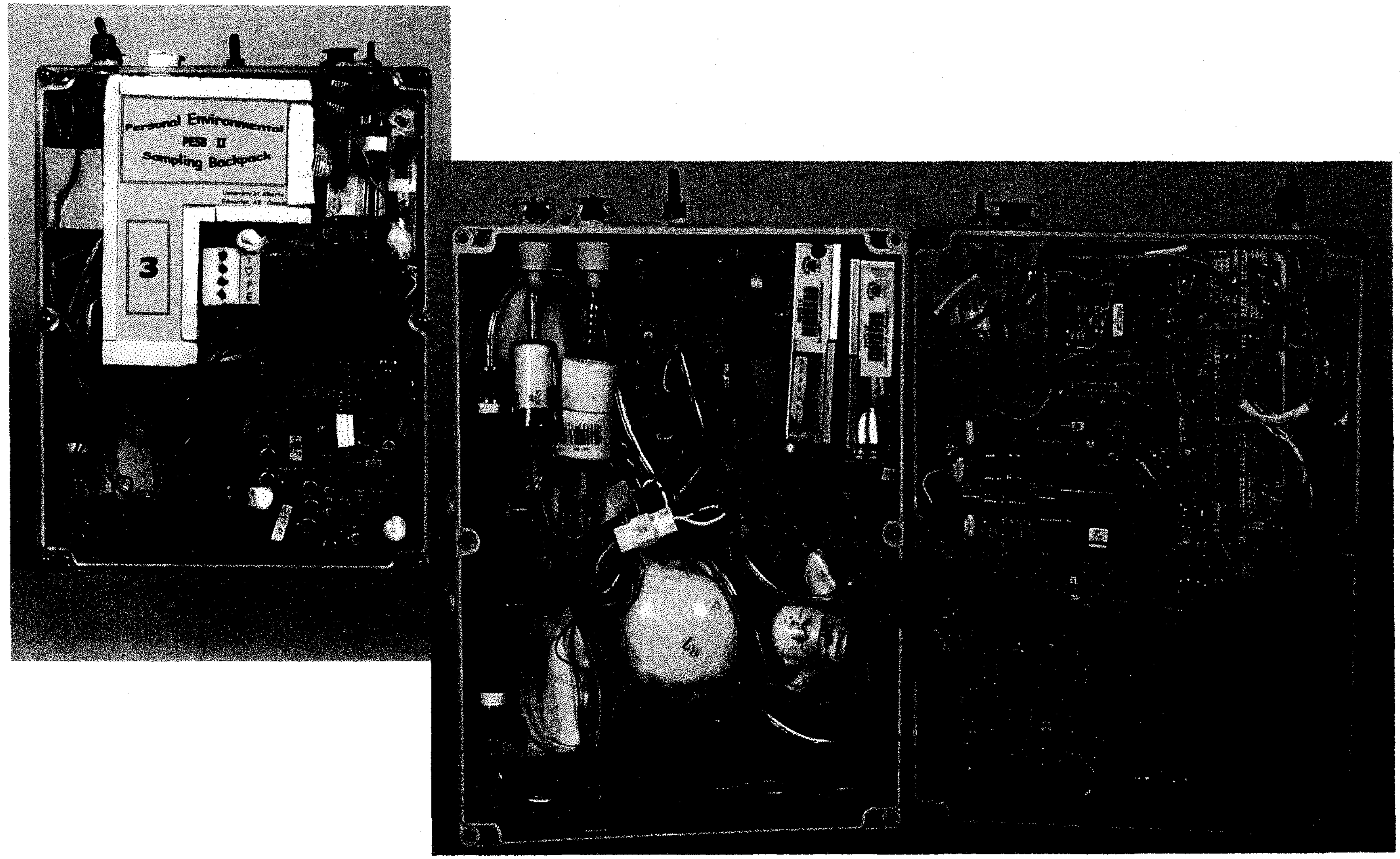

Figure 2.2. The Personal Environmental Sampling Backpack (PESB II) instrumentation

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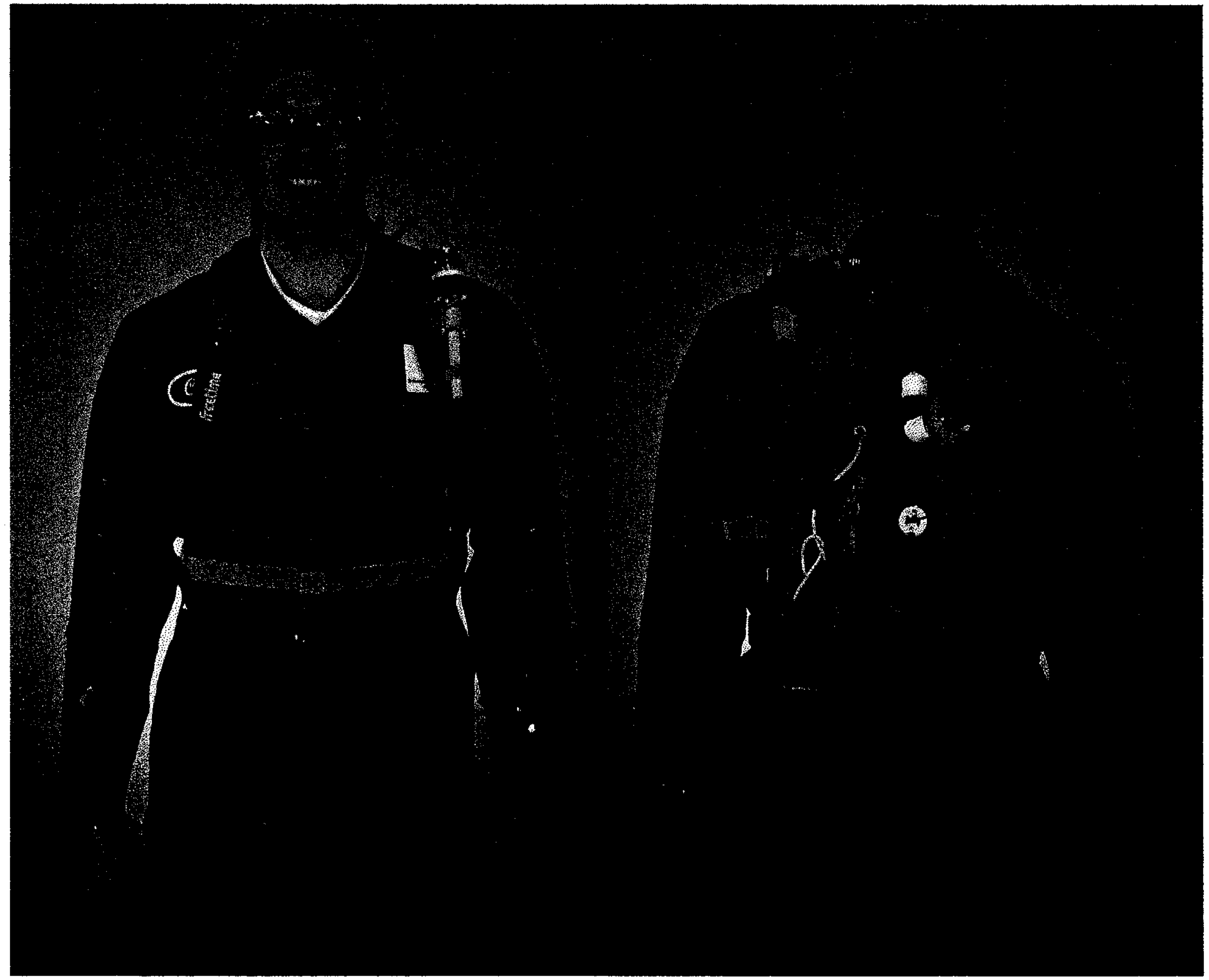

Figure 2.3 Front and back views of a worker wearing the Personal Environmental Sampling Backpack (PESB II) equipment

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Table 2.2. PESB II: Analytical accuracy of the gases used in the calibration[a] of the monitoring equipment.

Gas	Concentration	Analytical accuracy*
Carbon dioxide (CO_2)	9000 ppm	± 2 %
Hydrogen sulfide (H_2S)	10 ppm	± 1 ppm
Ammonia (NH_3)	50 ppm	± 5 %

* Information provided by Praxair, Edmonton, Alberta

[a] Calibration procedures are outlined in Appendix 2.2

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Table 2.3. PESB II: Estimate of the accuracy of the H_2S and CO_2 exposure data

Gas	Calibration gas analytical accuracy, and instrument accuracy	Data accuracy
H_2S: mean exposure 0.6 ppm*		
Calibration gas	± 1 ppm (10%) (Table 2.2)	
Instrument accuracy	± 5 % (Table 2.1)	
Accuracy of H_2S data (over ≤ 30 s equipment lag time):	Step one[a]: $(10)^2 + (5)^2 = 125$ Step two[a]: $(125)^{1/2} = 11.2\%$ Step three: 11.2% of 0.6 ppm = 0.07 ppm	0.6 ± 0.07 ppm
CO_2: mean exposure 1660 ppm*		
Calibration gas	± 2 % (Table 2.2)	
Instrument accuracy	± 5 % (Table 2.1)	
Accuracy of CO_2 data (over < 60 s equipment lag time):	Step one[a]: $(2)^2 + (5)^2 = 29$ Step two[a]: $(29)^{1/2} = 5.4\%$ Step three: 5.4% of 1660 ppm = 89.6 ppm	1660 ± 89.6 ppm

* Overall mean H_2S and CO_2 exposure data from Chapter three

[a] Source: Plog et al., 1996

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It was not possible to establish a correction factor for the NH_3 data with any degree of confidence. In addition, the accuracy of the NH_3 instrumentation was also questionable since the span of the unit would shift greatly pre- and post-sampling. For these reasons, it was decided that the NH_3 results would not be reported.

Researchers need to be aware of the cross-sensitivity present between NH_3 and H_2S gases and thoroughly test NH_3 equipment prior to use in pig barn environments.

2.9. H_2S sensors' cross-sensitivity to isopropyl alcohol

The biosecurity protocol required that the PESB II instrumentation case be wiped down with 97% isopropyl alcohol prior to placing it into the cloth hiking backpack. When the H_2S sensor was exposed to the vapours from the isopropyl alcohol, the unit would at times, record negative readings. This determination was made following visual inspection of the H_2S exposure graphs generated for each worker. Follow-up interviews were conducted with workers whose H_2S exposures were found to be negative, to determine what chemicals or agents were in use during particular activities. No laboratory tests were conducted to evaluate the extent of this cross-sensitivity. This cross-sensitivity was also found to occur when Farrowing workers dipped cutting tools in alcohol between pigs during processing activities, when Nursery/Grower-Finisher workers were marking pigs with livestock marker spray (which utilizes an alcohol-based carrier medium), and also when workers sprayed themselves with mosquito repellant (an alcohol-based product). Where H_2S exposure readings were negative due to cross-sensitivity with alcohol vapours, data were not included in further analyses.

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In some barns where H_2S monitors are routinely worn, the on-board equipment alarms may be audible in circumstances where workplace activities involve the use of alcohol-based products. In such instances, the monitor's alarm would not be responding to H_2S exposures above safety limits. Negative H_2S readings also highlight the importance of examining H_2S exposure data prior to calculating time-weighted-average exposures. If this is not done, there is a risk that these negative readings would be included and that the overall exposure would be underestimated. Future studies may need to evaluate alternate disinfection products to wipe down the PESB II instrumentation and still meet biosecurity protocol requirements.

2.10. Conclusions

When the present study was in the planning stages, there was no one piece of "off the shelf" monitoring instrumentation that could capture all potential contaminants in a configuration compatible with current biosecurity requirements in modern pig barns. Therefore, prior to the pilot study, the PESB technology had to be developed. After the pilot study, CA Ouellette, the agricultural research engineer involved with this project, made modifications to the original system to reduce weight and size, improve data logging capability, reduce sampling intervals, improve CO_2 monitoring, and add H_2S monitoring capability. It was this second version, the PESB II system, that was used in the current study.

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Chapter Three

Seasonal Workplace Exposures of Specialty Career Pig Barn Workers

3.1 Introduction

The pork producing industry requires a highly skilled, stable labour force. The development and retention of the skilled workforce necessary for the growth of the industry is dependent, in part, on ensuring a healthy work environment. Over the past 10 to 15 years, pig barn work has evolved from operations where workers only spent a portion of their day in the barn, to the current situation where full-time work, > 8 hours per day for 10 or 11 consecutive days, is performed in enclosed housing facilities. Today's workers have to be highly specialized and have specific job responsibilities depending on the specialty area of the barn where they work. Barn specialty areas include: the Dry Sow/Breeding area housing gilts, sows (young and older female pigs of reproductive age) and boars (male breeding pigs); the Farrowing area housing sows and piglets (newborn pigs); the Nursery area for weaned piglets; and the Grower/Finisher area for grower and finisher pigs (Berg, 1975).

The increase in the length of the workshift in the barn, along with demonstrated levels of airborne particulate and gases inside these facilities, has resulted in net increases in daily exposures for workers to air contaminants. Investigations into the health hazards of pig barn workers have identified a number of air contaminants that could affect lung health. They include: dust [total, inhalable (50% cut-point at 100 μm) and respirable

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(50% cut-point at 4.0 μm)]; gases [ammonia (NH_3), hydrogen sulfide (H_2S), and carbon dioxide (CO_2)]; and endotoxin (Curtis et al., 1975; Thedell et al., 1980; Clark et al., 1983; Donham and Popendorf, 1985; Donham et al., 1986; Phillips, 1986; Morrison et al., 1993). Dust in pig barns originates primarily from pig dandruff, dried fecal material and urine, feed, microorganisms, dust mites and bedding material (Bundy and Hazen, 1975). CO_2 is a normal byproduct of pig respiration. NH_3 gas is produced mainly from urine decomposition on floor surfaces. It is highly soluble in water and at high concentrations can irritate the mucous membranes of the eyes, nose, throat and upper respiratory system. Researchers speculate that NH_3 gas can adhere to respirable dust particles, which are subsequently carried deep into the lungs (Schwartz et al., 1992), and which may add to ammonia's potential toxic effects. H_2S is a by-product of the anaerobic breakdown of manure. At low concentrations H_2S can cause eye irritation. However, the inhalation of H_2S at or above concentrations of 150 ppm can cause olfactory nerve paralysis. Fatalities occur at concentrations approaching 1000 ppm (ATSDR, 1999).

Endotoxins are inherent components of the cell wall of gram negative bacteria and are biologically active, whether they are still a part of, or independent of, the bacterial cell (Preller et al., 1995). Studies suggest that endotoxins may induce conditions such as broncho-constriction, organic dust toxic syndrome, or mucous membrane irritation (Olenchock, 1997). Research suggests that endotoxins may be responsible for reduction in lung function and bronchial reactivity and are therefore emerging as one of the more important classes of contaminants in pig barn environments (Donham et al., 1989; Rylander et al., 1989; Zejda et al., 1994; Schwartz et al., 1995; Vogelzang et al., 1998).

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To identify potential predictors of respiratory dysfunction, a number of studies have evaluated feed types, feeding methods, flooring types, presence of bedding material (Vogelzang et al., 1996; Attwood et al., 1987; Holness et al., 1987), and cleaning activities and barn hygiene (Preller et al., 1995; Duchaine et al., 2000).

The air quality inside pig barns can be affected by a number of factors, including ventilation rate, stocking density, pig activity, level and type of feeding, barn cleanliness, manure management, barn management and barn and fan maintenance (Honey and McQuitty, 1979; Feddes et al., 1984; Barber et al., 1991a; Smith et al., 1993; Barber et al., 1993). The primary purpose of a barn ventilation system is to dilute the atmospheric contaminants (water vapour, CO_2, and other barn gases, including NH_3, H_2S, and barn aerosols, including dust) with fresh air from outside. Ventilation inside barns typically controls indoor barn temperature, when a surplus of building energy is produced. As barn temperatures rise above set-points, ventilation exhaust fans, situated either along the walls or ceilings, are either switched on or have their rotational speeds increased in proportion to the temperature change. Through adjusting fan speed, more fresh air is drawn into the barn through air inlets located on the ceiling or walls of the rooms, to mix with and dilute barn air. When a ventilation system functions properly, air quality within room airspaces can be maintained within "acceptable" limits. Low outdoor ambient air temperatures during the coldest winter months pose a challenge to maintaining proper air quality in barns. In the winter season there is a compromise between indoor air quality (introducing cold air) and the economics of providing supplemental heat. During summer, however, barn fans can operate at a capacity that results in improved air quality

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due to increased air contaminant dilution.

To date, no research has reported the real-time monitoring of personal exposures on a continuous basis of specialty-area career pig barn workers to air contaminants which may contribute to potential health effects (dust, endotoxin, CO_2, NH_3, H_2S) over a full work shift ($\geq$ 8 hours). Historically, large intensive pig facilities and their workers have been inaccessible to researchers due to the facilities' stringent biosecurity requirements. Some studies have identified the potential for exposures to be greater in certain pig barn specialty areas, but these assessments were based primarily on area-monitoring. Area-monitoring does not provide evidence on individual worker exposure, hence personal exposure monitoring is needed. As well, most previous studies confined monitoring to a selected room within a particular specialty area, but were not conducted on a scale that captured exposures in all rooms within a specialty area, or different areas of a barn.

This purpose of this study was to evaluate the personal air contaminant (respirable dust, endotoxin, CO_2, NH_3, H_2S, RH and barn temperature) exposures of specialty-area pig barn workers, and to determine whether these exposures differed by specialty-area or by season.

3.2 MATERIALS AND METHODS

3.2.1 Study design

The study used a cross-sectional design and was conducted over the winter (February to April) and summer (June to August) of 2000 in Alberta, Canada. Ethics approval was obtained from the Health Research Ethics Board (B: Health Research) of

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the Faculty of Medicine, University of Alberta.

3.2.2 **Research Setting**

3.2.2.1 **The barns**

In 1999, the primary investigator (IIW), compiled a comprehensive list of Alberta pig farms that employed full-time pig barn workers. There were 70 barns that employed a total of 290 career pig barn workers (Wenger, 1999b); over half (54%) employed three or more full-time employees. Pig barns were considered eligible for this study if they were Farrow-to-Finish or Farrow-to-Wean farms, and if the barns employed a minimum of 4 full-time workers. Farms were excluded if they were owned and operated by the Hutterite Bretheren (workers in the Hutterite pig barns do not have the same workshift lengths as those in non-Hutterite barns), were a research facility, were a Farrow-to-early-Wean operation (piglets weaned at less than 14 days of age), or if the farming operations specialized in nursery or finishing pigs only. Of the 70 pig farms, only 57 had a farrowing component. Of the 57 barns, only twenty (13 Farrow-to-Finish; 7 Farrow-to-Wean) met the inclusion criteria listed above. They were stratified by type of farming operation and ranked by number of full-time employees. Priority was given to Farrow-to-Finish operations since employees in such facilities represented the broadest range of worker specialities. Fifteen eligible pig barns were randomly selected to be contacted. Ten barns (8 Farrow-to-Finish; 2 Farrow-to-Wean) agreed to participate and allowed the study team access to their facilities, while 5 (Farrow-to-Finish) denied access. Reasons for denying access included: visitors were not allowed in for any reason (N=3); the barn was in the midst of expansion and participation would have increased upheaval (N=1);

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and the potential for barn access would compromise pig health (N=1). Non-participating pig barns were exclusively Farrow-to-Finish and were on average, smaller in size than participating farms (Table 3.1).

3.2.2.2 **The specialty work areas**

A modern pig barn is typically constructed as a number of isolated specialty areas interconnected by a common hallway (Figure 1.1, Chapter one). Each specialty area consists of a number of animal rooms, separated by walls and doors. These areas house individual classes (types and ages) of pigs. Each individual animal room has its own unique airspace, with an individually controlled ventilation system that is designed to meet the requirements of the animals housed within the room. The Dry Sow/Breeding area houses sows, boars and maiden and bred gilts in stalls and pens. The Farrowing area houses sows and their piglets, in farrowing crates. The Nursery area houses nursery pigs and has similar characteristics as those of the Farrowing area. Both have All-in, All-out animal flow (pigs are moved into and out of the same room as a group), fully slatted flooring, and the areas are thoroughly washed and disinfected between groups. The Grower/Finisher areas of barns house grower and finisher pigs, respectively.

During a three-day farm visit, a walk-through survey was conducted to collect barn management information (Appendix 3.2). Detailed data were collected for each speciality area that included number and dimensions (m^2) of individual rooms, animal inventory and estimated pig weights, types of penning and flooring, method of manure

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Table 3.1. Demographics of participating and non-participating Alberta pig farms

	Participating pig farms	Non-participating pig farms
Number of farms	10	5
Type of operation (N)		
Farrow to Finish	8 (80%)	5 (100%)
Farrow to Wean (no nursery)	1 (10%)	0
Farrow to Wean (with nursery)	1 (10%)	0
Average number of sows (mean ± SD)	1310 ± 776	870 ± 325
Full-time employees (mean ± SD)	7.1 ± 4.1	6.8 ± 0.5

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handling and removal schedules, animal flow characteristics and room/area cleaning procedures, types of feed and methods of feeding, information on heating, ventilation, and re-circulation systems present.

Eleven barn management variables were selected because of their possible contributions to endotoxin, respirable dust mass, and H_2S. Selection was based on biological plausibility and objective- rather than subjective-measured variables (such as whether a particular room was viewed as being clean, for example). Number of rooms, manure pit depth, and stocking density were collected as continuous variables. The remaining 8 barn management variables (type of manure system, frequency of pit draining, type of flooring, feed type, feeding method, animal flow, area washed, and area disinfected) were collected as categorical data, each collapsed into 3 categories (Appendix 3.5).

3.2.3 Study Sample

3.2.3.1 The workers

Only career pig barn workers were asked to participate in this study. For this research, a *career pig barn worker* was defined as a full-time worker who derived his or her sole income from working in the barn, spending a minimum of eight hours per workshift inside the pig barn with regular weekly work-shifts (Wenger, 1999a). Employees were excluded from this study if they were maintenance workers, summer students, or worked in more than one defined specialty area in the barn. Each participating pig farm was contacted prior to the farm visit to obtain current number and first names of specialty workers in each of four specialty areas in the barn, Dry

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Sow/Breeding, Farrowing, Nursery, and Grower/Finisher, and to obtain information on the work schedules of these workers. Prior to each farm visit, one worker from each of the Dry Sow/Breeding, Farrowing and Grower/Finisher specialty areas was randomly selected to wear a Personal Environmental Sampling Backpack (PESB II). An additional worker was randomly selected from among these same specialty areas to wear the fourth PESB II, except in barns which had specialty Nursery workers. In such instances, a Nursery worker was randomly assigned to wear a PESB II. On arrival at the farm, the study was explained to the workers, and they were invited to participate. If a participating worker either declined further participation or was away on subsequent days, another worker from the same barn and specialty area was recruited to the study. Written informed consent was obtained from all of the participating workers.

The number of workers who worked exclusively in the Nursery area were too small to evaluate on their own (3 workers in winter and 2 workers in summer), and approximately half of the workers who were responsible for the Nursery area, were also responsible for the Grower area or the combined Grower/Finisher areas (47% in winter and 57% in summer). This made it impossible to separate out only the Grower/Finisher exposures for these workers. For these reasons, the Nursery area and Grower/Finisher areas, were combined into one specialty area for this study.

3.2.4 Data Collection

3.2.4.1 The team

The field team was comprised of the project manager (IIW), two full-time

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assistants, and an agricultural engineer (CA Ouellette) who calibrated and maintained the equipment in the field. The trained observers (project manager and assistants) were present for all winter and summer data collection sessions to ensure quality and consistency of data collection. All aspects of this study were in compliance with biosecurity and farm entry protocols (Appendix 3.3) and equipment cleaning and disinfection protocols (Appendix 3.4).

3.2.4.2 **Monitoring Equipment**

Personal sampling for airborne constituents was accomplished with four second generation Personal Environmental Sampling Backpacks (PESB II). Modifications were made to the first generation PESB equipment, described by Ouellette et al. (1999), based on results and recommendations from the pig barn worker pilot study (Wenger, 1999a). The real-time monitoring equipment contained in the PESB II included a dust particle counter (ABACUS 301, Particle Measuring Systems Inc.), NH_3 and H_2S gas sensors (Toxi-Ultra, Biosystems Inc.), a CO_2 gas sensor (YES-206, Young Environmental Systems Inc.), and RH (MICRO SWITCH, Honeywell Inc.) and dry-bulb temperature sensors (HOBO®, Hoskin Scientific). PESB II equipment specifications are presented in Table 2.1 (Chapter Two).

Calibrations of the NH_3, H_2S and CO_2 sensors were conducted pre- and post-sampling in the field maintenance office, using certified gas mixtures, with 100% nitrogen gas (N_2) as a zero gas and the appropriate concentrations of span gases, balanced with N_2, for the various sensors (9000 ppm, 50 ppm, and 9 ppm, for CO_2, NH_3, and H_2S, respectively). The ABACUS™ 301 dust particle counters were factory calibrated prior to

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the start, and at the end of the study. While in the field, daily meticulous cleaning of the dust sensor chambers was conducted with 99% isopropyl alcohol and canned air to remove sticky pig barn dust. Taylor and Reynolds (2001) also reported the necessity of a similar cleaning of the internal sensing chambers of the ME PDM-3 Miniram to ensure proper operation and to maintain instrument zeros. A record of all equipment malfunctions and equipment repairs was catalogued.

3.2.4.3 **Exposure Monitoring**

During the winter (February to April) and summer (June to August) of 2000, personal contaminant exposures were monitored for 4 pig barn workers in each of the 10 barns, throughout their entire work-shifts (including breaks), over 3 consecutive days of a work week (Tuesday through Thursday). Sampling was not conducted on Mondays and Fridays due to shift changes and scheduled days off. The same 10 farms were visited in the winter and summer. While workers generally wore the PESB IIs themselves, there were occasions, such as working in narrow spaces or when conducting the pressure washing activity, where the Observers were required to wear the instrumentation while following the worker.

All contaminants monitored by the PESB II were from the breathing zone on the right side of the study participants. Barn air drawn from within the worker's breathing zone (through an isokinetic probe[1], affixed to the cloth backpack of the PESB II in a down-ward orientation), passed through all in-line contaminant sensors using a personal

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[1] An isokinetic probe is a device attached to the end of a sampling tube which allows for the capture of a representative sample of particulates from a moving airstream. Isokinetic means that air velocity in the probe is equal to the air velocity approaching the probe's inlet. (Hinds, 1982)

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air sampling pump. The flow rate was calibrated to 2.8 L/min ± 5%, to match the flow rate used in the factory calibration of the dust counter sensors. No pre- and post-flow calibrations were possible on site due to stringent biosecurity restrictions. To compensate, pre- (late the night before) and post-monitoring (late afternoon following) flow rate calibrations were conducted off-site in the field maintenance office by CA Ouellette, the agricultural research engineer. A pack card (one per PESB II per day) was used to record sampling information (Appendix 3.1).

Environmental parameters. The continuous environmental parameters monitored by the PESB II instrumentation included carbon dioxide (CO_2), relative humidity (RH), and indoor barn temperature. Data were stored at 10-s intervals throughout the entire work day. In addition, outdoor temperature was monitored for the duration of each 3-day farm visit using a battery operated weather station that had a Model CR10 Data logger fitted with either a Temperature probe (Model 107, Campbell Scientific, Inc., Logan, UT) (winter) or a custom Type T thermocouple temperature probe (Campbell Scientific Inc., Logan, Utah) (summer). Equipment availability necessitated the change in temperature probe. Temperature data were downloaded at the conclusion of each 3-day farm visit.

Respirable dust counts. Respirable dust counts were stored as continuous data at 10-s intervals throughout the work day, in four cumulative (optical diameter) size fractions: >0.3 µm, >0.5 µm, >1.0 µm (data from this size fraction were used to calculate the 0.5-1.0 µm, and the 1.0-5.0 µm differential size counts), and >5.0 µm.

Respirable dust mass. In addition to dust particle counting, respirable dust was

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collected over the full work shift to determine both the respirable dust mass exposure (mg/m^3), and to quantify the airborne concentrations of respirable endotoxin, measured in endotoxin units per cubic meters of air (EU/m^3). Respirable dust (≤ 10 μm) was collected through a 10-mm Dorr-Oliver nylon cyclone pre-selector (Sensidyne, Clearwater, FL) situated in the breathing zone on the left side of the study participants. The respirable dust was collected on desiccated and pre-weighed 37-mm binder-free, glass-fiber filters with a porosity of 1.0 μm (Type A/E, catalog number 227-7, SKC Inc., Eighty Four, PA), supported by cellulose support pads (SKC Inc., Eighty Four, PA), and housed in two-piece closed-face cassettes which were sealed with a cellulose shrink band. The separate air stream flow for the gravimetric dust collection was controlled using a GilAir II constant flow air sampling pump (Sensidyne, Clearwater, FL) and calibrated for a flow rate of 1.7 L/min ± 5%, following NIOSH Method 0600 for respirable nuisance dust (NIOSH, 1994). In addition to the four sample cassettes, one field blank was transported to each farm and carried around in an outer-zippered pocket of the hiking backpack, by a randomly selected worker, over the full workshift. The blank was used as a check for endotoxin contamination of the glass fiber filters and glass fiber filter loss during post-weighing handling.

Prior to storage, individual endotoxin cassettes were connected via their outlet ends to a desiccant cassette (silica gel) using a 2" piece of flexible vinyl tubing and placed individually in small re-sealable bags. The cassette-desiccant pairs were placed in refrigerators and stored at 4.4°C ± 0.8°C until shipment for analysis. All samples and field blanks collected during the winter and summer portion of the study were shipped

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with freezer packs, via a courier, for analysis. Two shipments were made, one at the conclusion of each seasons' sampling.

Endotoxin analyses. Respirable dust mass and endotoxin analyses were conducted at the Environmental Health Sciences Research Center at the University of Iowa, College of Public Health (Thorne, 2000). All field blanks were included in the analyses. Prior to post-weighing, all glass-fiber filters were brought to equilibrium in a dedicated environmentally controlled weighing room for a minimum of 2 hours. The filters were post-weighed (on the same pre-weighing scale) using a Mettler MT-5 microbalance (Mettler Instruments Corp., Hightstown, NJ) and placed in 50 mL pyrogen-free centrifuge tubes and stored at 4°C until analysis. The filters were then washed in 10 mL pyrogen-free water with 0.05% Tween-20 with moderate shaking for 1 hour. The endotoxin content of the respirable dust was determined using the Kinetic chromogenic assay, Kinetic-QCL (catalog number 50-650U, BioWhittaker, Walkersville, MD), using a 96-well microplate reader (Fisher BioTech, Pittsburgh, PA) and based on EC-6 standard endotoxin. Results were reported as EU/m^3 of air.

Cross-sensitivity of NH_3 with H_2S. In-barn NH_3 and H_2S exposure data (continuous) were stored every 20 s. During the course of the study, the quality of the NH_3 sensors, its response time following exposure and its cross-sensitivity to other in-barn gases, most notably H_2S, were questioned. Of major concern to data validity was the cross-sensitivity reaction that was discovered between the background levels of H_2S present in the pig barn environment and the NH_3 sensors used for NH_3 quantification in this study. This led to erroneous NH_3 readings, especially during higher H_2S exposure

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activities, such as manure removal. In-laboratory tests (Appendix 2.1) were conducted by this research group, and a level of this cross-sensitivity was found to range between 1 to 5 ppm NH_3 for every 1 ppm of H_2S exposure, and was highly dependent on individual sensors. It was not possible to establish a correction factor for the NH_3 data with any degree of confidence. For this reason, no NH_3 results are available from this research.

3.2.4.4 **Data Calculations**

Data were stored by the data logger as numbers of particles per 10 seconds (respirable dust counts), as concentration in parts per million (ppm) (H_2S), and as analog to digital (A/D) readings (CO_2, RH, and barn temperature). All data files were visually inspected for data integrity and missing data. Prior to data calculations, A/D readings were converted to measurement units (Appendix 3.6). Data for CO_2 and H_2S exposures were corrected for zero and span readings using pre- and post-calibration data. H_2S data were graphed and zeros were visually inspected for drift and adjusted if required. Respirable dust count data were transformed to particles/mL concentrations. Additional differential size distributions were calculated by subtracting one cumulative size fraction from another one of interest, yielding three supplemental differential dust count categories: 0.3 to 0.5 μm particles/mL, 0.5 to 1.0 μm particles/mL and 1.0 to 5.0 μm particles/mL. For the purposes of this manuscript, the respirable dust particles of sizes >0.5 μm (not sizes >0.3 μm) will be presented as these represent respirable dust generated within the barn environment (Zhang et al., 1994). All data are presented as a Time-Weighted-Average (TWA) exposures over the full workshift, and were not adjusted to an 8-hour TWA.

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3.2.4.5 **Statistical Analysis**

The exposure data were collected as continuous variables. Frequency histograms were generated for each variable (examples are presented in Appendix 3.9). Data were checked for normality (histograms and geometric standard deviation (GSD)) and were transformed using natural logs, as required, if the GSD for each variable was >1.5 (Perkins, 1997), to achieve a normal distribution. Transformed exposure variables included all the dust count variables (particles/mL), respirable dust mass (mg/m^3), H_2S (ppm), endotoxin (EU/m^3), and stocking density (kg/m^2). Geometric means (GM) and GSDs were calculated (Perkins, 1997). Descriptive statistics were performed on all data to assess the frequency and distribution of the data collected. For continuous data, Pearson *r* correlations were tested (variables are listed in Table 3.5) and results were used for descriptive purposes, for the evaluation of the strength and significance of association among variables, and for the evaluation of variables for subsequent model building. Correlations for the categorical data were tested using the Fisher's Exact method. Characteristics of participating and non-participating barns and workers were compared using a two independent sample t test. Seasonal differences in air contaminant exposures for variables listed in Table 3.4 (winter-summer) were compared using a paired sample t test for workers who had both winter and summer exposure measurements. Career pig barn worker specialty air contaminant exposure differences were tested using one-way ANOVA with Scheffe as the post hoc test (continuous data), and crosstabs with the Fisher's Exact method as the post hoc test (categorical data). To test the statistical differences between personal contaminant exposures and day of visit (Tuesday,

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Wednesday, Thursday), a repeated measures analysis was conducted, using an F test and based on Pillai's statistic. Univariate linear regression analyses, with ln-transformed endotoxin ($lnEU/m^3$), ln-transformed respirable dust mass ($lnmg/m^3$), and ln-transformed H_2S (lnH_2S) as the dependent variables, were conducted to select appropriate exposure and barn management explanatory variables (listed in Tables 3.6, 3.10 and 3.14) for inclusion into subsequent multivariable linear analyses. Decisions for inclusion were based on explanatory variables having a p-value of ≤ 0.20 in the univariate analysis and on biological plausibility. Instead of the traditional step-wise regression analysis, a purposeful multivariable linear analyses was used to develop final predictive models with natural log-transformed endotoxin ($lnEU/m^3$), respirable dust mass ($lnmg/m^3$), and H_2S (lnH_2S) as the outcome variables. The selection of the final best fit models were based on the models with the highest adjusted R^2 value. Variables in the final model were tested for interactions. Regression diagnostics were conducted to test regression assumptions and the fit of the model.

To determine whether ventilation differences by season (CO_2 exposure was used as the proxy for ventilation rate), influenced the seasonal differences in endotoxin, respirable dust mass and H_2S exposures of pig barn workers, the winter and summer data sets were combined into one data set. Repeated measures random effects models (mixed models) using all worker-days of data, were used to analyze the winter-summer data simultaneously. These models allowed for the analysis of unbalanced data (all workers did not work over all 6 possible workshifts). In these models, interactions between season and ventilation rate differences (indicated by CO_2 concentration) were examined.

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Models were fitted for natural log-transformed endotoxin ($\ln EU/m^3$), respirable dust mass ($\ln mg/m^3$) and H_2S ($\ln H_2S$), respectively. The first order autoregressive and compound symmetry covariance structures were considered for the residuals. Univariate repeated random effects models were used to determine the predictor variables initially considered for inclusion in the multivariable models. The fit of each multivariable model was assessed using Akaike's Information Criterion (AICC). Data were analyzed using SPSS, version 12.0 software (SPSS Inc., Chicago, IL), and SAS, version 8e software (SAS Institute Inc., Cary, NC). P-values were considered statistically significant at $p \leq 0.05$.

3.3 RESULTS

3.3.1 Barn characteristics

Eight of the study barns were Farrow-to Finish and two barns were Farrow-to-Wean, one of which had an on-site nursery (Table 3.1). Herd sizes averaged 1310 sows, ranging from 350 to 2400 sows (3500 to 24,000 pigs per barn). The majority of barns had underfloor manure pits with pull-plug manure removal systems. Three study barns had solid flooring in their Grower/Finisher areas. Two of these used a flush system to remove manure from the barn while the third used bedding (wood shavings) and a manual manure removal system. All of the study barns had mechanical (negative pressure) ventilation systems. Hot water heating systems predominated in the majority of the Dry Sow/Breeding and Farrowing specialty areas of the study barns, and were present in just over half of the Nursery/Grower-Finisher areas. Unvented gas-fired unit heaters were utilized in three of the barns to heat the Dry Sow/Breeding area, while two barns and one

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barn, respectively, used this form of heat in the Nursery/Grower-Finisher and Farrowing areas. Two barns utilized either infra-red or electric heaters in the Nursery area. The remaining barn used a pre-heat airspace system throughout, where attic air was pre-heated with a gas-fired unit heater. Four barns had liquid feeding systems, in which either the entire barn, or pigs in at least one specialty area was liquid fed. In the remaining 6, two used pellets/crumbles alone, two predominantly used ground feed throughout, and two used a combination of ground feed and pellets/crumbles. While the majority had continuous flow systems, only two of the study farms incorporated an All-in, All-out animal flow system in the Grower/Finisher area, a system where all pigs are completely removed from the room, the entire room is washed (and in most cases disinfected), then allowed to dry thoroughly before a new batch of pigs is brought back into the room.

3.3.2 **Specialty Work Areas**

There were a number of differences in farm characteristics found among the three specialty work areas (Appendix 3.7 and Appendix 3.8). Significant differences were found for type of flooring ($p<0.0001$), method of feeding ($p<0.01$), animal flow ($p<0.0001$), area washed ($p<0.0001$), and area disinfected ($p<0.0001$).

In the study barns, the Dry Sow/Breeding area consisted of an average of 4 large rooms (range 1 to 8 rooms), which was significantly fewer rooms than found in the Nursery/Grower-Finisher ($p<0.0001$) or Farrowing ($p=0.007$) areas. The animals in the Dry Sow/Breeding area were predominantly fed a ground feed ration via drop-feeding systems. The manure system in this area consisted primarily of manure pits located under partially slatted flooring, and run as continuous flow systems. Pit depths in this area did

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not differ from that of other areas in the barn (p=0.12). Animals in the Dry Sow/Breeding area weighed an average of 190 kg. The stocking density (kg/m^2) was highest in this area of the barn (Table 3.4), and was found to be in compliance with the recommended code of practice guidelines for pigs (Connor, 1993). Stocking density in the Dry Sow/Breeding area was found to be significantly greater than that for the Farrowing area in both seasons. No significant stocking density differences existed between the Dry Sow/Breeding and Nursery/Grower-Finisher areas in either season. In the study barns, rooms in the Dry Sow/Breeding area of the barn were never routinely washed or disinfected.

Sow weights in the Farrowing specialty area averaged 190 kg, while piglet weights ranged from 1.2 to 8 kg. There were significantly greater numbers of animal rooms in this area of the pig barn (9 on average, ranging from 4 to 13) compared with the Dry sow/Breeding area, but significantly fewer rooms than in the Nursery/Grower-Finisher area (p=0.005). Sows in the Farrowing area were predominantly hand-fed a ground feed ration while piglets were predominantly fed a crumble ration. The manure system in this area consisted exclusively of manure pits located under predominantly fully-slatted flooring. The pits were routinely drained every three to four weeks, corresponding to when the rooms were completely vacated, thoroughly washed and then disinfected.

The Nursery/Grower-Finisher area (where pigs ranged in weight from 14 to 110 kg) was shown to have significantly more animal rooms, 15 rooms (range 2 to 27 rooms), than the Farrowing and Dry Sow/Breeding areas (p=0.005 and p=0.007, respectively). In winter, stocking density (kg/m^2) in the Nursery/Grower-Finisher area was not found to be

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significantly different from either the Farrowing or the Dry Sow/Breeding areas (Table 3.4) and was found to be in compliance with the recommended code of practice guidelines for pigs (Connor, 1993). However, in summer, stocking density was found to be significantly greater in the Nursery/Grower-Finisher area than the Farrowing area, but were still within recommended stocking guidelines. Pigs in the Nursery/Grower-Finisher area were predominantly self fed a ground feed ration. The pit manure system was found under partially-slatted flooring, similar to the Dry Sow/Breeding area. Other commonalities observed between the collective Nursery/Grower-Finisher area and the Dry Sow/Breeding area included that rooms were typically run as continuous flow systems with no routine washing or disinfecting of rooms.

3.3.3 Study Participants

The study barns employed a total of 73 career pig barn workers, with an average of 7.3 employees per barn (range 3 to 16 workers). One of the study barns had less than 4 full-time employees due to staffing changes prior to the commencement of the study. Of the 56 randomly selected workers asked to participate in the study (45 winter and an additional 11 in summer), 53 (94.6%) agreed to wear the PESB II, and were enrolled in the study. Eight workers were lost to follow-up between the winter and summer visits (4 were no longer employees of the pig barn; 3 were away on vacation/leave at the time of the visit; and 1 worker declined further participation).

During the winter study, 30 of the 43 study participants, (69.8%) wore the PESB II instrumentation for all three consecutive winter work shifts, while during the summer, 31 out of the 40 study participants (77.5%) wore the instrumentation for all three study

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days. In all, 20 study participants (37.7%) wore the PESB II instrumentation for all 6 study work-shifts. Reasons cited by the 22 workers (13 winter and 9 summer) for not wearing the equipment over the entire 3-day study periods per season included: sick day(s), scheduled day(s) off or vacation (N=10); unwilling to wear the instrumentation for more than one day (N=2); and cover-off workers (N=10). Cover-off workers were specialty pig barn workers from the same study barn, who met the inclusion criteria, were recruited to the study, and were usually from the same specialty work area (70%) as the workers they were replacing. Participating and non-participating workers were similar (Table 3.2).

There were slightly more Dry Sow/Breeding and Nursery/Grower-Finisher workers than Farrowing workers monitored because of the method employed in randomly assigning the fourth PESB II (Table 3.2). There were differences in the gender of workers in the different specialty areas. In the Dry Sow/Breeding specialty area, 12 of the 17 workers (71%). In the Farrowing area, 9 of the 15 workers (60%) were female. In the Nursery/Grower-Finisher area, 14 of the 19 workers (74%) were male. The 5 female workers in this area worked predominantly in the Nursery area. The average age of the study participants was 33.6 years, with 64% of the workers being male. Workers in this study were employed by the individual study barns for an average of 1.6 ± 2.2 years. Seventy-five per cent of the workers were previously employed in intensive pig barns, with an average of 6.6 ± 6.6 years of previous pig barn work experience.

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Table 3.2. Demographics of Workers who wore the PESB II exposure instrumentation (PESB II Wearers) and non-Participating PESB II wearers in the Pig Barn Worker Exposure Study

	PESB II wearers	Non-PESB II wearers
Number of workers	53	3
Age (years) (mean ± SD)	33.6 ± 9.5	36.5 ± 8.9
Gender		
Males	34 (64%)	0
Females	19 (36%)	3 (100%)
Specialty area		
Dry Sow/Breeding	17 (32%)	1 (33%)
Farrowing	15 (28%)	2 (67%)
Nursery, Grower/Finisher	19 (36%)	0
All areas	2 (4%)	0
Bi-weekly work schedule*		
10 d on 4 d off	5 (9%)	0
11 on 3 off	13 (25%)	0
12 on 2 off	6 (11%)	1 (33%)
5 on 2 off	4 (8%)	1 (33%)
12 on 2 off, then 5 on 2 off	4 (8%)	1 (33%)
11 on 3 off, then 5 on 2 off	3 (6%)	0
8 on 2 off, then 2 on 2 off, then 10 on 4 off	5 (9%)	0
Other schedule	13 (25%)	
Years worked in present barn (mean ± SD)	1.6 ± 2.2	0.9 ± 1.4†
Previous job as pig barn worker (N)		
Yes	39 (74%)	2 (67%)
No	14 (26%)	1 (33%)

* Indicates consecutive days worked, followed by consecutive days off

† Two of the three workers had only been working in the present barn for 1 month

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3.3.4 Personal Exposure Monitoring

On average, career pig barn workers' exposures were monitored in this study for 9.3 ± 0.6 h per day.

3.3.4.1 Environmental Parameters

Outdoor Temperature. The average outdoor temperature during the winter portion of the study was considerably lower than that for summer ($p<0.0001$) (Table 3.3). Outdoor temperatures were moderately and significantly positively correlated with barn temperature during the winter ($r=0.54$, $p \leq 0.001$) and summer ($r=0.66$, $p \leq 0.001$) (Table 3.5).

Barn Temperature. As seen in Table 3.3, barn temperatures averaged 20.2 °C in winter and 23.1 °C in the summer, with an overall highly significant difference found between seasons ($p<0.0001$). A trend to specialty worker barn temperature exposure differences were observed between the Farrowing and Nursery/Grower-Finisher areas in the winter season ($p=0.06$), with the Nursery/Grower-Finisher area exhibiting slightly cooler temperatures (Table 3.4). There were no differences found in barn temperatures by sampling day in either winter ($p=0.18$) or summer ($p=0.50$).

Carbon Dioxide. Overall, CO_2 concentrations were the highest during the winter and the lowest during the summer ($p \leq 0.0001$), as expected by the higher ventilation in the summer (Table 3.3). A slightly higher degree of variability in CO_2 exposure was found for workers during the winter months, when compared to the summer, likely as a result of a greater range of ventilation rates during winter than summer among the different

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Table 3.3. Overall Personal Contaminant Exposures and Stocking Density Comparisons of Career Pig Barn Workers in Winter and Summer in Alberta

Pig Barn Contaminants (including stocking density)	Winter mean ± SD	Summer mean ± SD	Statistical significance[B]
N	43	37	
Environmental parameters			
OutdoorT[C] (°C)	4.1 ± 6.6	17.3 ± 1.9	$p<0.0001$
BarnT (°C)	20.2 ± 1.6	23.1 ± 1.4	$p<0.0001$
CO_2 (ppm)	1657 ± 340	975 ± 202	$p<0.0001$
RH (%)	48 ± 7	51 ± 8	$p=0.025$
[A]**Respirable Dust**			
>0.5 μm particles/mL	20.5 ± 1.5	12.5 ± 1.7	$p=0.001$
0.5-1.0 μm particles/mL	10.2 ± 1.7	6.2 ± 2.1	$p=0.011$
1.0-5.0 μm particles/mL	8.0 ± 1.5	4.9 ± 1.5	$p<0.0001$
>5.0 μm particles/mL	1.7 ± 1.8	0.9 ± 1.6	$p<0.0001$
Dust mass (mg/m^3)	0.26 ± 1.8	0.23 ± 2.0	$p=0.22$
[A]**Endotoxin**			
EU/m^3	395 ± 1.8	185 ± 2.3	$p<0.0001$
[A]**Gases**			
H_2S (ppm)	0.6 ± 2.0	0.5 ± 1.7	$p=0.23$
[A]**Stocking density (kg/m^2)**	50.9 ± 1.7	52.6 ± 1.6	$p=0.45$

[A] Variables were not normally distributed and were therefore ln-transformed. Results are presented as geometric mean ± geometric standard deviation

[B] Statistical difference, paired t test, between winter and summer exposures are based on 27 matched winter-summer worker pairs

[*]Statistical significance $p\leq0.01$; [†]Statistical significance $p\leq0.05$; [‡] Statistical significance $p\leq0.10$

[C] Outdoor temperature for the winter excludes the temperatures of the visit to the first barn (N=3) due to equipment un-availability

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Table 3.4. Comparison of environmental parameters, H_2S, stocking density, dust particle counts, dust mass, and endotoxin exposures by specialty pig barn workers across winter and summer seasons

Contaminant	Dry Sow/Breed	Farrowing	Nursery,Grow/Finish	Significance[B]
Winter: N	16 mean ± SD	12 mean ± SD	15 mean ± SD	
Barn Temperature (°C)	20.0 ± 1.6	21.1 ± 1.1	19.8 ± 1.7	p=0.06 (F-N‡)
CO_2 gas (ppm)	1758 ± 373	1483 ± 264	1690 ± 323	p=0.09 (F-D‡)
Relative Humidity (%)	48 ± 7	42 ± 5	52 ± 6	p= 0.0001 (F-N*; F-D‡)
H_2S gas[A] (ppm)	0.6 ± 2.1	0.7 ± 1.9	0.6 ± 1.9	p=0.45
Stocking density[A] (kg/m²)	69.3 ± 1.6	34.0 ± 1.4	50.7 ± 1.8	p=0.001 (D-F**)
>0.5 μm particles/mL[A]	21.6 ± 1.4	17.3 ± 1.7	22.1 ± 1.4	p=0.36
0.5-1.0 μm particles/mL[A]	11.0 ± 1.6	9.2 ± 1.9	10.3 ± 1.6	p=0.82
1.0-5.0 μm particles/mL[A]	8.5 ± 1.4	6.5 ± 1.6	9.1 ± 1.3	p=0.08 (F-N‡)
>5.0 μm particles/mL[A]	1.8 ± 1.7	1.2 ± 2.0	2.2 ± 1.5	p=0.057 (F-N†)
Dust mass (mg/m³)[A]	0.28 ± 1.8	0.19 ± 1.5	0.32 ± 1.9	p=0.044 (F-N‡)
[A] EU/m³	341 ± 2.2	314 ± 2.3	556 ± 2.3	p=0.83
Summer: N	13	10	14	
Barn Temperature (°C)	23.1 ± 1.1	23.6 ± 1.0	22.9 ± 1.9	p=0.52
CO_2 gas (ppm)	921 ± 147	974 ± 214	1026 ± 235	p=0.41
Relative Humidity (%)	49 ± 10	48 ± 6	55 ± 6	p=0.036 (D-N‡; F-N‡)
H_2S gas[A] (ppm)	0.4 ± 1.5	0.2 ± 1.9	0.3 ± 2.0	p=0.16
Stocking density[A] (kg/m²)	72.0 ± 1.5	32.8 ± 1.4	55.1 ± 1.6	p<0.0001 (D-F**; F-N†)
>0.5 μm particles/mL[A]	11.9 ± 1.5	11.2 ± 1.7	14.1 ± 1.9	p = 0.55
0.5-1.0 μm particles/mL[A]	5.9 ± 1.9	6.2 ± 2.1	6.7 ± 2.3	p = 0.91
1.0-5.0 μm particles/mL[A]	4.8 ± 1.3	4.1 ± 1.5	5.6 ± 1.5	p = 0.14
>5.0 μm particles/mL[A]	0.9 ± 1.4	0.6 ± 1.0	1.2 ± 1.8	p = 0.001 (F-N*)
Dust mass (mg/m³)[A]	0.23 ± 1.7	0.15 ± 1.9	0.32 ± 2.0	p = 0.025 (F-N†)
[A] EU/m³	184 ± 2.1	101 ± 2.1	288 ± 2.1	p = 0.006 (F-N*)

[A] This variable was not normally distributed and therefore ln-transformed. Results are presented as geometric mean ± geometric standard deviation. [B] Statistical difference between specialty worker groups where F-N depicts a difference between FA and N/GF workers and F-D depicts a difference between FA and DS/B workers. ** Statistical significance p≤0.001; † Statistical significance p≤0.05; ‡ Statistical significance p≤0.10

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Table 3.5. Pearson correlations for environmental and contaminant exposures in winter and summer

	OT	BT	RH	CO_2	KG[A]	>pt5[A]	51[A]	15[A]	>5[A]	[A]mg/m^3	[A]EUm^3	[A]H_2S
Winter:												
Outdoor temp (OT)	1.00											
Indoor temp (BT)	.54**	1.00										
R. Humidity (RH)	-.27	-.48**	1.00									
CO_2 gas (CO_2)	-.46*	-.11	.56**	1.00								
kg/m^2 (KG)	.12	-.13	.22	.04	1.00							
>0.5 cmL (>pt5)	.15	-.01	.35†	.38†	.44*	1.00						
0.5-1.0 cmL (51)	.35†	.16	.21	.20	.48**	.93**	1.00					
1.0-5.0 cmL (15)	-.09	-.25	.46*	.49*	.30‡	.89**	.67**	1.00				
>5.0 cmL (>5)	-.21	-.29‡	.26‡	.34†	.30†	.51**	.21	.72**	1.00			
Gravimetric (mg/m^3)	-.03	-.45*	.22	-.02	.43*	.38†	.29‡	.40*	.33†	1.00		
EU/m^3 (EUm^3)	-.43*	-.49**	.52**	.31†	.04	.23	.09	.35†	.33†	.12	1.00	
H_2S gas (H_2S)	-.18	.24	.13	.41*	.12	.37†	.31†	.34†	.22	-.04	-.01	1.00
Summer:												
Outdoor temp (OT)	1.00											
Indoor temp (BT)	.66**	1.00										
R. Humidity (RH)	.004	.21	1.00									
CO_2 gas (CO_2)	-.32‡	-.01	.37†	1.00								
kg/m^2 (KG)	-.21	-.04	.07	-.01	1.00							
>0.5 cmL (>pt5)	-.36†	-.09	.32‡	.27	.27	1.00						
0.5-1.0 cmL (51)	-.27	.05	.30‡	.27	.28	.95**	1.00					
1.0-5.0 cmL (15)	-.34†	-.27	.31‡	.22	.18	.84**	.67**	1.00				
>5.0 cmL (>5)	-.32‡	-.40†	.07	-.04	.13	.21	-.03	.48*	1.00			
Gravimetric (mgm^3)	-.44*	-.34†	.27	.14	.27	.45*	.30‡	.56**	.30‡	1.00		
EU/m^3 (EUm^3)	-.05	-.18	-.19	-.24	.08	-.002	-.19	.29‡	.58**	.20	1.00	
H_2S gas (H_2S)	-.29‡	-.27	.08	.14	-.05	.39†	.37†	.41†	-.15	.32‡	-.05	1.00

[A] Indicates continuous variables that were ln-transformed prior to analysis
cmL stands for dust counts per mL of barn air
** Significance $p \leq 0.001$; * Significance $p \leq 0.01$; † Significance $p \leq 0.05$; ‡ Significance $p \leq 0.10$

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specialty areas of the barns. CO_2 was also significantly negatively associated with outdoor temperature in winter (r=-0.46, p≤0.01) (Table 3.5). There were no differences in CO_2 exposures by sampling day in either winter (p=0.96) or summer (p=0.36).

Relative Humidity. Overall, RH exposures among pig barn workers monitored for this study were significantly lower during the winter compared to the summer (p=0.03) (Table 3.3). Among worker specialties during the winter (Table 3.4), a difference was found between the Nursery/Grower-Finisher workers and the Farrowing workers, whereby Nursery/Grower-Finisher workers were exposed to significantly higher RH than their counterpart workers (p<0.0001). Furthermore, a trend toward significance was noted between Farrowing and Dry Sow/Breeding workers (p≤0.10). In the summer, while an overall significant difference was still found to exist among specialty workers (p=0.036), only a trend to a difference was found between Dry Sow/Breeding and Nursery/Grower-Finisher workers (p≤0.10) and between Farrowing and Nursery/Grower-Finisher workers (p≤0.10). RH exposures were seen to be more variable within the Dry Sow/Breeding specialty, particularly in the summer, when compared to the other worker specialties. A significant positive correlation was found between RH and CO_2 for winter only (r=0.56, p≤0.001) (Table 3.5). For winter, there were no RH differences found by sampling day (p=0.51). However, in summer, a borderline difference was found between the sampling days of Tuesday, Wednesday, and Thursday in the study barns (p=0.051). Further analysis showed that there was a trend towards slightly higher RH on Tuesday relative to Wednesday (p=0.06).

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3.3.4.2 **Respirable Dust**

Respirable Dust Counts. Overall, for both winter and summer (Table 3.3), dust concentrations were seen to decrease with increasing aerodynamic diameter. Further, dust concentrations were found to be higher in winter than in summer, with significant differences found between seasons. The smallest contributions to the cumulative dust particle concentration of >0.5 μm/mL were dust particles in the >5.0 μm size fraction. Dust exposures vary throughout the work shift, depending on the work task undertaken. When exposures among worker specialties were evaluated (Table 3.4), significant differences were only found for the largest aerodynamic dust particle size, >5.0 μm particles/mL in the summer, where Nursery/Grower-Finisher workers were significantly higher exposed than Farrowing workers ($p \leq 0.01$). No day differences were found for any of the dust count variables in this investigation in either winter or summer.

In general, dust count data for the different dust size fractions were found to be moderately to very strongly and significantly correlated with one another (Table 3.5). The exception for both seasons was the weak and non-significant associations found between the particle size distributions of 0.5-1.0 μm and >5.0 μm, in winter and summer.

Respirable Dust Mass. A total of 300 glass fiber filters from the winter and summer were post-weighed following full workshift sampling, prior to endotoxin evaluation, to determine respirable dust exposure. Of these, 60 (20%) were submitted as field blanks, and 240 as field samples. Non-detects, likely due to a combination of the small amounts of dust collected on the filter and excessive filter loss during the post-weighing procedure, represented 3% (N=9) of the field samples collected during the

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winter and summer exposure study.

The exposure to respirable dust (Table 3.3) was found to be highest in winter compared to summer, results which were consistent with those observed using real-time particle counting. However, these differences were not found to be significantly different between seasons ($p=0.22$). Significant dust mass exposure differences were observed among the three worker specialties however (Table 3.4) in winter ($p=0.044$) and in summer ($p=0.025$). For both seasons, workers in the Nursery/Grower-Finisher areas were the highest exposed, while those in the Farrowing areas were the lowest exposed to respirable dust. In winter, a significant sampling day exposure difference ($p=0.04$) was found for respirable dust mass for Nursery/Grower-Finisher workers between the Tuesday and Thursday sampling days.

3.3.4.3 **Respirable Endotoxin**

During the winter, career pig barn workers were found to be exposed to significantly higher respirable endotoxin than during the summer ($p<0.0001$) (Table 3.3). Exposures were found to be the lowest overall for Farrowing workers when compared with the other pig barn worker specialties. These differences among worker specialities were only found during summer between the Farrowing and Nursery/Grower-Finisher workers ($p\leq0.01$) (Table 3.4). Exposures to endotoxin were found to have a strong and highly positive correlation with RH ($r=0.52$, $p<0.0001$) during the winter season, with a negative low, but non-significant correlation found between these two variables in summer ($r=-0.19$) (Table 3.5). A similar relationship was found for outdoor temperature and endotoxin, whereby a moderately negative correlation was found between these two

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variables, in the winter season only (r=-0.43, $p \leq 0.01$). These correlations suggest that a higher RH and a lower outdoor temperature contribute to the higher endotoxin exposures seen among pig barn workers in this study in the winter season. A significant sampling day difference was found for endotoxin in winter (p=0.04) for Nursery/Grower-Finisher workers. This difference was found between the Tuesday and Thursday sampling days, corresponding to the particulate sampling day differences reported previously.

3.3.4.4 **In-barn Gas Exposures**

H_2S. On average, workers in this study were found to be exposed to average H_2S concentrations of <1.0 ppm over the workshift (Table 3.3). No differences were observed in H_2S exposures between the winter and summer seasons (p=0.23). Furthermore, no differences were observed in H_2S exposures among worker specialties in either winter (p=0.45) or summer (p=0.16) (Table 3.4). No differences were found in average H_2S exposures among day of visit in either winter (p=0.22) or summer (p=0.15). Peak exposures to H_2S among this cohort of pig barn workers ranged from 0.1 ppm (the limit of detection of the H_2S monitor) in both seasons, to a high of 94 ppm in the winter (N=1 worker), and a high of >100 ppm (the upper detection limit of the monitoring equipment) in summer (N=1 worker). In general, peak exposures to H_2S were lower in summer than in winter. In winter, there were no differences observed in peak H_2S exposures of workers by day of visit (p=0.22). However, in summer, a significant difference was found between visits on Tuesday and Thursday (higher peak exposures), when compared to Wednesday (p=0.003). During the winter, 28% (N=12) of the workers were exposed to H_2S at concentrations greater than 20 ppm during the three day study period. This

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exceeds the present Alberta Government established ceiling limit for H_2S exposure (Alberta Human Resources and Employment, 2002). During the summer, 22% (N=8) of the workers were exposed to H_2S concentrations exceeding 20 ppm. Individual workers from all specialties conducted manure removal tasks as part of their regular barn work routines, hence high peak exposures were seen among all worker specialties.

3.3.4.5 **Multivariable Analyses**

Multivariable regression analyses were conducted to develop predictive models for career pig barn workers' exposures to natural log-transformed endotoxin ($lnEU/m^3$), respirable dust mass ($lnmg/m^3$) and H_2S (lnH_2S), for both winter and summer. Both continuous variables and categorical variables were regressed individually on endotoxin ($lnEU/m^3$) (Table 3.6), respirable dust mass ($lnmg/m^3$) (Table 3.10), and H_2S (lnH_2S) (Table 3.14), and those that had a p-value ≤ 0.20 were included in the respective multivariable models.

Repeated measures random effects models (mixed models) utilizing all worker-days of data, were used to analyze the winter/summer data simultaneously. Univariate repeated measures random effects models were used to determine the predictor variables initially considered for inclusion in the multivariable models. Both continuous and categorical variables were regressed individually on endotoxin ($lnEU/m^3$) (Table 3.8), respirable dust mass ($lnmg/m^3$) (Table 3.12), and H_2S (lnH_2S) (Table 3.16). Those variables that had a p-value ≤ 0.20 were included in the respective random effects (mixed) models.

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Endotoxin. (Multivariable regression analysis)

Winter. The final predictive model for workers' winter exposures to endotoxin included flooring type, relative humidity and feeding method. Interactions between the predictors in the final multivariable model were tested and none were found to be significant. The model explained 63% of the variance (Table 3.7). After controlling for relative humidity and feeding method, solid flooring contributed to a significantly higher endotoxin exposure when compared with fully slatted flooring (Table 3.7). No differences were observed between partially and fully slatted flooring. Furthermore, both drop and self feeding contributed to significantly higher endotoxin exposures, when compared with liquid feeding, after controlling for RH and flooring type.

Summer. The final predictive model for workers' exposures to endotoxin in the summer season included the concentration of dust particles in the size fraction >5.0 μm and flooring type. Interactions between the predictors in the final multivariable model were tested and none were found to be significant. The model explained 54% of the variance (Table 3.7). After controlling for >5.0 μm dust particles/mL, solid flooring was found to contribute to significantly higher endotoxin exposures when compared with fully slatted flooring ($p<0.0001$).

Endotoxin (Repeated measures random effects models)

Winter/summer seasons combined. The final predictive model for workers' exposures to endotoxin in the combined winter/summer data included CO_2, season, flooring type, feeding method, and season*CO_2 (Table 3.9). A significant season by CO_2 interaction was found ($p=0.03$), indicating that CO_2 (a measure of barn ventilation)

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contributed to seasonal differences in the endotoxin exposures of pig barn workers in this study.

Respirable dust mass concentration (Multivariable regression analysis)

Winter. The final predictive model for workers' winter exposures to respirable dust mass concentration (mg/m^3) included indoor barn temperature and stocking density. Interactions between the predictors in the final multivariable model were tested and none were found to be significant. The model explained 30% of the variance (Table 3.11). After controlling for barn temperature, stocking density contributed to significantly higher respirable dust mass concentration (mg/m^3) exposures (Table 3.11).

Summer. The final predictive model for workers' exposures to respirable dust mass concentration (mg/m^3) in the summer season, only included the variable barn temperature. The model explained 9% of the variance (Table 3.11). The model shows that a decrease in barn temperature was associated with an increase in respirable dust mass exposure.

Respirable dust mass (Repeated measures random effects models)

Winter/summer seasons combined. The final predictive model for workers' exposures to respirable dust mass in the combined winter/summer data included barn temperature and stocking density (Table 3.13). No significant season by CO_2 interaction was found, indicating that CO_2 (a measure of barn ventilation) did not contribute to seasonal differences in the respirable dust mass exposures of pig barn workers in this study.

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H_2S (Multivariable regression analysis)

Winter. The final predictive model for workers' winter exposures to H_2S included carbon dioxide, flooring type and feeding method. Interactions between the predictors in the final multivariable model were tested and none were found to be significant. The model explained 55% of the variance (Table 3.15). After controlling for CO_2 and feeding method, solid flooring contributed to significantly lower H_2S exposures when compared to fully slatted flooring. No differences were observed between partially and fully slatted flooring. Both drop feeding and self feeding contributed to significantly higher H_2S exposures, after controlling for CO_2 and flooring type.

Summer. No predictive model was developed for workers' summer exposures to H_2S. This is because none of the barn management variables were found to be significant predictor variables for this contaminant in summer (Table 3.14).

H_2S (Repeated measures random effects models)

Winter/summer seasons combined. The final predictive model for workers' exposures to H_2S in the combined winter/summer data included CO_2, season, flooring type, and season*CO_2 (Table 3.17). A significant season by CO_2 interaction was found ($p=0.04$), indicating that CO_2 (a measure of barn ventilation) contributed to seasonal differences in the H_2S exposures of pig barn workers in this study.

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Table 3.6. Winter and summer continuous and categorical variables considered for multiple regression analysis to develop a predictive model of career pig barn worker's exposures to natural log-transformed endotoxin

	Winter (N=43)			Summer (N=37)		
Continuous Variables	β	SE	p-value	β	SE	p-value
Barn temperature	-.26	0.07	0.001	-.105	0.10	0.28
CO_2	9.67E-05	.000	0.66	-9.95E-04	0.001	0.15
RH	5.96E-02	0.02	<0.0001	-1.96E-02	0.12	0.26
Stocking density (kg/m^2)[A]	6.42E-02	0.24	0.79	.14	0.28	0.62
> 0.5 µm particles/mL[A]	0.47	0.31	0.14	-2.87E-03	0.27	0.99
0.5-1.0 µm particles/mL[A]	0.14	0.25	0.59	-.21	0.19	0.27
1.0-5.0 µm particles/mL[A]	0.75	0.32	0.023	.62	0.35	0.09
> 5.0 µm particles/mL[A]	0.47	0.21	0.032	.99	0.24	<0.0001
Gravimetric dust (mg/m^3)[A]	0.17	0.22	0.45	.24	0.20	0.24
H_2S[A]	-1.22E-02	0.19	0.95	-8.30	0.27	0.76
Categorical Variables	β	SE	p-value	β	SE	p-value
Type of manure system			0.032		0.41	0.037
No Pit	1.03	0.38	0.009	1.09	0.79	0.012
Both pit and no pit	8.95E-02	0.80	0.91	-.22	-	0.78
Pit[a]	-	-	-	-		-
Flooring type			0.001			<0.0001
Solid	1.58	0.46	0.001	1.90	0.44	<0.0001
Partially slatted	-.22	0.24	0.35	.60	0.24	0.020
Fully slatted[a]	-	-	-	-	-	-
Animal flow			0.80			0.51
Continuous	0.18	0.27	0.51	.27	0.29	0.36
Both continuous & AIAO	4.69E-02	0.53	0.93	.46	0.47	0.33
All-in, All-out (AIAO)[a]	-	-	-	-	-	-
Method of feeding			<0.0001			0.06
Drop/hand	0.82	0.26	0.003	7.71E-02	0.35	0.83
Self	1.43	0.30	<0.0001	.74	0.37	0.05
Liquid[a]	-	-	-	-	-	-
Feed type			0.001			0.42
Ground	0.97	0.28	0.001	.46	0.37	0.23
Pellets/crumbles	1.10	0.31	0.001	.18	0.40	0.66
Liquid[a]	-	-	-	-	-	
Area washed			0.58			0.20
No	5.83E-02	0.28	0.83	.41	0.29	0.16
No and yes	-.38	0.43	0.38	.68	0.42	0.12
Yes[a]	-	-	-	-	-	-
Area disinfected			0.55			0.21
No	0.11	0.28	0.70	.40	0.29	0.17
No and yes	-.35	0.43	0.42	.69	0.42	0.12
Yes[a]	-	-	-	-	-	-

Results presented in this table are from a univariate regression analysis; [a] indicates reference value

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Table 3.7. Multivariable predictors of natural log-transformed endotoxin exposures of pig barn workers in winter and summer*

Winter				Summer			
Variable	Regression Coefficient	SE[b]	p-value	**Variable**	Regression Coefficient	SE[b]	p-value
Intercept	3.59	0.56	<0.0001	Intercept	5.0	0.18	<0.0001
Flooring type			<0.0001	> 5.0 µm dust counts / mL	.84	0.21	<0.0001
Solid flooring	1.18	0.33	0.001				
Partially slatted flooring	-.32	0.18	0.09	Flooring type			0.001
Fully slatted flooring[a]	-	-	-	Solid flooring	1.60	0.37	<0.0001
				Partially slatted flooring	.29	.22	0.19
Relative Humidity	.04	.01	0.002	Fully slatted flooring[a]	-	-	-
Feeding Method			0.002				
Drop/hand feeding	.56	.20	0.009				
Self feeding	.95	.24	<0.0001				
Liquid feeding[a]	-	-	-				

* Results presented in this table are from a multiple regression analysis of the Winter and Summer data, respectively. The adjusted R^2 for the Winter model=63.3%, and for the Summer model=54.1%.

[a] Indicates reference category

[b] SE = Standard Error

Table 3.8. Continuous and categorical variables from random effects models considered for inclusion in the combined winter/summer multivariable model to determine whether CO_2 (a measure of barn ventilation) contributed to seasonal differences in career pig barn worker's exposures to natural log-transformed endotoxin

Continuous Variables	β	SE	p-value
Barn temperature	-.15	0.03	<0.0001
CO_2	7.45E-04	.000	<0.0001
RH	6.77E-03	0.009	0.45
Stocking density (kg/m^2)[A]	.32	0.20	0.12
> 0.5 μm particles/mL[A]	.79	0.31	<0.0001
> 5.0 μm particles/mL[A]	.77	0.09	<0.0001
Gravimetric dust (mg/m^3)[A]	.20	0.09	0.03
Categorical Variables	**β**	**SE**	**p-value**
Type of manure system			0.005
No Pit	1.16	0.33	0.001
Both pit and no pit	.03	0.65	0.97
Pit[a]	-	-	-
Flooring type			<0.0001
Solid	1.82	0.38	<0.0001
Partially slatted	.27	0.20	0.19
Fully slatted[a]	-	-	-
Animal flow			0.39
Continuous	.30	0.23	0.20
Both continuous & AIAO	.36	0.41	0.39
All-in, All-out (AIAO)[a]	-	-	-
Method of feeding			<0.0001
Drop/hand	.50	0.25	0.05
Self	1.14	0.28	<0.0001
Liquid[a]	-	-	-
Feed type			0.02
Ground	.76	0.27	0.008
Pellets/crumbles	.69	0.29	0.02
Liquid[a]	-	-	-
Area washed			0.51
No	.28	0.24	0.25
No and yes	.19	0.36	0.60
Yes[a]	-	-	-
Area disinfected			0.45
No	.31	0.24	0.21
No and yes	.21	0.36	0.56
Yes[a]	-	-	-
Season			<0.0001
Winter	.73	0.13	<0.0001
Summer[a]	-	-	-

Results presented in this table are from a univariate regression analysis; [a] indicates reference value

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Table 3.9. Multivariable predictors from repeated random effects model of natural log-transformed endotoxin exposures of pig barn workers in combined winter/summer data

Variable	Regression Coefficient	SE[b]	p-value
Intercept	4.85	0.42	<0.0001
CO_2	-4.04E-04	0.0004	0.26
Season			0.36
Winter	-.45	0.49	0.36
Summer[a]	-	-	-
Flooring type			<0.0001
Solid flooring	1.69	0.27	<0.0001
Partially slatted flooring	.16	0.15	0.29
Fully slatted flooring[a]	-	-	-
Feeding Method			<0.0001
Drop/hand feeding	.24	0.18	0.18
Self feeding	.98	0.19	<0.0001
Liquid feeding[a]	-	-	-
Season * CO_2			0.03
Winter * CO_2	9.23E-04	0.0004	0.03
Summer * CO_2[a]	-	-	-

[a] Indicates reference category
[b] SE = Standard Error

Table 3.10. Winter and summer continuous and categorical variables considered for multiple regression analysis to develop a predictive model of career pig barn worker's exposures to natural log-transformed respirable dust

	Winter (N=43)			Summer (N=37)		
Continuous Variables	β	SE	p-value	β	SE	p-value
Barn temperature	-.17	0.05	0.003	-.16	0.08	0.040
CO_2	-3.46E-05	0.000	0.90	4.72E-04	0.001	0.41
RH	1.79E-02	0.12	0.15	2.30E-02	0.014	0.10
Stocking density (kg/m^2)[A]	.46	0.15	0.004	.37	0.22	0.10
Endotoxin units (EU/m^3)[A]	8.43E-02	0.11	0.45	.16	0.14	0.24
Number of rooms	-8.58E-03	0.02	0.56	2.52E-02	0.018	0.16
Manure pit depth	5.22E-03	0.003	0.11	-3.89E-03	0.005	0.40
Categorical Variables	β	SE	p-value	β	SE	p-value
Type of manure system			0.50			0.10
No pit	.26	0.28	0.37	.27	0.34	0.44
Both pit and no pit	.49	0.60	0.42	1.39	0.66	0.043
Pit[a]	-	-	-	-	-	-
Flooring type			0.018			0.13
Solid	.40	0.35	0.26	.23	0.42	0.59
Partially slatted	.54	0.18	0.005	.48	0.24	0.048
Fully slatted[a]	-	-	-	-	-	-
Animal flow			0.13			0.044
Continuous	.37	0.18	0.048	.28	0.22	0.22
Both continuous & AIAO	.31	0.36	0.40	.92	0.36	0.014
All-in, All-out (AIAO)[a]	-	-	-	-	-	-
Method of feeding			0.48			0.10
Drop/hand	-.16	0.23	0.48	.15	0.29	0.61
Self	9.20E-02	0.26	0.73	.60	0.31	0.06
Liquid[a]	-	-	-	-	-	-
Feed type			0.93			0.17
Ground	-6.88E-02	0.23	0.77	.18	0.29	0.55
Pellets/crumbles	-9.30E-02	0.25	0.72	.56	0.31	0.09
Liquid[a]	-	-	-	-	-	-
Area washed			0.07			0.19
No	.43	0.19	0.025	.24	0.23	0.32
No and yes	.38	0.29	0.19	.63	0.34	0.07
Yes[a]	-	-	-	-	-	-
Area disinfected			0.07			0.07
No	.43	0.19	0.027	.40	0.23	0.09
No and yes	.39	0.29	0.18	.73	0.34	0.037
Yes[a]	-	-	-	-	-	-

Results presented in this table are from a univariate regression analysis; [a] indicates reference value

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Table 3.11. Multivariable predictors of natural log-transformed respirable dust mass exposures of pig barn workers in winter and summer*

Winter (N=43)				Summer (N=37)			
Variable	Regression Coefficient	SE[b]	p-value	**Variable**	Regression Coefficient	SE[b]	p-value
Intercept	6.54E-02	1.2	0.96	Intercept	2.25	1.74	0.21
Indoor temperature	-.15	0.05	0.004	Indoor temperature	-.16	0.08	0.04
Stocking density	.41	0.14	0.006				

* Results presented in this table are from a multiple regression analysis of the Winter and Summer data, respectively. The adjusted R^2 for the Winter model=30%, and for the summer model=9%.

[a] Indicates reference category

[b] SE = Standard Error

Table 3.12. Continuous and categorical variables from random effects models considered for inclusion in the combined winter/summer multivariable model to determine whether CO_2 (a measure of barn ventilation) contributed to seasonal differences in career pig barn worker's exposures to natural log-transformed respirable dust

Continuous Variables	β	SE	p-value
Barn temperature	-.07	0.02	0.002
CO_2	2.66E-04	0.000	0.018
RH	.02	0.006	0.003
Stocking density (kg/m^2)[A]	.38	0.12	0.003
Categorical Variables	**β**	**SE**	**p-value**
Type of manure system			0.05
No pit	.34	0.23	0.15
Both pit and no pit	.97	0.45	0.04
Pit[a]	-	-	-
Flooring type			0.008
Solid	.37	0.28	0.20
Partially slatted	.47	0.15	0.002
Fully slatted[a]	-	-	-
Animal flow			0.04
Continuous	.25	0.14	0.09
Both continuous & AIAO	.60	0.26	0.02
All-in, All-out (AIAO)[a]	-	-	-
Method of feeding			0.024
Drop/hand	-.09	0.17	0.60
Self	.34	0.19	0.08
Liquid[a]	-	-	-
Feed type			0.82
Ground	.02	0.19	0.91
Pellets/crumbles	.11	0.20	0.58
Liquid[a]	-	-	-
Area washed			0.06
No	.27	0.15	0.08
No and yes	.49	0.22	0.03
Yes[a]	-	-	-
Area disinfected			0.03
No	.31	0.15	0.04
No and yes	.53	0.22	0.02
Yes[a]	-	-	-
Season			0.13
Winter	.15	0.10	0.13
Summer[a]	-	-	-

Results presented in this table are from a univariate regression analysis; [a] indicates reference value

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Table 3.13. Multivariable predictors from repeated random effects models of natural log-transformed respirable dust exposures of career pig barn workers in the combined winter/summer data

Variable	Regression Coefficient	SE[b]	p-value
Intercept	-1.39	0.67	0.04
Barn temperature	-.07	0.02	0.001
Stocking density (lnkg/m^2)	.38	0.11	0.002

[b] SE = Standard Error

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Table 3.14. Winter and summer continuous and categorical variables considered for multiple regression analysis to develop a predictive model of pig barn worker's exposures to natural log-transformed H_2S

	Winter			Summer		
Continuous Variables	β	SE	p-value	β	SE	p-value
Barn temperature	.10	0.07	0.13	-.10	0.06	0.10
CO_2	8.21E-04	0.000	0.006	3.59E-04	0.000	0.42
RH	1.16E-02	0.01	0.42	5.27E-03	0.01	0.64
Stocking density (kg/m^2)[A]	.16	0.19	0.43	-5.51E-02	0.18	0.76
Endotoxin units (EU/m^3)[A]	-7.92E-03	0.13	0.95	-3.36E-02	0.11	0.76
Number of rooms	1.64E-02	0.02	0.33	1.37E-02	0.01	0.34
Manure pit depth	7.29E-03	0.004	0.05	1.42E-03	0.004	0.70
Categorical Variables	β	SE	p-value	β	SE	p-value
Type of manure system			0.004			0.15
No pit	-1.00	.29	0.001	-.17	0.27	0.55
Both pit and no pit	.32	.61	0.60	.97	0.52	0.07
Pit[a]	-	-	-	-	-	-
Frequency pit drain			0.001			0.92
>2 months (includes no pit)	-1.04	0.25	<0.0001	.10	.25	0.69
Every 3 to 4 weeks	-.28	0.20	0.18	4.61E-02	.20	0.82
Every 1 to 2 weeks	-	-	-	-	-	-
Flooring type			<0.0001			0.29
Solid	-1.67	0.35	<0.0001	-.54	0.34	0.12
Partially slatted	-.26	0.18	0.17	-.11	0.19	0.57
Fully slatted[a]	-	-	-	-	-	-
Animal flow			0.34			0.11
Continuous	-.27	0.21	0.21	-.36	0.18	0.05
Both continuous & AIAO	.18	0.42	0.68	1.30E-02	0.29	0.97
All-in, All-out (AIAO)[a]	-	-	-	-	-	-
Method of feeding			0.06			0.75
Drop/hand	.59	0.25	0.02	-8.66E-02	0.24	0.72
Self	.54	0.28	0.06	-.19	0.26	0.47
Liquid[a]	-	-	-	-	-	-
Area washed			0.38			0.29
No	-.29	0.22	0.19	-.23	0.19	0.23
No and yes	-.32	0.34	0.36	.14	0.27	0.62
Yes[a]	-	-	-	-	-	-
Area disinfected			0.59			0.49
No	-.21	0.22	0.37	-.13	0.19	0.50
No and yes	-.28	0.35	0.43	.18	0.28	0.51
Yes[a]	-	-	-	-	-	-

Results presented in this table are from a univariate regression analysis; [a] indicates reference value

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Table 3.15. Multivariable predictors of natural log-transformed H_2S exposures of pig barn workers in winter and summer[c]

Winter (N=43)			
Variable	Regression Coefficient	SE[b]	p-value
Intercept	-1.57	0.36	<0.0001
Carbon dioxide	5.36E-04	0.00	0.022
Flooring type			<0.0001
Solid flooring	-1.73	0.29	<0.0001
Partially slatted flooring	-.16	0.15	0.30
Fully slatted flooring[a]	-	-	-
Feed method			0.03
Drop feeding	0.53	0.19	0.01
Self feeding	0.51	0.21	0.02
Liquid feeding[a]	-	-	-

[*] Results presented in this table are from a multiple regression analysis of the Winter data. The adjusted R^2 for the Winter model=55%.

[a] Indicates reference category

[b] SE = Standard Error

[c] There is no predictive model for summer H_2S because no independent variables were found to be significant

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Table 3.16. Continuous and categorical variables from random effects models considered for inclusion in the combined winter/summer multivariable model to determine whether CO_2 (a measure of barn ventilation) contributed to seasonal differences in career pig barn worker's exposures to natural log-transformed H_2S

Continuous Variables	β	SE	p-value
Barn temperature	-.01	0.02	0.52
CO_2	3.28E-04	0.00009	0.001
RH	.004	0.006	0.47
Stocking density (kg/m^2)[A]	.08	0.13	0.55
Categorical Variables	**β**	**SE**	**p-value**
Type of manure system			0.02
No pit	-.61	.24	0.013
Both pit and no pit	.66	.48	0.18
Pit[a]	-	-	-
Frequency pit drain			0.06
>2 months (includes no pit)	-.51	0.21	0.02
Every 3 to 4 weeks	-.14	0.17	0.40
Every 1 to 2 weeks	-	-	-
Flooring type			0.001
Solid	-1.10	0.29	<0.0001
Partially slatted	-.14	0.14	0.33
Fully slatted[a]	-	-	-
Animal flow			0.24
Continuous	-.24	0.15	0.12
Both continuous & AIAO	.05	0.27	0.86
All-in, All-out (AIAO)[a]	-	-	-
Method of feeding			0.14
Drop/hand	.34	0.20	0.09
Self	.09	0.22	0.68
Liquid[a]	-	-	-
Area washed			0.51
No	-.18	0.16	0.26
No and yes	-.14	0.24	0.55
Yes[a]	-	-	-
Area disinfected			0.77
No	-.11	0.16	0.49
No and yes	-.11	0.24	0.65
Yes[a]	-	-	-
Season			0.82
Winter	.02	0.08	0.82
Summer[a]	-	-	-

Results presented in this table are from a univariate regression analysis; [a] indicates reference value

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Table 3.17. Multivariable predictors from repeated random effects models of natural log-transformed H_2S exposures of career pig barn workers in combined winter/summer data set

Variable	Regression Coefficient	SE[b]	p-value
Intercept	-.72	0.29	0.01
CO_2	2.03E-04	0.0003	0.43
Season			0.002
Winter	-1.05	0.34	0.002
Summer[a]	-	-	-
Flooring type			0.002
Solid	-1.05	0.27	<0.0001
Partially slatted	-.13	0.14	0.34
Fully slatted[a]	-	-	-
Season * CO_2			0.04
Winter * CO_2	5.80E-04	0.0003	0.04
Summer * CO_2[a]	-	-	-

[a] Indicates reference category
[b] SE = Standard Error

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3.4 Discussion

This study evaluated the personal exposures of specialty-area pig barn workers over two seasons in large intensive pig barns in Alberta. The results showed that Nursery/Grower-Finisher specialty-area workers had the highest respirable dust mass exposures in both winter and summer, the highest endotoxin exposures in summer, and the highest respirable dust count exposures (>5.0 μm) in summer, when compared to Farrowing workers.

Career pig barn workers who participated in this study represented a large fraction, approximately 18%, of all career pig barn workers employed by Alberta pig barns (Wenger, 1999b). Study participants had an average of 6.6 years of previous pig barn work experience, which was considerably shorter than those of other studies [10.7 ± 6.3 years (Zejda et al., 1994); 10.5 years (Holness et al., 1987); and 16.7 years (Vogelzang et al., 1998)]. In these earlier studies, the exposures of farm owners and family members were included in the study cohorts.

For the majority of air contaminants monitored, there were no differences in concentrations by day of visit (Tuesday, Wednesday, or Thursday). This study found a difference in RH and peak H_2S exposures by sampling day. While a day difference was found for the peak H_2S exposures in this investigation, manure pit work activities are conducted routinely when manure pits are full and so are not normally connected to a particular day of the week. Sampling day differences were also found for the respirable dust mass and endotoxin exposures of Nursery/Grower-Finisher workers, between Tuesday and Thursday. These differences were probably as a result of differences in pig

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moving workplace activities conducted by Nursery/Grower-Finisher workers on these two days (Chapter four).

In both winter and summer, CO_2 concentrations in the study barns, did not exceed the 5000 ppm Time-Weighted-Average (TWA) Threshold Limit Value (TLV) for this contaminant (ACGIH, 2001). During the winter portion of the study, lower than expected CO_2 concentrations were found as a result of the higher ventilation rates that were present during this season. Higher CO_2 concentrations are usually expected in winter because lower ventilation rates, typical of this season, means less fresh air is being brought into the barn and therefore there is less dilution of the CO_2 produced by the pigs. This was likely the result of the average temperature being above 0 °C during the winter portion of this study in 2000. No specialty-area CO_2 exposure differences were found for either winter or summer. Previous research utilizing area-monitoring to measure CO_2 contaminant concentrations in different specialty areas, found that the Farrowing area (Donham and Popendorf, 1985) and the Nursery area (Barber et al., 1991b) had the highest CO_2 concentrations. No such specialty area differences were found for CO_2 in the present study, where personal exposure monitoring was employed. This is despite the fact that lower ventilation rates are expected in the Farrowing and Nursery areas of barns to maintain the proper environment for the pigs that reside there.

Relative humidity varied between an average of 48% in winter and 51% in summer. Although this only represents a 6% increase from winter to summer, the difference was significant between seasons. This was a surprising result, given that higher relative humidity exposures were expected in winter given the lower ventilation

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rates in this season. Contributory sources of water vapour in barns include respiration from the pigs, animal activity and feeding level, the type of manure system in the barn, flooring type, and barn management including barn cleanliness (Barber et al., 1991a; Zhang et al., 1996). Increased water usage and lower pen/area hygiene likely contributed to the increased RH seen in the summer portion of the study, since with higher ventilation rates in summer, there is an increased amount of air movement at floor level resulting in increased evaporation of water from floor surfaces (Barber et al., 1991a). From a pig behaviour perspective, during periods of warmer temperatures, pigs have a tendency to play with their water sources (water nipples), partly as a cooling strategy, resulting in more water wastage and thus making available more water for evaporation. Furthermore, during times of warmer indoor barn temperatures, dunging patterns are likely to change. Where ordinarily pigs are encouraged to defecate and urinate on the slatted areas in the pens with the use of airflow patterns in the barn, during warmer temperatures, pigs will often defecate and urinate on the solid floor surfaces of the pen, to create opportunities for wallowing and thus evaporative cooling. This urine and fecal material can contribute to increased moisture evaporation and thus an increase in the relative humidity seen in the summer in the study barns. The suggestion of improper dunging patterns, was supported by the summer barn management questionnaire data, which showed that a high proportion of pens, particularly in the Nursery/Grower-Finisher areas, were messy, many with wet manure. In addition, many of the alleys in the rooms were reported to be wet.

Since respirable dust particles make up the aerosol fraction which are readily transported in air (Gao and Feddes, 1993), they should be subject to the same dilution

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effects as gases in the barn airspace during higher ventilation rates in summer. Results from this study support this. CO_2 and respirable dust count exposures were significantly lower in summer, when higher ventilation rates were expected.

Results from this study showed that workers in general were exposed to relatively few dust particles/mL in the size fraction >5.0 μm. Dust particles of different size fractions have different settling times. According to Hinds (1982), in still air, unit density particles of 100, 50, 10, 5, 1.0, and 0.5 μm aerodynamic diameters will settle in 1.2 s, 4 s, 1.6 min, 6.4, 143, and 500 min. As another comparison, it will take 0.5, 1.0, and 5.0 μm aerodynamic silica dust particles, 187, 54, and 2.5 min to fall 0.3 m (Hogan, 1996). The difference between the settling times reported by these two authors is a function of the different silica particle densities used in their calculations.

A significant difference was noted between Farrowing and Nursery/Grower-Finisher specialty workers in their exposures to dust particles >5.0 μm in aerodynamic size, for summer ($p<0.001$). These results are supported by Donham et al. (1986), who reported an increase in particle sizes, from the Farrowing areas through to the Finisher areas. These results were also supported by the significantly higher respirable dust mass exposures of Nursery/Grower-Finisher workers during the summer.

Dust particles of the sizes >5 μm have the greatest influence on mass measurements (Welford et al., 1992). Higher exposures to large dust particles are also likely the result of a significantly greater stocking density found in the Nursery/Grower-Finisher area during summer, when compared with the Farrowing area. Clark (1974), found that animal activity affected the larger particles in particular, so a higher level of

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animal activity in the Nursery/Grower-Finisher area among the group-housed pigs likely contributed to the continual re-entrainment of dust in the >5.0 μm size fraction. As well, dust particles will take time to settle depending on their size, as discussed previously. This was also reported by Perkins et al. (1997). These researchers found an initial rapid rise in dust counts following the commencement of piglet nursing activity, but that dust concentrations did not decline immediately at the end of nursing. Furthermore, with increased ventilation rates in the Nursery/Grower-Finisher area in summer, air within the barn airspace would be more turbulent, and thus, settling rates of particles of this large size fraction would be reduced (Hinds, 1982). This is supported by Morrison et al. (1993), who found that even with increased ventilation rates in summer, higher variable respirable dust levels were found as a result of increased animal activity. In addition, these results could also be indicative of activities involving closer contact with pigs through activities such as moving and weighing, where exposures to larger dust particles are more prevalent (Larsson et al., 2002).

No overall respirable dust mass concentration differences were found between summer and winter. This was supported by the final predictive model for workers' exposures to respirable dust mass in the combined winter/summer data, using repeated measures random effects models. This model showed that CO_2, a measure of barn ventilation, did not contribute to differences in respirable dust mass exposures of pig barn workers in this study.

Nursery/Grower-Finisher workers were found to have significantly higher respirable dust mass exposures than Farrowing workers. While no previous studies

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conducted personal monitoring of specialty-area workers for this contaminant, three studies reported results from area monitoring research conducted in different specialty areas. Respirable dust concentrations were found to be the highest in the Nursery area (Takai et al., 1996), in the Nursery and Grower/Finisher areas (Barber et al., 1991b) and the Farrowing area (Meyer and Manbeck, 1986). The difference in specialty area respirable dust mass exposures are likely the result of specialty-area activity differences (Chapter four).

In the present study, none of the pig barn worker exposures exceeded the ACGIH recommendations of 3.0 mg/m^3 for respirable particulate (ACGIH, 2001), either in winter or summer. The ACGIH recommendation treats respirable particulate as a single contaminant from any source and does not adequately reflect the complex and highly biological nature of the aerosol mixture in pig barn environments. Consequently, a more conservative guideline was proposed by Donham et al. (1989) of 0.23 mg/m^3 for area-sampled respirable dust and 0.28 mg/m^3 for personal-sampled respirable dust. Results from the present study, where personal sampling was employed, showed that the proposed 0.28 mg/m^3 guideline was exceeded by 42% and 27% of the workers in winter and summer, respectively.

Overall, Nursery/Grower-Finisher workers were found to have high exposures to respirable dust mass over both seasons. Given that workplace exposures are not consistent among the three different pig barn worker specialties, greater attention needs to be focused on the workers in the Nursery/Grower-Finisher areas to determine why exposures among these particular worker specialties are so high.

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Endotoxin concentrations (EU/m^3) were found to be significantly higher in winter than in summer. Furthermore, for specialty-area workers across seasons, endotoxin exposures were significantly higher in winter than in summer. Thus, the increase in barn ventilation in summer (lower CO_2 concentrations) appears to reduce the worker's overall endotoxin exposures, as a consequence of lower overall respirable dust particle exposures. This result was supported by the final predictive model for endotoxin, from the repeated measures random effects models, for the combined winter/summer data. CO_2, a measure of barn ventilation, was found to contribute significantly to differences in endotoxin exposures of pig barn workers by season. Respirable endotoxin exposures in this study were much higher than the 17 EU/m^3 reported by a study that evaluated the personal endotoxin exposures of 207 workers from 108 pig farms (Reynolds et al., 1996). During the summer, when overall endotoxin concentrations were low, Nursery/Grower-Finisher workers were still found to have significantly higher exposures to endotoxin compared to Farrowing workers. This was as a result of the significantly higher respirable dust mass concentrations of these workers, when compared to Farrowing workers, in this season. Significantly greater amount of time spent by Nursery/Grower-Finisher workers on the 'moving older pigs' work activity may have contributed to this finding (Chapter four).

Higher endotoxin exposures among the Nursery/Grower-Finisher workers are also supported by results from the barn management questionnaire which showed that the presence of more, and often wet manure, in the Nursery/Grower-Finisher area in summer. Perhaps the presence of this wet manure was conducive to the proliferation of gram

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negative bacteria in this specialty-area environment. Furthermore, the presence of manure on the solid surfaces of pens, once dried, could have contributed to the worker's higher exposures to dust of fecal origin, thereby contributing to the higher endotoxin exposures measured.

Overall, workers participating in this study were exposed to low average H_2S exposures, which were well below the ACGIH TWA exposure guideline of 10 ppm (ACGIH, 2001). However, the evaluation of *average* H_2S exposures gives a false sense of security. Peak H_2S exposures from this study paints an altogether different picture. Among the pig barn workers enrolled in this study, 28% and 22% of workers in winter and summer, respectively, exceeded the present Alberta Government ceiling limit of 20 ppm during their 3-day work shifts. There is proposed legislation in Alberta, to lower the ceiling limit for H_2S from 20 ppm to 15 ppm by the spring of 2004 (Alberta Human Resources and Employment, 2002). Were such a lower ceiling limit be in place today, 54% and 30% of the workers in the winter and summer, respectively, would have been in non-compliance. The results of this study show that standard operating procedures for the pit work job task need to be reviewed and modified, to ensure that worker's exposures do not exceed ceiling exposure guidelines. H_2S is a by-product of anaerobic digestion by microbes in the manure. As such, this gas is trapped in the liquid manure in below-floor pits in the barn. H_2S is released during the liquid manure removal operations from barns. Even though the pit work job task is confined to relatively few workers in each barn, workers from all specialties were involved in this particular job task. Indications are that only the workers themselves who are actually conducting the manure removal tasks have

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exposures which are unacceptably high. However, this may not be the case, since H_2S distributions within a room following pit plug removal were not found to be predictable, with unacceptable exposures being present at locations in the airspace, other than over the pit (Chénard et al., 2003).

The predictive models for endotoxin, respirable dust mass concentration, and H_2S showed interesting results. The presence of solid flooring was found to contribute to significantly higher endotoxin exposure in both winter and summer. Three of the study barns had solid floors in the Grower/Finisher areas. In two of these, flush systems were used to remove manure. Recycled water is typically used to flush manure from these barns on a regular basis throughout the day. The third barn had a manual manure removal system and also utilized wood shaving as bedding. The fact that manure is not removed from the environment in solid floor barns, as effectively as it is from partially or fully slatted flooring systems (in these latter systems, manure is continually pushed down by trampling action through the slots (of approximately 1" (25 mm) wide) in the flooring, into the pit below), is conducive to the proliferation of gram negative bacteria in these systems. It is not clear what role wood shavings had in the endotoxin exposures. However, results from a study that linked health questionnaire data to lung function testing data, reported that pig farmers using solid floor systems with wood shavings as bedding were at a higher risk for chronic respiratory ailments (Vogelzang et al., 1996). As mentioned previously, CO_2 concentration, a measure of barn ventilation, was found to contribute significantly to differences in endotoxin exposures of pig barn workers by season. Therefore, higher ventilation rates in summer, likely contribute to lower

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endotoxin exposures.

A higher stocking density (winter) and lower barn temperatures (winter and summer), were found to be predictive of respirable dust mass exposures. Interestingly, there was no season by CO_2 interaction found, when the winter and summer data sets were combined and analyzed simultaneously. The indicates that an increase in barn ventilation rates (using CO_2 as a measure of barn ventilation), does not contribute to (does not appear to be an effective measure), a reduction in the respirable dust mass exposures of workers in the pig barn.

It was only possible to develop a predictive model for H_2S in the winter. None of the barn management variables were found to be significant in the summer data set. In winter, not surprisingly, solid flooring contributed to significantly lower H_2S exposures, because without liquid manure in underfloor pits, there is no H_2S. Higher CO_2 concentrations were found to be predictive of higher H_2S. This is tied to ventilation of the airspace. The final predictive model for workers' exposures to H_2S in the combined winter/summer data, using repeated measures random effects models, supported these results. Carbon dioxide, a measure of barn ventilation, was found to contribute to differences in H_2S concentration by season. With a lower ventilation rate, exposures to gases, including H_2S are expected to be higher. Conversely, with higher ventilation rates in summer, lower H_2S exposures are expected. This significant ventilation influence is also likely the reason why none of the variables were significant in the predictive model for H_2S in summer.

It is not clear why feeding method (both drop feeding and self feeding) were

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significant predictors of H_2S exposures. Perhaps this variable is a surrogate for another variable, such as sulfur content of feed, that was not evaluated in this study. The sulfur content of pig feed has been shown to influence H_2S concentrations (Grant Clark, personal communication, December 10, 2003).

3.5 Study Limitations

Lack of NH_3 data from this research was a limitation as its contribution to other contaminants could not be evaluated in this study.

In this study, Nursery worker specialties were combined with Grower/Finisher worker specialties. This created difficulties with many of the barn management variables, because of the differences in flooring types, feed types and methods and areas washed and disinfected, between the two areas. In addition, the higher level of hygiene as a result of the All-in, All-out nature of the Nursery area was obscured with such an amalgamation. Furthermore, Nursery barns are run at high environmental temperatures when newly weaned pigs are introduced into this area, and this may result in this specialty area contributing to high contaminant exposures. Future studies should focus on the exposure evaluations of specialty Nursery workers, as a separate class of workers.

Placing the PESB II monitoring equipment on the floor during breaks is seen as a limitation of this study. If the monitoring equipment cannot be worn during these activities, then attempts should be made to have the equipment positioned close to the worker(s) at breathing height.

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3.6 Summary

The purpose of this study was to determine whether the personal exposures of specialty-area pig barn workers to barn contaminants varied by worker specialty and by season. Winter exposures were consistently higher than summer exposures for the majority of contaminants monitored. Exposure differences were found to exist for specialty-area workers. Nursery/Grower-Finisher workers were shown to have the highest respirable dust mass exposures in both winter and summer, the highest respirable dust count exposures in the size fraction >5.0 μm in summer, and the highest endotoxin exposures in summer, when compared to Farrowing-area workers. Solid flooring contributed to significantly higher endotoxin exposures and to significantly lower H_2S exposures of workers. Lower barn temperature (winter and summer) coupled with a higher stocking density in winter, contributed to higher respirable dust mass exposures.

For the majority of airborne contaminants monitored, there were no differences in concentration by day of visit (Tuesday, Wednesday, or Thursday). However, for Nursery/Grower-Finisher workers, higher respirable dust mass (mg/m^3) and endotoxin exposures were found for exposures on Tuesday's when compared to Thursday sampling days. Further analysis showed that significantly greater pig movement activities occurred on Tuesdays relative to Thursdays. While none of the workers in the study exceeded the 3 mg/m^3 TWA-TLV for respirable dust mass concentration, more than 25% exceeded a more conservative guideline of 0.28 mg/m^3.

Even with low overall H_2S exposures among workers enrolled in this study, almost 25% of the workers in both seasons were found to exceed occupational ceiling

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exposure limits for this gas. Since H_2S exposures are predominantly from manure removal activities, a closer evaluation of how workers are conducting this particular work task is warranted.

The higher exposures of Nursery/Grower-Finisher workers, relative to the other workers specialties monitored in this investigation, suggests that a more in-depth evaluation needs to be made of this specialty worker group into the causes of their higher exposures to airborne contaminants.

3.7 **Conclusions**

From this study, the following conclusions can be drawn:

- Pig barn workers should be enrolled in studies based on the specialty-area in which they work, not on their status of 'just' being a pig barn worker.
- Workplace exposure differences exist for specialty-area pig barn workers. Nursery/Grower-Finisher workers have higher exposures to respirable dust and endotoxin compared to Farrowing workers.
- Solid floors in pig barns are associated with higher endotoxin exposures than slatted floors.
- Personal monitoring is more appropriate than area monitoring for measuring air contaminant exposures of pig barn workers in modern pig barns because this allows the *actual* exposures of the workers to be monitored as they conduct their varied workplace activities in the many rooms and areas throughout the modern confinement pig barn.

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Chapter Four

Contaminant Exposures During Workplace Activities in Modern Pig Barns: The Use of Real-time Respirable Dust, Gas Monitoring and Time Activity Diaries

4.1 Introduction

Time activity diaries are chronological recordings of activities conducted over the day and usually include information on start and stop times, the location where the activity was conducted, and whether other people were present in the area or involved with the activity itself (Robinson, 1988; Sexton and Ryan, 1988; Robinson and Thomas, 1991). Data are typically recorded by the study participants themselves, following a more structured diary format in which study participants record each activity conducted, in 15-min time blocks over the entire workday, selecting from a list of pre-determined activities (Kains, 1994; Preller et al., 1995b; Vogelzang et al., 1998a). While such a modified diary format ensures greater data recording compliance, there is a chance that not all activities conducted during the day will be captured. This is especially true if more than one activity is conducted during a 15-min time interval. Direct observational methods (where observers shadow study participants and record all activities conducted by these individuals over specified time periods), are an alternative to self-reporting (Robinson and Godbey, 1997). While direct observation results in more objective and unbiased activity data recording, it is seldom used because of the substantial increase in study costs.

Within the occupational context, time-activity diaries can be used as a decision-making tool to evaluate time management inefficiencies. For example, a time activity

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diary was developed by Kains (1993) for use by Ontario pig farmers. The highly-structured types of workplace tasks conducted on pig farms made it possible for the development of an activity logbook. The pig farmers were asked to record activity data every 15 min over the workday for a 2-week period (Kains, 1994). Some of the farmers were reluctant to record the data, even though participation would have only meant 1 hour of time commitment over the 2 week period.

The linkage of activity diary data with personal exposure monitoring data is important for comparing the exposures of workers in one area or for one task to the exposures of another. Data linkage is also important because it allows for: exposures across studies to be compared; data to be incorporated into exposure modelling processes; and evaluation of unacceptable exposures and tasks that may have contributed to them (Duan and Mage, 1997).

Only 5 studies have been published that have used time activity diaries, for the prediction of activity-specific workplace exposures of pig barn workers. All of these studies used the same pig barn worker cohort. In these studies, pig barn workers were asked to record daily activities for 21 pre-determined activities, in 15-minute intervals, for 7 days during winter and again in summer (Preller et al., 1995a; Preller et al., 1995b; Vogelzang et al., 1998a; Vogelzang et al., 1998b; Vogelzang et al., 2000). Length of time spent conducting activities in different "compartments" of the barns "Farrowing, Sow, Piglets and Finishing" (Preller et al., 1995a) were calculated using the diary data. Using empirical modelling, the association between activities conducted by the workers and the personal inhalable dust and endotoxin exposures sampled over two workshifts, one in

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winter and one in summer, were developed.

The study described below is the first to utilize observer-recorded activity diary data and to link these data to real-time personal air contaminant exposures of career pig barn workers. The purpose of this study was twofold: to determine whether the types and duration of activities conducted by workers in modern pig barns varied by specialty worker type; and to determine whether airborne contaminant exposures differed by workplace activity conducted by the different workers specialties. Recommendations for the protection of workers are also outlined.

4.2 MATERIALS AND METHODS

4.2.1 Study design

Using a cross-sectional design, this study followed pig barn workers, by area specialty, over the winter (February to April) and summer (June to August) of 2000, in Alberta. For the purposes of this paper, only the data from the winter sampling were used (Chapter Three) because of higher overall air contaminant concentrations during this season. Full details about the barn and worker selection, environmental contaminant monitoring equipment, and data calculation methodology are reported previously (Chapter Three) and are summarized below. Ethical approval for this study was obtained from the Health Research Ethics Board (B: Health Research) of the Faculty of Medicine, University of Alberta.

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4.2.2 Research Setting

4.2.2.1 The barns

Pig barns were eligible for this study if they were Farrow-to-Finish or Farrow-to-Wean farms and if the barns employed a minimum of four full-time workers. Priority was given to Farrow-to-Finish operations since employees in such facilities represented the broad range of workers and activities of interest. A total of 20 barns, met the inclusion criteria, and 15 were randomly selected to be contacted. Ten barns (8 Farrow-to-Finish; 2 Farrow-to-Wean) agreed to participate and allowed the study team access to their facilities. Barn herd sizes averaged 1310 sows, ranging from 350 to 2400 sows (3,500 to 24,000 pigs per production site).

4.2.3 Study Sample

4.2.3.1 The workers

Career pig barn workers were asked to participate in this study (Wenger, 1999). Employees were excluded if they were maintenance workers, students, or worked in more that one defined area of specialization in the barn. Three workers from each of the 10 barns (one worker from each of the Dry Sow/Breeding, Farrowing and Nursery/Grower-Finisher specialty areas) were randomly selected to be followed by a study team member (trained observer) and to wear a Personal Environmental Sampling Backpack (PESB II). If a participating worker either declined further participation or was away on subsequent study days, another worker from the same barn and specialty area was recruited to the study. Of the 38 randomly selected workers, 36 (95%) agreed to participate in the study. Written informed consent was obtained from all participating workers. Study participants

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were asked to record all activities they conducted over the workshift, in individual worker diaries, which were given to them at the start of each visit day (Appendix 4.1). Completed diaries were collected at the conclusion of each visit.

The number of workers who worked exclusively in the Nursery area were too small to evaluate on their own (3 workers in winter), and approximately half of the workers who were responsible for the Nursery area, were also responsible for the Grower area or the combined Grower/Finisher areas (47% in winter and 57% in summer). This made it impossible to separate out only the Grower/Finisher exposures for these workers. For these reasons, the Nursery area and Grower/Finisher areas, were combined into one specialty area for this study.

4.2.4 Data Collection

4.2.4.1 The study team

The field team was comprised of the project manager (IIW), two full-time assistants, and an agricultural research engineer (CA Ouellette), who calibrated and maintained the equipment in the field. The trained observers[1] (project manager and assistants) were randomly assigned to follow the same worker for 3 consecutive days, recording all activities conducted over each full workshift, in a time activity diary developed for this study (Appendix 4.2). Activities were recorded by the observers every

[1] Observer training was conducted prior to the start of the study. This was accomplished by having observers follow a worker at the University of Alberta pig farm during portions of a number of workshifts. Activity data recorded by all observers were then reviewed and discussed during debriefing sessions. Debriefing sessions were also held at the end of every day the study team was out in the field (on the drive back to the motel).

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time a worker changed activities or changed zones (moving from a hallway into a room, or moving from an alleyway into a pen, for example).

4.2.4.2 **Exposure monitoring**

Personal contaminant exposures were monitored for 3 pig barn workers in each of the 10 barns, throughout their entire workshifts (including breaks), over 3 consecutive days of a work week (Tuesday through Thursday). Sampling was not conducted on Mondays and Fridays due to shift changes and scheduled days off. If a participating worker either declined further participation or was away on subsequent study days, another worker from the same barn and specialty area was recruited to the study. During coffee and lunch breaks, workers took their backpacks off, so the equipment was not worn by workers during these activities. Instead, monitoring equipment was placed along the wall, on the floor of the coffee/lunch area, so as to be out of the way.

Personal sampling for airborne constituents was accomplished with three second generation PESB IIs. The real-time monitoring equipment contained in the PESB II included a dust particle counter (ABACUS 301, Particle Measuring Systems Inc.), ammonia (NH_3) and hydrogen sulfide (H_2S) gas monitors (Toxi-Ultra, Biosystems Inc.), a carbon dioxide (CO_2) gas monitor (YES-206, Young Environmental System Inc.), and relative humidity (RH) (HIH-3602-A, MICRO SWITCH, Honeywell Inc.) and dry-bulb temperature (HOBO® H8 external temperature probe, Hoskin Scientific) sensors. PESB II equipment specifications are presented in Table 2.1 (Chapter Two).

Barn air drawn from within the worker's breathing zone (through an isokinetic probe affixed to the cloth backpack of the PESB II), passed through all in-line air

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contaminant sensors using a personal air sampling pump. The calibrated flow rate of 2.8 L/min ± 5% was chosen as the dust count sensors were factory calibrated to this flow rate.

The majority of barn air contaminants were monitored on a continuous basis and were stored by a custom-designed data logger (Orthopaedic Innovations, Inc., Edmonton, AB) at 10-s intervals throughout the entire workday. These included CO_2, RH, indoor barn temperature, and respirable dust counts in four (optical diameter) cumulative size fractions (>0.3 μm particles/mL, >0.5 μm particles/mL, >1.0 μm particles/mL, and >5.0 μm particles/mL). For the purposes of this manuscript, the respirable dust particles of a size >0.5 μm (not >0.3 μm) will be presented, as these represent respirable dust generated within the barn environment (Zhang et al., 1994). Dust particle counting technology was employed in this study as individual workplace activities were too short a duration to allow for the reliable collection of sufficient respirable dust for gravimetric analysis.

4.2.4.3 **Diary Data**

To facilitate the coding of activity data, a coding scheme was developed for this study (Appendix 4.2). All workplace activities recorded by the observers, were grouped into analogous activity categories and assigned 3-digit activity codes (Table 4.1). Each activity performed by a worker was then coded using the specific code assigned to that activity. Activity data were entered into a Microsoft Excel® spreadsheet, and the data were rigorously checked[2], by cross-checking with a study team member, for both coding

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[2] The project manager (IIW) and a study team member responsible for data entry, would read each line of data to each other to check for data entry errors. These were then corrected in the data set. When IIW was making the determinations of the start and finish times for activities conducted by each study participant, coding errors were identified and subsequently corrected. This ensured the consistency of activity diary coding.

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Table 4.1 Outline of activity coding

Activity Code	Activity Code	Activity Code
100 - Breeding	500 - Health	900 - Other/Miscellaneous
110 - Stimulating heat	510 - Barn/Health Check	910 - Breaks
120 - Heat checking	520 - Animal Identification	920 - Rest
130 - Natural breeding	530 - Treatments	930 - Smoking
140 - Semen collection	540 - Vaccinating	940 - Study requirements
150 - Artificial insemination	550 - Repair ruptures	950 - Checking/looking
160 - Pregnancy checking	560 - Animal restraint	960 - Driving
170 - Backfat probing	570 - Animal Euthanasia	970 - Handling other animals
180 - Boar testing	580 - Tender Loving Care	
200 - Cleaning	600 - Maintenance	
210 - Solid manure removal	610 - Construction	
220 - Spreading bedding	620 - Building structure	
230 - Sweeping/dust removal	630 - Equipment	
240 - Pressure washing	640 - Environment adjustment	
250 - Dead pig removal	650 - Machinery and tools	
260 - Washing and garbage	660 - Manure system repair	
270 - Pit work	670 - Welding	
280 - Biosecurity	680 - Pest control	
290 - Household chores		
300 - Farrowing	700 - Moving pigs	
310 - Farrowing preparation	710 - Gate adjustments	
320 - Inducing farrowing	720 - Weaning/moving piglets	
330 - Assisting farrowing	730 - Moving/herding pigs	
340 - Checking sows	740 - Sorting/selecting pigs	
350 - Piglet care	750 - Weighing pigs	
360 - Processing litters		
370 - Cross-fostering piglets		
400 - Feeding	800 - Work preparations	
410 - Feeding preparations	810 - Work clothing on/off	
420 - Feed delivery	820 - Walking	
430 - Dry feeding	830 - Get/return supplies	
440 - Liquid feeding	840 - Talk with co-workers(s)	
450 - Watering	850 - Record-keeping	
460 - Creep feeding	860 - Finding co-workers(s)	
470 - Checking feed system	870 - Waiting	
480 - Cleaning feeders		

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and data entry errors.

Start and finish times for activities conducted by each study participant during a full workshift were identified by one of the investigators (IIW) with extensive knowledge and understanding of pig barn environments and activities. Workplace activities were included in the analysis if they were ≥ 1 min in duration. Activities were excluded if the activity was: less than 1 min in duration; limited to walking from zone to zone or area to area; talking or meeting with co-workers; looking for co-workers; looking for, getting or returning supplies; or assembling supplies required for a particular activity in a location (such as in the shop, hallway, office area, or medicine room) other than where the included activity took place.

Three data files (activity, H_2S, contaminants monitored by the equipment (PESB II)) per worker per visit day, were linked by worker ID and date of visit using a Quick Basic 4.5 computer program (Microsoft Corporation®, Redmond, WA). The program calculated mean, minimum, maximum and median contaminant exposures for each study activity event over the work day (events file). The overall time spent on each activity and the corresponding overall daily mean, minimum, maximum and median contaminant exposures were then calculated (daily file). The overall daily averages, from the daily files, were used in the preparation of this manuscript.

Eighty-five observer activity diary data files were linked to 85 PESB II exposure data files and 80 corresponding H_2S data files. Four H_2S files were missing due to unavailable H_2S sensors at the beginning of the winter study, and one file was missing due to a data logger malfunction.

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4.2.4.4 **Statistical analysis**

The daily exposure data represent the total duration of, and contaminant exposures for, each activity conducted by an individual worker during each day of the 3-day barn visit. The basic unit of analysis in this study was workplace activity. In order to merge the activity and exposure data for one worker over three sampling days, the daily activity exposure data were sorted by worker ID and worker specialty. Air contaminant exposures for each individual activity conducted by each worker were averaged over the 3-day winter visit. Descriptive statistics are reported as daily means, standard deviation, median, minimum and maximum exposures. Non-parametric analyses (Kruskal-Wallis and Mann-Whitney U test) were used in the analysis of the data due to small sample sizes. A Kruskal-Wallis test was used to test activity duration and contaminant exposure differences across worker specialties. Where differences were found, a Mann-Whitney U test was used to test the pairwise specialty differences. The reported p-values are those in which the Bonferoni correction for multiple comparisons (for 3 specialty groups), was applied.

Mean respirable dust (> 0.5 μm dust particles/mL) exposures were dichotomized to < 20 particles/mL (low respirable dust exposure) and ≥ 20 particles/mL (high respirable dust exposure). A Chi-square test was used to test low and high respirable dust exposures across pig barn worker specialties. Where differences were found, an odds ratio was calculated to determine the likelihood of a high exposure occurrence for a particular worker specialty group. To test whether respirable dust exposures were higher during moving pig activities, activities were recoded into either *moving* (combining

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activity codes 130 for natural breeding, 720 for moving piglets, 730 for moving older pigs, 740 for sorting/selecting, and 750 for weighing) or *non-moving* activities (all other activities). Mean exposures were compared between moving and non-moving activities using an independent samples t-test. Data were analyzed using SPSS, version 10.0 software (SPSS Inc., Chicago, IL), and p-values were considered statistically significant at $p \leq 0.05$.

4.3 RESULTS

4.3.1 Study Participants

Thirty six career pig barn workers participated in this study (22 men; 14 women), with an average age of 34.3 years. Of these, 13 study participants worked in the Dry Sow/Breeding area, 13 in the Farrowing area, and 10 in the combined Nursery/Grower-Finisher area. The majority of the study participants (58%) worked all 3 winter study days, while 8 workers (22%) and 7 workers (19%), worked only one or two days, respectively. Reasons for not participating for all 3 study days included: sick day(s), scheduled day(s) off or vacation (N=6); unwilling to wear the PESB II instrumentation for more than one day (N=2), and cover-off workers (N=7). Cover-off workers were specialty pig barn workers from the same barn who met the inclusion criteria, were recruited to the study, and were usually from the same specialty work area (83%) as the workers they were replacing. The average workshift duration in this study was 9.4 hours (564 min).

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4.3.2 Activity diaries and workplace activities

4.3.2.1 Observer diaries

Observers recorded an average of 600 lines of data per worker per day, while the worker's themselves only recorded an average of 12 lines of data per day. Worker diaries did not contain sufficient information to develop an adequate time activity profile for the workday and therefore observer diaries were used as the primary time activity data source.

Activity diary data from a total of 85 full workshift observer diaries, out of a possible 90, were collected in this study. Five observer diaries were excluded. Three (representing data from one study participant) were excluded because of incomplete time-activity profiles; one was excluded because the worker did not meet the eligibility requirements of the study; and one was excluded, because an observer diary was lost.

4.3.2.2 Worker activities

Career pig barn workers in this study conducted 68 different workplace activities (Table 4.1). This paper reports only those activities conducted by at least 2 workers, as some of these tasks were conducted by only one worker within a particular worker specialty. A number of activities conducted by workers are both unique to individual specialty areas, while others are conducted by workers across all specialty areas (Table 4.2).

Activities unique to specialty areas.

Dry Sow/Breeding area. Activities unique to the Dry Sow/Breeding specialty area included: heat checking (walking the boar through the barn to check for sows/gilts in

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Table 4.2. Duration of time (min/day), spent by ≥2 workers per pig barn worker specialty, conducting individual workplace activities

ACTIVITY	Dry/Sow breeding (N=13) mean ± SD [median] (min-max)	Farrowing (N=13) mean ± SD [median] (min-max)	Nursery/Grower-Finisher (N=10) mean ± SD [median] (min-max)	Significance[B] (Kruskal-Wallis)
100 - Heat checking/breeding				
120 - Heat checking	30.8 ± 24.3 [29.7] N=11	—	—	—
130 - Natural breeding	47.9 ± 49.2 [25.7] N=5	—	—	—
150 - Artificial insemination	54.9 ± 25.9 [61.0] N=11	—	—	—
200 - Manure removal/cleaning				
210 - Scraping solid manure	32.3 ± 25.3 [32.7] N=8	21.7 ± 12.3 [16.0] N=7	100.3 ± 108.0 [100.3] N=2	0.35
230 - Sweeping	4.0 ± 2.8 [4.0] N=2	8.5 ± 3.5 [8.5] N=2	—	0.22
270 - Pit work	13.9 ± 15.7 [6.0] N=6	31.3 ± 44.2 [11.0] N=3	11.1 ± 8.3 [7.0] N=6	0.89
300 - Farrowing & piglet care				
330 - Farrowing assistance	—	40.1 ± 36.1 [26.0] N=7	—	—
360 - Piglet processing	—	85.5 ± 36.6 [78.8] N=12	—	—
370 - Cross-fostering	8.0 ± 1.4 [8.0] N=2	19.8 ± 16.5 [14.0] N=11	—	0.24
400 - Feeding & feed delivery				
430 - Dry feeding	18.5 ± 8.8 [17.0] N=11	102.6 ± 43.1 [92.8] N=8	31.1 ± 8.9 [31.0] N=7	<0.0001 (D-F**; F-N*)
440 - Liquid feeding	35.8 ± 51.2 [13.5] N=4	34.3 ± 5.2 [34.3] N=2	—	0.36
460 - Creep feeding	7.5 ± 2.1 [7.5] N=2	15.2 ± 11.2 [12.3] N=10	—	0.33
470 - Checking feed system	7.3 ± 6.0 [8.0] N=3	6.0 ± 4.2 [6.0] N=2	13.2 ± 8.6 [9.5] N=3	0.57
480 - Cleaning feeders	9.9 ± 7.8 [6.0] N=5	—	15.8 ± 12.4 [19.5] N=3	0.37
500 - Barn check & treatments				
510 - Barn check	17.2 ± 18.3 [12.7] N=10	14.9 ± 10.3 [11.2] N=10	41.5 ± 21.8 [31.0] N=7	0.02 (D-F†; D-N†; F-N†)
520 - Animal identification	15.6 ± 19.0 [9.0] N=7	34.1 ± 36.9 [23.0] N=5	29.0 ± 9.9 [29.0] N=2	0.39
530 - Pig treatments	9.5 ± 7.6 [7.8] N=8	31.2 ± 35.8 [14.0] N=11	32.1 ± 29.1 [27.0] N=7	0.27
540 - Vaccinations	19.7 ± 9.8 [18.0] N=5	8.5 ± 0.7 [8.5] N=2	46.3 ± 8.8 [43.5] N=4	0.01 (D-N†)
600 - Maintenance				
660 - Manure system repair	—	1.0 ± 0.0 [1.0] N=2	33.0 ± 14.1 [33.0] N=2	0.15
700 - Moving & weighing				
720 - Weaning/moving piglets	35.5 ± 35.9 [29.0] N=4	31.7 ± 19.7 [26.0] N=6	39.7 ± 9.1 [36.0] N=3	0.88
730 - Moving older pigs	63.0 ± 31.9 [57.7] N=13	24.4 ± 18.2 [20.0] N=11	89.1 ± 58.3 [89.2] N=10	0.002 (D-F*; F-N†)
740 - Sorting/selecting	38.0 ± 18.4 [38.0] N=2	—	48.2 ± 36.5 [51.3] N=4	0.59
750 - Weighing	52.0 ± 46.7 [52.0] N=2	—	56.6 ± 35.0 [70.2] N=4	0.53
800 - Work preparations				
850 - Record-keeping	42.9 ± 48.9 [24.3] N=10	20.8 ± 18.2 [16.0] N=12	10.4 ± 5.4 [11.5] N=6	0.16
900 - Other (miscellaneous)				
911 - Breaks	107.7 ± 30.0 [105.0] N=13	106.6 ± 34.1 [98.0] N=13	99.2 ± 44.4 [85.3] N=10	0.53

[B] Statistical difference between specialty worker groups: D-N difference between Dry Sow/Breeding and Nursery/Grower-Finisher workers; D-F, between Dry Sow/Breeding and Farrowing; and F-N, difference between Farrowing and Nursery/Grower-Finisher. For statistical significance (Mann-Whitney U), $^{\dagger}p<0.05$; $^{*}p\leq0.01$; $^{**}p\leq0.001$. N represents the numbers of workers conducting a particular activity. Duration of time spent on activities were not adjusted to an average workshift length.

heat), natural breeding (moving sows and boars to breeding pens and supervising breeding), and artificial insemination (isolating a boar in front of a group of sows/gilts for artificial insemination in their stalls). These activities constituted almost a quarter (24%) of the Dry Sow/Breeding worker's average workday, with the remainder of the day spent conducting barn checking, feeding, moving pigs and record keeping.

Farrowing area. Assistance during farrowing (watching the sows during farrowing, pulling and reviving piglets), piglet processing (teeth clipping, iron injections, tail docking, castrating), cross-fostering (moving piglets of the same size to foster sows), and creep feeding (scooping highly digestible feed to piglets in farrowing crates), were activities conducted exclusively in the Farrowing area. They constituted 28% of the workday for Farrowing workers. Of these activities, workers spent the most time processing piglets (86 min), with 92% of workers in this area conducting this task during the 3-day visit. Two Dry/Sow Breeding workers were also observed to conduct cross-fostering and creep feeding activities in the Farrowing area, to cover for workers who were away.

Nursery/Grower-Finisher. Sorting (moving male or female pigs together into individual pens, or moving pigs of similar weights into pens) and weighing (moving pigs to a weigh scale to determine growth rate or readiness for shipping) activities, were unique to the Nursery/Grower-Finisher area. Forty per cent of the Nursery/Grower-Finisher workers conducted these job tasks, representing 19% of their workday. Two workers from the Dry Sow/Breeding worker specialty were also observed to conduct weighing tasks (to assist co-workers) and sorting/selecting activities (for the purposes of

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selecting replacement gilts for the breeding herd).

Activities common to specialty areas

Manure removal and cleaning. As can be seen in Table 4.2, relatively little time was spent on a daily basis scraping solid manure (manure is manually scraped from the solid surfaces of pens to the slatted areas, behind sows in stalls, in alleyways and crates) or removing liquid manure (pit work) from the barns. However, as one barn in this study did not have a pit system in the Finisher area, two Nursery/Grower-Finisher workers were observed spending over 1.5 hours, on average, on this one manual cleaning task (Table 4.2). No significant differences were found in the average amount of time workers, from the three different specialty areas, spent conducting the manure removal or cleaning activities. Workers from all three specialty areas were seen to conduct the pit work activity, a task involving the checking of manure pit levels and lifting or replacing the pit plug for the removal of liquid manure from underfloor liquid manure pits. However, while 60% of workers in the Nursery/Grower-Finisher area were seen to conduct this activity, only 46% and 23% of workers performed this task in the Dry Sow/Breeding and Farrowing specialty areas, respectively. Moreover, less than 50% of all participating workers were responsible for this task during the study visits.

Feeding and feed delivery. Within the feeding and feed delivery activity category, only the dry feeding activity (involving either the manual scooping of feed, or the pulling of levers to release feed from overhead storage containers (drop feeding)) was conducted by the majority of workers within a particular specialty area. Farrowing workers spent significantly more time dry feeding than Dry Sow/Breeding or Nursery/Grower-Finisher

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workers ($p<0.0001$) (Table 4.2). Four barns in this study were liquid fed barns, in which either the entire barn, or at least one specialty area was liquid fed. Only workers in the Dry Sow/Breeding and Farrowing areas in these 4 barns were seen to conduct this task, which primarily involved checking that adequate feed was being delivered to the pigs by the automated feeding system.

Barn Checking and pig treatments. Seventy five per cent of workers who participated in this study conducted the barn checking activity. This activity involved walking through the animal rooms, looking for sick pigs (or in the case of Dry Sow/Breeding workers, sows/gilts in heat), broken feeders, water lines, penning and equipment. Nursery/Grower-Finisher workers spent significantly more time than either Dry Sow/Breeding or Farrowing workers on this task, while Farrowing workers were seen to spend the least amount of time on this activity when compared with Dry Sow/Breeding workers ($p=0.02$) (Table 4.2).

No significant differences were seen in the amount of time spent by workers in all three specialty areas either treating pigs or on animal identification (tagging/tattooing) activities. However, Nursery/Grower-Finisher workers spent significantly more time than Dry Sow/Breeding workers vaccinating animals ($p=0.01$). The activity of vaccinating pigs in the Nursery/Grower-Finisher area is primarily conducted in the Nursery barn.

Moving and weighing pigs. This study found that 94% of all participating workers were involved in moving older pigs. However, Farrowing workers (who were primarily responsible for moving sows/gilts to and from the farrowing barn), spent significantly less time on this task, compared with Dry Sow/Breeding workers

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(responsible for moving sows/gilts to and from the Farrowing barn and within the dry sow barns) and Nursery/Grower-Finisher workers (responsible for moving pigs from pen to pen or room to room in the nursery, grower and finisher barns) (p=0.002) (Table 4.2).

Workers from all three specialty areas spent time during the 3-day study visit moving newly weaned piglets (herding newly weaned piglets down the alleyways and hallways of the barn to the nursery area, or in the case of the two Farrow-to-Wean operations, herding piglets to a waiting truck for transport to a nursery facility). No overall differences were noted across worker specialties in the amount of time spent conducting this activity (Table 4.2).

4.3.3 **Exposure data**

4.3.3.1 **Winter environmental parameters**

Barn temperature and Relative humidity. Barn temperature and RH exposures were similar across workplace activities conducted by specialty pig barn workers in this investigation.

Carbon Dioxide. Figure 4.1 is an example of the carbon dioxide exposures of a Nursery-Grower/Finisher worker over various work activities during a 9.1-h winter workshift. No overall differences were found in CO_2 exposures during workplace activities (Table 4.3). The majority of the mean CO_2 exposures for the various tasks conducted by workers in this study were found to be lower than 3000 ppm (Table 4.3). The exception was for sweeping activities conducted by Dry Sow/Breeding workers and vaccinating activities conducted by Nursery/Grower-Finisher workers. Overall, exposures ranged from 200 ppm to a peak of 9240 ppm. For the majority (62%) of

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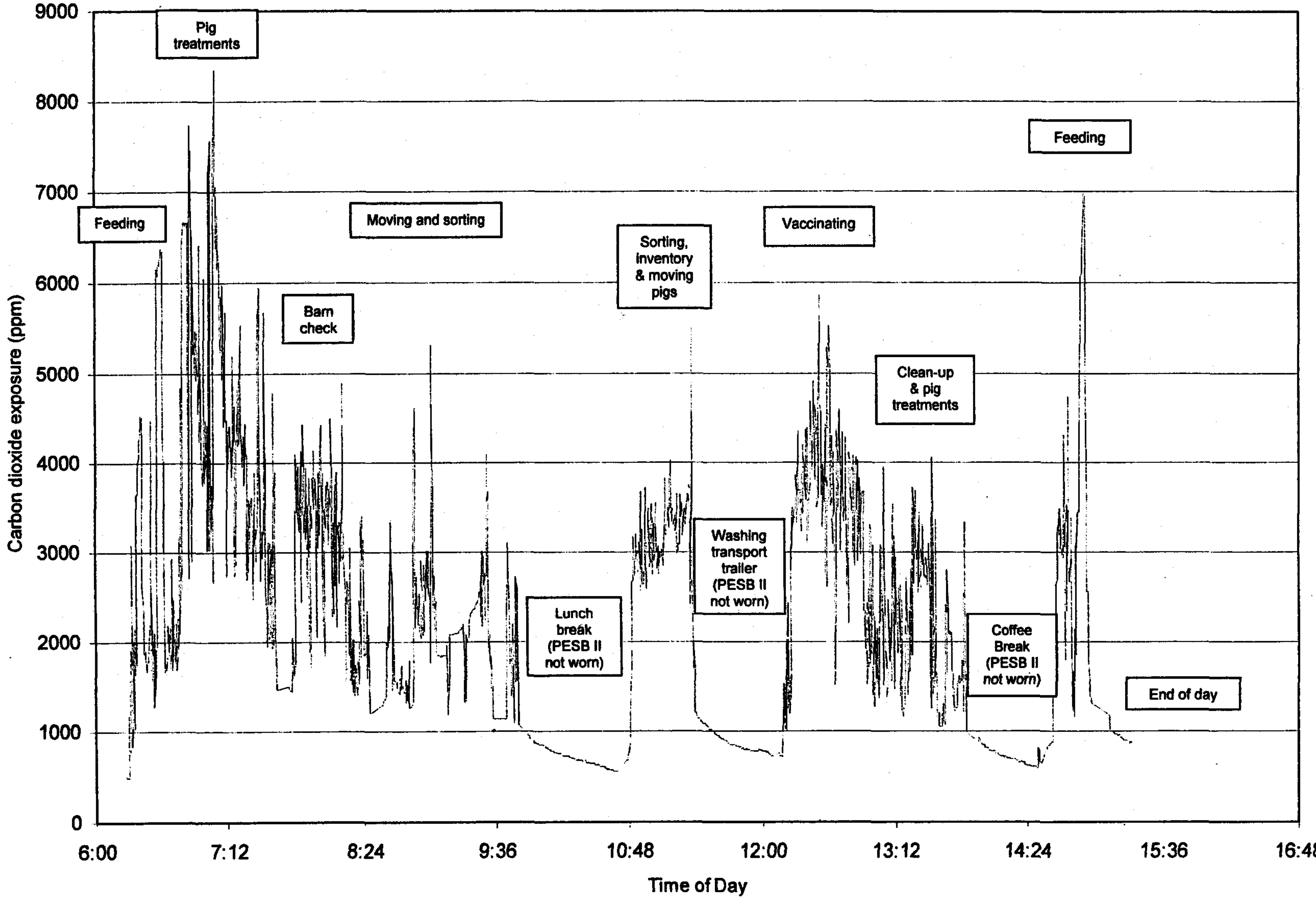

Figure 4.1. CO_2 (ppm) exposures of a Nursery-Grower/Finisher worker over various work activities during a 9.1-h winter workshift

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Table 4.3. CO_2 Exposures of Specialty Pig Barn Workers Conducting Workplace Activities in which ≥ 2 workers were involved

	CO_2 (ppm)			
ACTIVITY	Dry Sow/Breeding (N=13) mean ± SD [median] (min-max)	Farrowing (N=13) mean ± SD [median] (min-max)	Nursery/Grower-Finisher (N=10) mean ± SD [median] (min-max)	Significance
100 - Heat checking/breeding	2508 ± 790			
120 - Heat checking	2570 ± 1018 [2495] (484-8635) N[1]=11	—	—	—
130 - Natural breeding	2194 ± 799 [2203] (1049-6828) N=5	—	—	—
150 - Artificial insemination	2682 ± 1204 [2242] (473-9241) N=11	—	—	—
200 - Manure removal/cleaning	2439 ± 1541	1582 ± 454	1830 ± 482	
210 - Scraping solid manure	3374 ± 2227 [2941] (523-8621) N=8	1836 ± 589 [2057] (360-5645) N=7	2052 ± 465 [2052] (325-5009) N=2	0.15
230 - Sweeping	3082 ± 336 [3082] (2658-3921) N=2	1905 ± 74 [1905] (620-2753) N=2	—	0.12
270 - Pit work	1838 ± 781 [1790] (525-4816) N=6	1767 ± 816 [2196] (368-4030) N=3	1709 ± 689 [1637] (431-5262) N=6	0.97
300 - Farrowing & piglet care		1746 ± 514		
330 - Farrowing assistance	—	1510 ± 369 [1550] (304-4346) N=7	—	—
360 - Piglet processing	—	1879 ± 533 [1955] (330-7689) N=12	—	—
370 - Cross-fostering	1345 ± 189 [1345] (765-2879) N=2	1666 ± 518 [1666] (449-4497) N=11	—	0.32
400 - Feeding & feed delivery	2624 ± 1864	1692 ± 340	2221 ± 680	
430 - Dry feeding	2762 ± 1996 [2395] (529-8689) N=11	1801 ± 335 [1768] (318-6531) N=8	2504 ± 1009 [2071] (347-7568) N=7	0.15
440 - Liquid feeding	1804 ± 691 [1835] (427-8780) N=4	1657 ± 99 [1657] (491-4223) N=2	—	0.36
460 - Creep feeding	1785 ± 166 [1785] (968-3026) N=2	1670 ± 412 [1754] (374-6424) N=10	—	0.67
470 - Checking feed system	1796 ± 856 [2003] (837-2868) N=3	1798 ± 1194 [1798] (393-3210) N=2	1705 ± 512 [1737] (554-5692) N=3	0.95
480 - Cleaning feeders	2849 ± 473 [2875] (965-4231) N=5	—	2422 ± 727 [2307] (403-8800) N=3	0.30
500 - Barn check & treatments	2318 ± 844	1664 ± 426	2388 ± 662	
510 - Barn check	2559 ± 1062 [2163] (456-9066) N=10	1822 ± 552 [1712] (449-6726) N=10	2235 ± 614 [2216] (291-5295) N=7	0.10
520 - Animal identification	2205 ± 792 [1980] (635-5260) N=7	1539 ± 277 [1576] (572-3254) N=5	2316 ± 550 [2316] (495-5842) N=2	0.11
530 - Pig treatments	1898 ± 644 [1773] (444-4662) N=8	1836 ± 414 [1895] (491-6267) N=10	2824 ± 1000 [3031] (475-8361) N=7	0.11
540 - Vaccinations	2533 ± 1725 [2267] (679-9079) N=5	1967 ± 377 [1967] (536-2706) N=2	3059 ± 1043 [2945] (473-8097) N=4	0.67
600 - Barn maintenance				
660 - Manure system repair	—	1523 ± 31 [1523] (1264-1708) N=2	1632 ± 393 [1632] (400-4076) N=2	0.37
700 - Moving & weighing pigs	2251 ± 926	1769 ± 419	2114 ± 396	
720 - Moving piglets	1977 ± 426 [1972] (740-3914) N=4	1850 ± 328 [1749] (387-4887) N=6	2177 ± 344 [2141] (417-4042) N=3	0.35
730 - Moving older pigs	2260 ± 1006 [1875] (222-9228) N=13	1679 ± 500 [1792] (349-5037) N=10	1996 ± 487 [1942] (260-6139) N=10	0.16
740 - Sorting/selecting	2153 ± 236 [2153] (753-3605) N=2	—	2295 ± 212 [2270] (436-5293) N=4	0.53
750 - Weighing	1856 ± 68 [1856] (1215-2793) N=2	—	2203 ± 651 [1953] (492-4229) N=4	0.30
900 - Other (miscellaneous)	1206 ± 877	821 ± 171	850 ± 755	
911 - Coffee/lunch	1252 ± 1032 [922] (202-8756) N=13	821 ± 171 [827] (261-7912) N=13	854 ± 352 [805] (256-4403) N=10	0.20

[B] Statistical difference between specialty worker groups where D-N depicts a difference between Dry Sow/Breeding workers and Nursery/Grower-Finisher workers; D-F depicts a difference between Dry Sow/Breeding and Farrowing; and F-N depicts a difference between Farrowing and Nursery/Grower-Finisher

For statistical significance, †$p<0.05$; *$p \leq 0.01$; **$p \leq 0.001$. [1]N represents the numbers of workers conducting a particular activity activities conducted, peak exposures were seen to exceed 5000 ppm. In Figure 4.2, the majority of activity-specific exposures were seen to exceed the mean daily CO_2 exposures of 1660 ppm during winter, as reported in Chapter Three. As would be expected, CO_2 exposures during breaks (coffee/lunch) were lower, on average, than for other activities conducted by workers in this study. In Figure 4.2, some activities were seen to contribute more, while others less, to the average workshift CO_2 exposure (from Chapter three) highlighted on the graph.

4.3.3.2 **Respirable dust (>0.5 μm particles/mL)**

Figure 4.3 depicts the respirable dust counts (>0.5 μm) exposures of a Nursery-Grower/Finisher worker over various work activities during a 9.1-h winter workshift. Farrowing workers were found to be exposed to the lowest respirable dust count exposures during dry feeding, compared to Dry Sow/Breeding or Nursery/Grower-Finisher workers (p=0.03) (Table 4.4). Dry Sow/Breeding workers were found to have significantly higher respirable dust exposures during barn checking, when compared with Farrowing and Nursery/Grower-Finisher workers (p=0.01), and during pig treatment activities, when compared with Farrowing workers (p=0.04).

For the majority of activities conducted by pig barn workers in this study, mean respirable dust count exposures were found to be less than 30 particles/mL. However, dust counts were found to be > 30 particles/mL for the sweeping activity (conducted by Farrowing workers), checking the feed system (conducted by Dry Sow/Breeding and Farrowing workers), animal identification and vaccinating activities (conducted by

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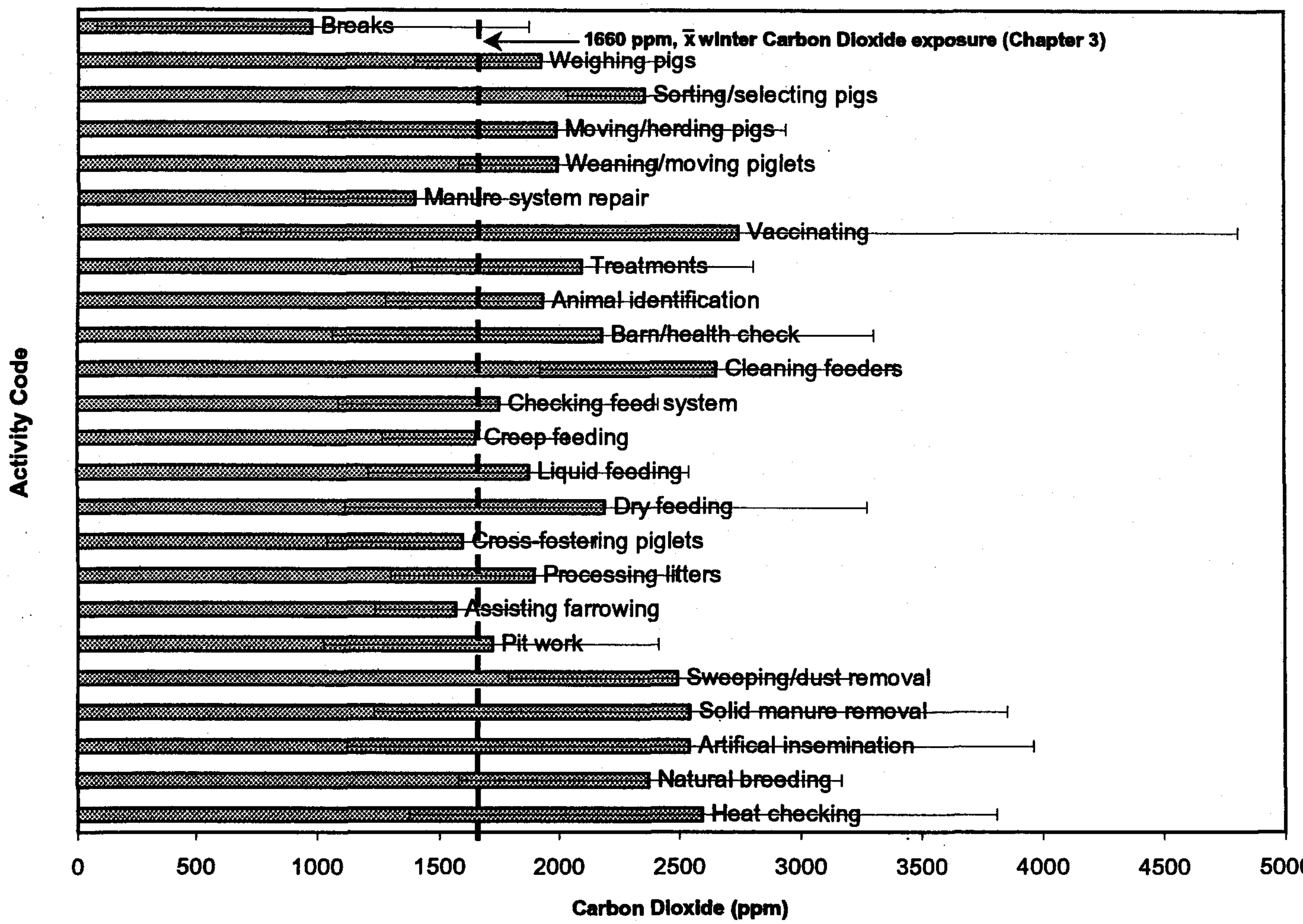

Figure 4.2. Activity-specific CO_2 exposures of pig barn workers. The overall mean winter CO_2 exposure from Chapter 3 (Paper One) is highlighted. The whiskers represent the SD for each mean activity-specific CO_2 exposure.

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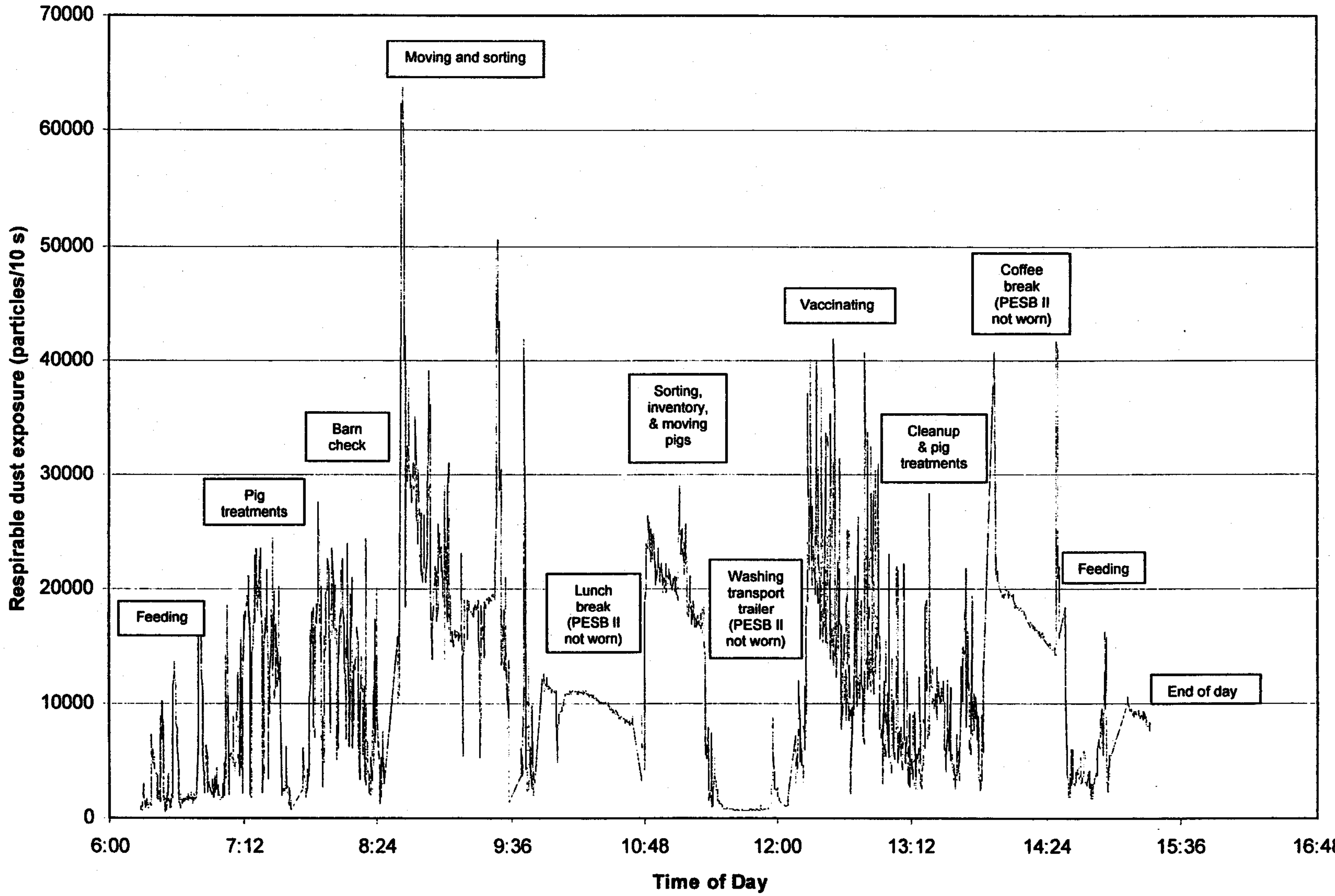

Figure 4.3. Respirable dust (>0.5 μm) (particles/10 s) exposures of a Nursery-Grower/Finisher worker over various work activities during a 9.1-h winter workshift

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Table 4.4. Respirable Dust Particle Count exposures of specialty pig barn workers conducing workplace activities in which ≥ 2 workers were involved.

	>0.5 µm dust particle counts / mL			
ACTIVITY	Dry Sow/Breeding (N=13) mean ± SD [median] (min-max)	Farrowing (N=13) mean ± SD [median] (min-max)	Nursery/Grower-Finisher (N=10) mean ± SD [median] (min-max)	[B] Significance
100 - Heat checking/breeding	24.7 ± 7.5			
120 - Heat checking	25.9 ± 9.1 [24.3] (2.7-132.1) N=11	—	—	—
130 - Natural breeding	26.2 ± 10.5 [29.1] (2.6-107.8) N=5	—	—	—
150 - Artificial insemination	21.6 ± 8.0 [17.8] (1.3-115.2) N=11	—	—	—
200 - Manure removal/cleaning	21.7 ± 11.0	20.0 ± 13.7	18.5 ± 11.0	
210 - Scraping solid manure	24.4 ± 10.2 [21.3] (1.6-76.2) N=8	24.3 ± 20.4 [16.9] (0.9-129.9) N=7	16.6 ± 3.4 [16.6] (0.8-105.1) N=2	0.53
230 - Sweeping	23.8 ± 6.6 [23.8] (15.7-48.6) N=2	35.9 ± 7.0 [35.9] (5.6-89.7) N=2	—	0.12
270 - Pit work	25.9 ± 18.6 [20.3] (3.0-137.8) N=6	15.5 ± 6.4 [11.9] (1.7-72.7) N=3	14.2 ± 9.8 [13.0] (0.6-129.3) N=6	0.40
300 - Farrowing & piglet care		14.2 ± 6.4		
330 - Farrowing Assistance	—	12.0 ± 6.7 [10.7] (0.1-139.4) N=7	—	—
360 - Piglet processing	—	15.9 ± 8.8 [13.9] (0.3-129.5) N=12	—	—
370 - Cross-fostering	15.1 ± 1.4 [15.1] (1.3-48.6) N=2	14.9 ± 11.8 [11.9] (0.4-124.6) N=11	—	0.55
400 - Feeding & feed delivery	21.6 ± 8.1	15.2 ± 6.5	20.7 ± 13.1	
430 - Dry feeding	24.8 ± 7.4 [23.7] (0.8-118.8) N=11	17.7 ± 3.2 [17.0] (0.9-133.6) N=8	19.6 ± 15.4 [13.4] (0.3-139.2) N=7	0.03 (D-F†; F-N*)
440 - Liquid feeding	16.7 ± 4.8 [16.2] (1.4-127.5) N=4	18.9 ± 10.6 [18.9] (1.6-98.7) N=2	—	1.00
460 - Creep feeding	15.2 ± 0.1 [15.2] (2.9-52.9) N=2	13.8 ± 6.2 [14.2] (0.3-117.4) N=10	—	0.67
470 - Checking feed system	36.5 ± 20.8 [36.5] (19.6-55.5) N=2	33.1 ± 28.1 [33.1] (2.2-64.0) N=2	20.6 ± 8.5 [20.0] (5.3-129.4) N=3	0.56
480 - Cleaning feeders	25.2 ± 13.4 [19.7] (3.7-122.7) N=5	—	27.9 ± 28.2 [23.2] (0.2-89.2) N=3	0.88
500 - Barn check & treatments	24.3 ± 5.8	13.1 ± 7.6	22.5 ± 8.6	
510 - Barn check	25.7 ± 8.5 [24.2] (0.5-139.0) N=10	12.7 ± 6.7 [11.7] (0.6-139.8) N=10	19.9 ± 7.9 [19.0] (0.2-136.2) N=7	0.01 (D-F†; D-N†; F-N†)
520 - Animal identification	22.3 ± 8.4 [22.2] (3.0-164.0) N=7	18.7 ± 14.4 [16.5] (0.6-128.7) N=5	31.5 ± 8.9 [31.5] (2.6-95.9) N=2	0.31
530 - Pig treatments	20.7 ± 7.0 [17.5] (1.9-96.6) N=8	13.1 ± 8.4 [12.3] (0.8-300.8) N=11	21.6 ± 11.5 [21.7] (0.6-79.5) N=7	0.04 (D-F†)
540 - Vaccinations	25.6 ± 11.3 [22.7] (1.8-85.5) N=5	18.7 ± 8.4 [18.7] (1.6-46.4) N=2	30.3 ± 8.0 [29.3] (1.2-91.8) N=4	0.50
600 - Maintenance				
660 - Manure system repair	—	8.1 ± 3.5 [8.1] (5.3-11.4) N=2	21.4 ± 5.8 [21.4] (2.3-124.8) N=2	0.17
700 - Moving & weighing pigs	23.9 ± 8.1	19.9 ± 8.6	27.0 ± 8.5	
720 - Moving piglets	15.5 ± 7.0 [16.3] (1.0-57.4) N=4	25.2 ± 10.4 [26.6] (0.6-131.0) N=6	28.1 ± 17.3 [31.8] (0.6-102.2) N=3	0.17
730 - Moving older pigs	23.7 ± 7.2 [22.2] (0.6-129.3) N=13	18.6 ± 7.6 [17.3] (0.9-98.4) N=11	25.3 ± 9.7 [22.9] (0.2-137.7) N=10	0.15
740 - Sorting/selecting	33.3 ± 16.8 [33.3] (4.5-69.4) N=2	—	32.6 ± 3.5 [33.1] (2.3-88.6) N=4	0.59
750 - Weighing	33.7 ± 9.4 [33.7] (4.4-88.0) N=2	—	22.3 ± 11.4 [25.6] (0.4-104.7) N=4	0.25
900 - Other (miscellaneous)	25.8 ± 26.4	23.3 ± 28.0	25.9 ± 22.9	
911 - Coffee/lunch	25.4 ± 26.3 [14.4] (0.5-147.5) N=13	23.3 ± 28.0 [15.5] (0.3-141.6) N=13	25.9 ± 31.4 [17.2] (0.2-137.4) N=10	0.96

[B] Statistical difference between specialty worker groups where D-N depicts a difference between Dry Sow/Breeding workers and Nursery/Grower-Finisher workers; D-F depicts a difference between Dry Sow/Breeding and Farrowing; and F-N depicts a difference between Farrowing and Nursery/Grower-Finisher

For statistical significance, $^{\dagger}p<0.05$; $^{*}p\leq0.01$; $^{**}p\leq0.001$. [1]N represents the numbers of workers conducting a particular activity

Nursery/Grower-Finisher workers), sorting and selecting pigs (conducted by Dry Sow/Breeding and Nursery/Grower-Finisher workers), and weighing activities (conducted by Dry Sow/Breeding workers). In 88% of the activities evaluated in this study, peak respirable dust count exposures exceeded 100 particles/mL at some point during the activity. The highest peak exposure was noted for a Farrowing worker conducting the pig treatment task. Dust exposures during coffee and lunch breaks in designated areas were not found to be different than exposures in the rest of the barn, except for those activities noted above.

Figure 4.4 presents the activity-specific respirable dust count exposures of participating pig barn workers. A number of workplace activities appear to result in high respirable dust exposures among workers, including sorting/selecting, vaccinating, cleaning feeders, sweeping, and natural breeding. Sixty per cent of workplace activities conducted by workers in this study, were seen to exceed the mean daily winter exposure of 20.5 particles/mL (Chapter Three).

When respirable dust exposures were dichotomized into either high (≥20 particles/mL) or low (<20 particles/mL) exposures, a significant difference was found among specialty workers (Table 4.5). The proportion of activities where respirable dust exposures were low (< 20 particles/mL) among Dry Sow/Breeding workers, was found to be significantly greater, 106 out of 201 (53%), than for those of Farrowing workers, 55 out of 196 (28%) (χ^2=25.1, df=1, p<0.0001). More importantly, Farrowing workers were almost 3 times as likely to be exposed to higher respirable dust counts when conducting

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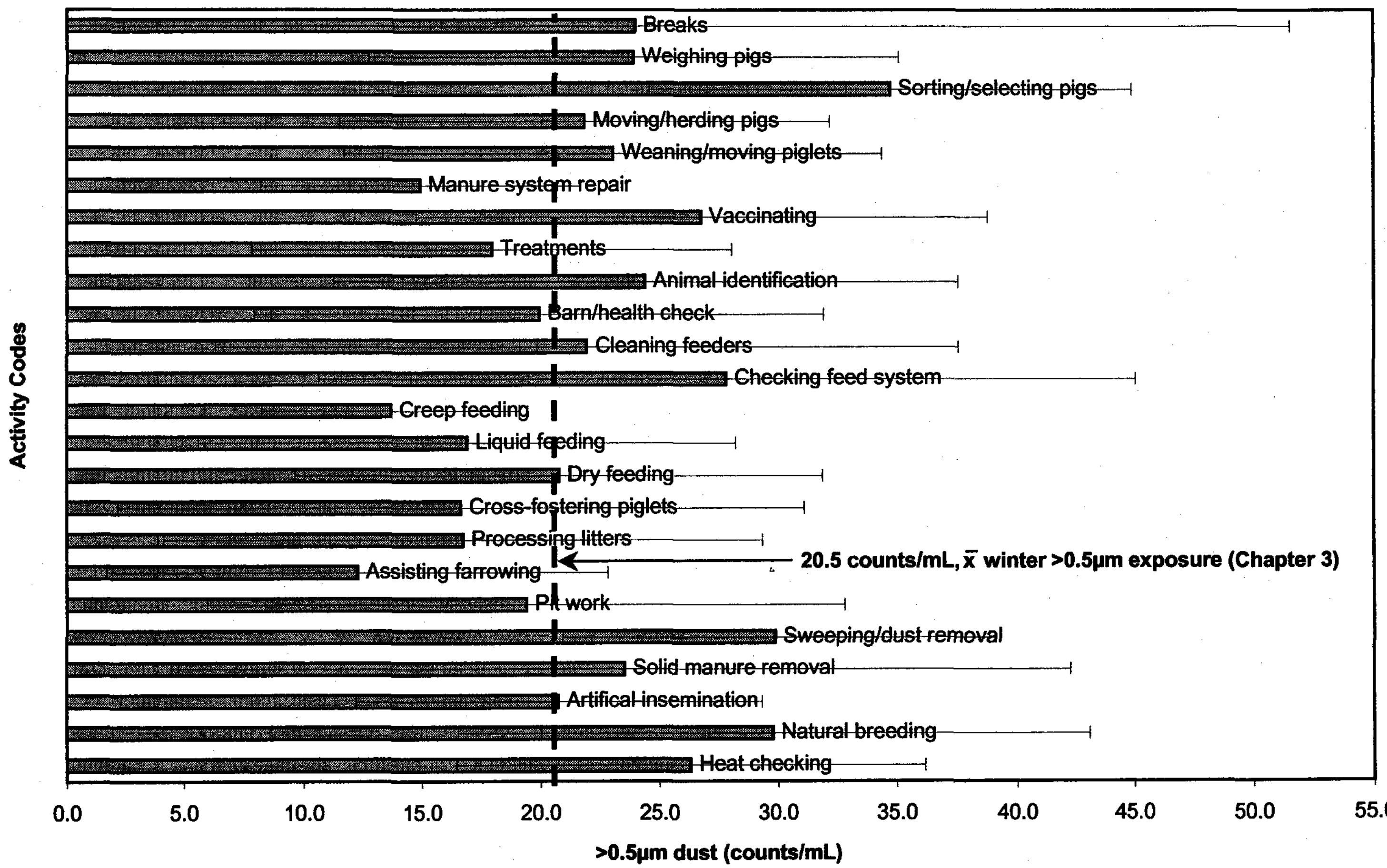

Figure 4.4. Activity-specific respirable dust count exposures (>0.5 µm particles/mL) of pig barn workers. The overall time-weighted average (TWA) exposure from Chapter Three is highlighted. The whiskers represent the SD for each activity-specific respirable dust count exposure.

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Table 4.5. High (≥20 particles/mL) and low (< 20 particles/mL) respirable dust exposures of workers conducting workplace activities in the 3 different specialty areas in pigs barns

Respirable dust exposures (>0.5 particles/mL)	Worker Specialization			
	Dry Sow / Breeding	Farrowing	Nursery/Grower-Finisher	TOTAL
< 20 particles/mL (low)	106 (53%)	55 (28%)	68 (55%)	229 (44%)
≥ 20 particles/mL (high)	95 (47%)	141 (72%)	55 (45%)	291 (56%)
TOTAL	201 (100%)	196 (100%)	123 (100%)	520 (100%)

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their work tasks, when compared to Dry Sow/Breeding workers (OR=2.9, 95% CI: 1.9-4.3). As well, the proportion of low respirable dust exposure activities conducted by Nursery/Grower-Finisher workers, were also significantly greater, 68 out of 123 (55%), than those of Farrowing workers, 55 out of 196 (28%) (χ^2=23.6, p<0.0001). As was the case for Dry Sow/Breeding workers, Farrowing workers were 3 times more likely to be exposed to higher respirable dust count exposures when conducting their workplace activities, when compared to Nursery/Grower-Finisher workers (OR=3.2, 95% CI: 2.0-5.1).

Respirable dust exposures were also compared for workplace activities involving the moving of pigs to those not involving pig movements (Table 4.6). Workers conducting pig movement activities had higher exposures to respirable dust (> 0.5 μm particles/mL), and this difference tended towards significance (p=0.054).

4.3.3.3 **Hydrogen Sulfide**

Figure 4.5 depicts the H_2S (ppm) exposures of a Nursery-Grower/Finisher worker over various work activities during a 9.0-h winter workshift. Overall, activity-specific H_2S exposures were low (< 4 ppm) on average, for all workplace tasks examined in this study (Table 4.7). Moreover, for 96% of the activities conducted by workers in this study, mean exposures were ≤ 2 ppm. No differences were found in H_2S exposures among workplace activities conducted by Dry Sow/Breeding, Farrowing or Nursery/Grower-Finisher workers. However, 84% of activity-specific H_2S exposures were seen to exceed the mean daily (winter) exposure for this contaminant (Figure 4.6).

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Table 4.6. Respirable dust (>0.5 μm dust particles/mL) exposures of workers when conducting moving/herding and non-moving activities

Moving pig activities*	Number of activities	Respirable dust (> 0.5 μm particles/mL) count exposures
		mean ± SD
Moving / herding pigs	67	24.6 ± 10.4
Non-moving activities	453	20.7 ± 15.8

* Activities were coded as "moving" if they were natural breeding (130), moving newly weaned piglets (720), moving older pigs (730), sorting/marking pigs (740), and weighing pigs (750) activities

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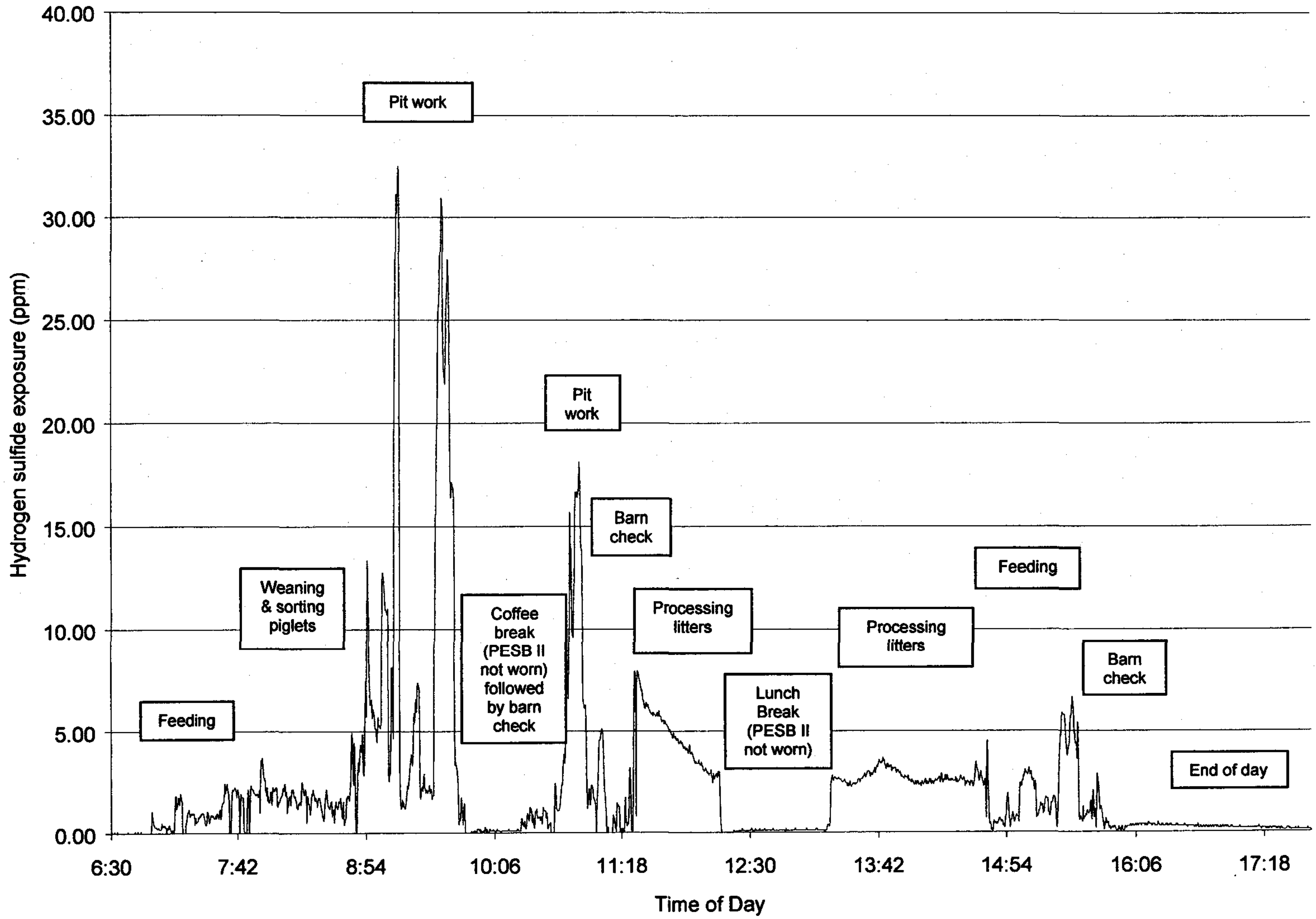

Figure 4.5. Hydrogen sulfide (ppm) exposures of a Nursery-Grower/Finisher worker over various work activities during a 9.0-h winter workshift

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Table 4.7. Hydrogen Sulfide gas exposures of specialty pig barn workers conducing workplace activities in which ≥ 2 workers were involved.

	H_2S (ppm)			
ACTIVITY	Dry Sow/Breeding (N=13) mean ± SD [median] (min-max)	Farrowing (N=13) mean ± SD [median] (min-max)	Nursery/Grower-Finisher (N=10) mean ± SD [median] (min-max)	[B] Significance
100 - Heat checking/breeding	0.9 ± 0.5			
120 - Heat checking	0.8 ± 0.4 [0.8] (0-3.9) N[1]=11	—	—	—
130 - Natural breeding	0.8 ± 0.6 [1.0] (0-7.1) N=5	—	—	—
150 - Artificial insemination	1.0 ± 0.9 [0.7] (0-24.4) N=11	—	—	—
200 - Manure removal/cleaning	1.2 ± 0.9	0.7 ± 0.6	1.0 ± 0.9	
210 - Scraping solid manure	1.4 ± 1.2 [1.1] (0-11.2) N=8	0.6 ± 0.5 [0.5] (0-7.6) N=7	0.3 ± 0.1 [0.3] (0-14.9) N=2	0.15
230 - Sweeping	2.0 ± 0.7 [2.0] (1.1-3.3) N=2	—	—	0.22
270 - Pit work	3.2 ± 1.8 [2.4] (0-47.5) N=6	3.3 ± 4.5 [1.1] (0-32.5) N=3	1.9 ± 2.2 [0.8] (0-94.0) N=6	0.35
300 - Farrowing & piglet care		1.0 ± 0.8		
330 - Farrowing Assistance	—	0.6 ± 0.3 [0.6] (0-4.0) N=6	—	—
360 - Piglet processing	—	0.9 ± 0.6 [0.7] (0-21.2) N=11	—	—
370 - Cross-fostering	0.2 ± 0.1 [0.2] (0-0.6) N=2	0.9 ± 0.9 [0.7] (0-4.1) N=11	—	0.17
400 - Feeding & feed delivery	0.9 ± 0.5	1.0 ± 0.7	1.9 ± 1.6	
430 - Dry feeding	0.9 ± 0.5 [0.9] (0-14.8) N=11	1.4 ± 0.8 [1.2] (0-61.5) N=8	1.8 ± 1.6 [1.2] (0-18.7) N=7	0.50
440 - Liquid feeding	0.7 ± 0.2 [0.7] (0-16.4) N=4	1.0 ± 0.2 [1.0] (0-18.7) N=2	—	0.17
460 - Creep feeding	0.7 ± 0.2 [0.7] (0-3.1) N=2	1.0 ± 1.1 [0.7] (0-67.0) N=10	—	1.00
470 - Checking feed system	0.6 ± 0.8 [0.3] (0-1.6) N=3	0.6 ± 0.1 [0.6] (0-1.4) N=2	3.2 ± 3.1 [1.9] (0-53.1) N=3	0.15
480 - Cleaning feeders	1.4 ± 0.6 [1.1] (0.4-2.6) N=5	—	1.4 ± 0.9 [1.7] (0-3.3) N=3	0.88
500 - Barn check & treatments	0.8 ± 0.5	1.0 ± 0.7	1.1 ± 0.6	
510 - Barn check	1.0 ± 0.6 [0.8] (0-43.5) N=10	1.2 ± 0.9 [0.8] (0-17.8) N=9	1.2 ± 0.5 [1.0] (0-15.9) N=7	0.62
520 - Animal identification	0.9 ± 0.6 [0.6] (0-2.4) N=6	0.7 ± 0.6 [0.7] (0-2.7) N=4	0.6 ± 0.4 [0.6] (0-1.1) N=2	0.75
530 - Pig treatments	0.7 ± 0.5 [0.7] (0-15.7) N=7	0.9 ± 0.9 [0.9] (0-8.3) N=11	1.4 ± 1.2 [0.7] (0-8.8) N=7	0.44
540 - Vaccinations	0.5 ± 0.3 [0.5] (0-11.0) N=5	—	1.1 ± 0.6 [1.1] (0-2.9) N=4	0.09
600 - Maintenance				
660 - Manure system repair	—	0.7 ± 0.5 [0.7] (0.2-1.7) N=2	2.4 ± 2.5 [2.4] (0.3-18.1) N=2	0.30
700 - Moving & weighing pigs	1.0 ± 0.7	1.1 ± 1.1	0.8 ± 0.5	
720 - Moving piglets	0.7 ± 0.5 [0.6] (0-2.3) N=4	1.1 ± 0.8 [1.0] (0-7.0) N=6	0.6 ± 0.3 [0.5] (0-1.3) N=3	0.56
730 - Moving older pigs	1.0 ± 0.7 [0.6] (0-29.1) N=13	1.2 ± 1.3 [0.7] (0-55.0) N=11	0.7 ± 0.4 [0.7] (0-5.1) N=10	0.72
740 - Sorting/selecting	0.8 ± 0.5 [0.8] (0.2-2.9) N=2	—	0.8 ± 0.9 [0.6] (0-6.2) N=4	1.00
750 - Weighing	0.9 ± 1.3 [0.9] (0-8.1) N=2	—	1.2 ± 1.3 [1.4] (0-25.0) N=4	0.88
900 - Other (miscellaneous)				
911 - Coffee/lunch	0.2 ± 0.2 [0.2] (0-4.3) N=13	0.2 ± 0.1 [0.1] (0-3.0) N=13	0.3 ± 0.2 [0.3] (0-8.5) N=10	0.46

[B] Statistical difference between specialty worker groups where D-N depicts a difference between Dry Sow/Breeding workers and Nursery/Grower-Finisher workers; D-F depicts a difference between Dry Sow/Breeding and Farrowing; and F-N depicts a difference between Farrowing and Nursery/Grower-Finisher

For statistical significance, †$p<0.05$; *$p \leq 0.01$; **$p \leq 0.001$. [1]N represents the numbers of workers conducting a particular activity

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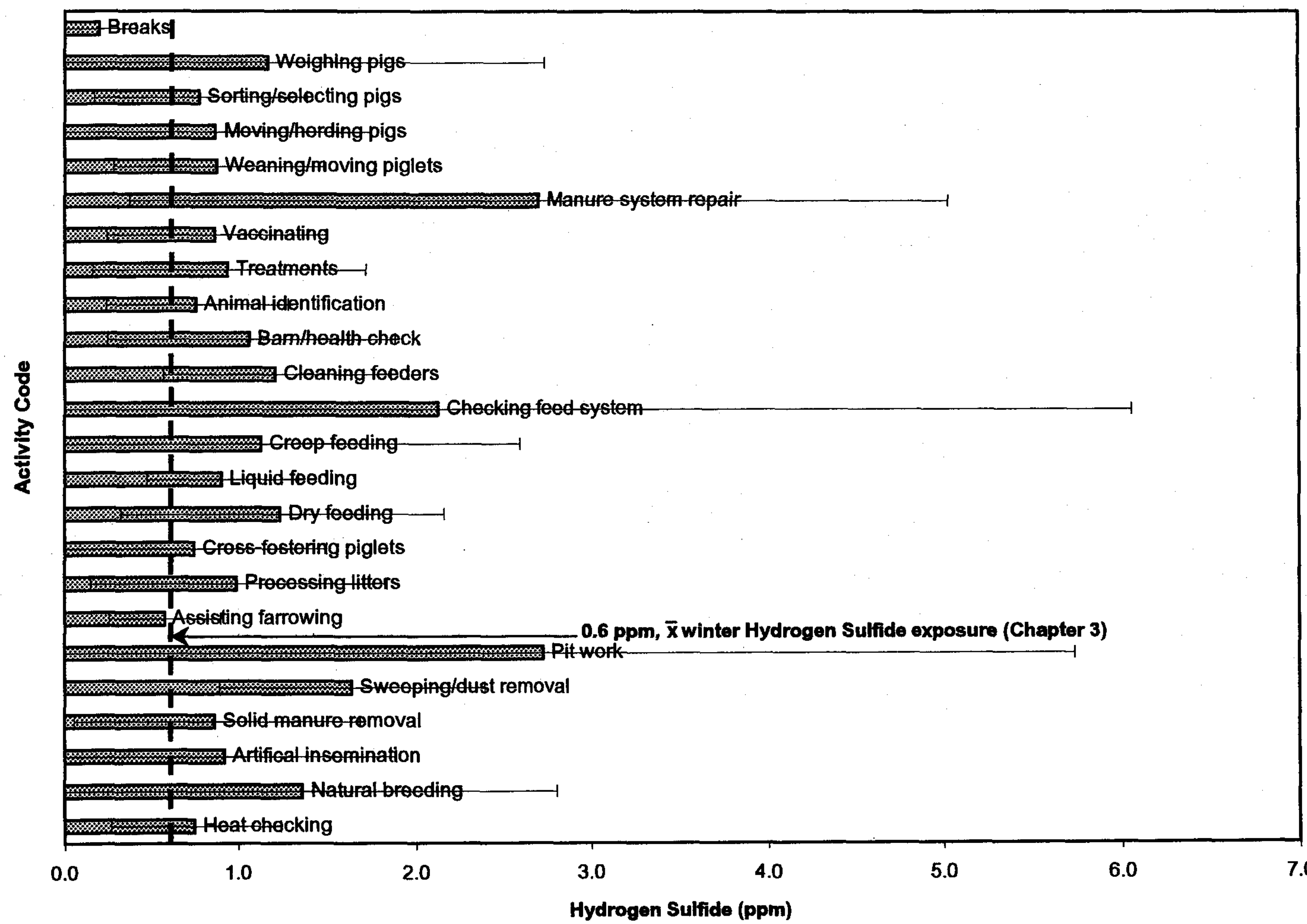

Figure 4.6. Activity-specific H_2S exposures of pig barn workers. The overall mean winter exposure from Chapter 3 (Paper One) is highlighted. The whiskers represent the SD for each activity-specific H_2S exposure.

Some workplace activities were seen to contribute more than others to the overall average H_2S workshift exposure (from Chapter three), highlighted in Figure 4.6.

More importantly however, in 19 workplace activities, workers were exposed to concentrations of H_2S exceeding the Alberta Government proposed 15 ppm exposure limit for this contaminant. Peak exposures were found among pit work and manure system (pump repair) activities, where such exposures are expected. In fact, the highest H_2S exposure recorded in this investigation was 94 ppm for a Nursery/Grower-Finisher worker conducting the pit work activity. However, peak ($\geq$ 15 ppm) H_2S exposures were also found among workplace activities not associated with liquid manure removal from barns. In the Dry Sow/Breeding specialty area, H_2S exposures $\geq$ 15 ppm occurred while workers were conducting the barn checking, moving older pigs, pig treatment, artificial insemination and liquid feeding activities. Among Farrowing workers, the job activities leading to high H_2S exposures included dry, liquid and creep feeding, barn checking, piglet processing and moving older pigs. For workers in the Nursery/Grower-Finisher area, conducting the dry feeding, feeding system check, barn checking and weighing pig activities resulted in exposures to H_2S above the 15 ppm ceiling limit.

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4.4 Discussion

4.4.1 Activity-specific workplace exposures

In this study, activity-specific workplace exposures were only evaluated for the activity itself[3], and did not include supporting activities that occurred prior to or immediately following a given task (ie. those activities coded in this study as work preparation activities including: walking from zone to zone or area to area; talking or meeting with co-workers; looking for co-workers; looking for, getting or returning supplies; or assembling supplies required for a particular activity in a location (such as in the shop, hallway, office area, or medicine room) other than where the included activity ultimately took place). This was intentional, because it was important to the study to evaluate exposures for the workplace task itself, and not have exposures diluted by anticipated lower contaminant levels in supporting areas. However, it is important to point out that workplace activities were included in this study, even if they were not solely conducted in the animal rooms. The moving of older pigs activity is an example, where pigs are not just moved from pen to pen within an animal room. This is a task that is also conducted in hallways of barns where pigs are moved from room to room or to the designated shipping areas of the barns. The use of observer-recorded data allowed just such an evaluation, since workers had included "work preparation" activities in the data they themselves had recorded.

[3] Supporting activities were excluded by IIW during the determination of start and finish times for included activities.

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4.4.1.1 **Carbon Dioxide.**

Mean CO_2 exposures during workplace activities, did not exceed the TWA-TLV of 5000 ppm for this contaminant (ACGIH, 2001). In only a few occasions did the CO_2 exposure exceed the suggested air quality guideline of 3000 ppm (Wathes and Charles, 1994), indicating that specialty workers in this winter study, were conducting workplace activities in well ventilated barns. Warmer than average outdoor temperatures during the winter in the present study (mean temperature 4 °C, ranging from -9 to 14 °C) likely contributed to higher barn ventilation rates, and therefore the lower CO_2 concentrations seen (Chapter Three).

For two activities, however, CO_2 concentrations were higher than 3000 ppm. Dry Sow/Breeding workers conducting the sweeping tasks may have encountered stale pockets of air in the barns (i.e. areas of incomplete air mixing). Higher CO_2 exposures seen during vaccinating activities, conducted by Nursery/Grower-Finisher workers, probably reflects the lower ventilation rates seen in Nursery barns to achieve warm (30 °C) and draft-free environmental conditions for newly introduced nursery pigs (Barber et al., 1991b). Encountering stale air pockets during other workplace activities also likely contributed to the high peak CO_2 exposures noted in this study. As well, since some of the workplace tasks occurred at "pig level", there is a possibility that some of the higher CO_2 exposures seen may be attributable to the higher respiration rates of the pigs during times of higher animal activity in response to the presence of the workers (Barber et al., 1991a).

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4.4.1.2 **Respirable dust count exposures.**

In this study, laser dust particle counting was employed to compare the activity-specific respirable dust exposures of three different pig barn specialty worker groups. This technology was used because it would not have been possible to collect sufficient respirable dust mass to measure gravimetrically during short duration (< 2 hours) activities (Preller et al., 1995a). Other research groups have used laser dust particle counting as well. Some used this technology primarily as a tool to determine the effectiveness of dust suppression technologies (Welford et al., 1992; Perkins and Feddes, 1996; Zhang et al., 1996; Senthilselvan et al., 1997; Zhang et al., 1998; Lemay et al., 2000), while other research groups used laser dust particle counting to evaluate respirable dust concentrations in Farrowing and Finishing barns (Nicks et al., 1993), to evaluate the effects of sow and piglet activity on respirable dust concentrations (Perkins et al., 1997), and to evaluate the health effects of respirator use (Dosman et al., 2000). Research groups are presently evaluating the suitability of similar dust counting technology, as alternatives to gravimetric sampling because of cost, ease of use and obtaining results in a shorter time frame (Taylor and Reynolds, 2001).

Farrowing workers were found to have the lowest respirable dust count exposures during dry feeding, compared with Dry Sow/Breeding and Nursery/Grower-Finisher workers, despite spending significantly more time on the dry feeding activity. While pigs in all specialty areas of the study barns were predominantly fed a ground feed ration (Chapter Three), the fineness of grind may have contributed to the worker's respirable dust exposures (Holness et al., 1987). However, fineness of grind was not evaluated in

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the present study. It is perhaps more likely, that the feeding method employed in the Farrowing area (predominantly hand scooping feed into individual sow feeders) did not liberate as much respirable dust as the drop feeding method for sows in the Dry Sow/Breeding barns, or the filling of automated feeders for pigs in the Nursery/Grower-Finisher barns. The differing exposure results for Farrowing workers in this study are supported by another study where workers who used floor feeding methods (feed is dumped onto the floor for groups of pigs, which is roughly akin to drop feeding), had higher personal respirable dust exposures when compared to those who used automated or hand feeding methods (Holness et al., 1987). In contrast to the Holness et al. (1987) study, differences were also found between automated feeding (Nursery/Grower-Finisher areas) and scoop feeding activities (Farrowing areas) in the present study. This was likely because specialty area exposures were not evaluated by Holness et al. (1987) study.

Farrowing workers were found to have the lowest respirable dust count exposures during barn checking when compared with Dry Sow/Breeding and Nursery/Grower-Finisher workers. These low exposures may be the result of the clean surroundings in which Farrowing workers conduct their activities. Farrowing rooms are thoroughly washed (including the removal of dust from walls and ceilings) following a 3-week residency time of pigs in this area, coinciding with piglet weaning (Chapter Three). Since increased animal activity was shown to result in greater variability in respirable dust levels (Morrison et al., 1993), the presence of Farrowing workers in the Farrowing rooms during the barn checking activity, did not appear to create as much excitement and thus activity level, as occurred in the Dry Sow/Breeding and Nursery/Grower-Finisher areas.

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As well, the respirable dust count exposures of Dry Sow/Breeding workers in particular may be higher during barn checking, because this particular task is conducted by these workers immediately following drop feeding. From a pig management perspective, this is the best time to conduct this task. However, from a respirable dust exposure perspective, this appears to be the worst time to conduct this activity, since dust exposures will be higher.

When high ($\geq$20 particles/mL) and low (< 20 particles/mL) respirable dust count exposure of workers were evaluated, Farrowing workers were 3 times as likely as Dry Sow/Breeding or Nursery/Grower-Finisher workers to be exposed to high respirable dust counts, when conducting workplace activities. This was a surprising result given that the Farrowing areas had the lowest stocking densities, compared to other specialty areas in the barn (Chapter Three), and that accumulated dust is removed every three weeks when the rooms are washed. The activities of the piglets in these areas, both during nursing episodes and during play, must therefore contribute to higher respirable particulate exposures. Perkins et al. (1997) found similar high exposures in these areas. Once respirable particulate concentrations were high, Perkins et al. (1997) found that it took a period of time before concentrations declined. So, hourly nursing episodes, on-going piglet play, and activities associated with the presence of the worker in the room, all contribute to the higher activity-specific respirable exposures seen among Farrowing workers.

An interesting result, highlighted in Figure 4.4, bears discussion. This figure, presents the activity-specific >0.5 μm dust particle/mL exposures of all participating

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workers, regardless of specialty. The activity of sorting and selecting pigs, stands out as having the highest respirable dust exposures compared to all other workplace activities conducted by workers in this investigation. To gain an understanding of why this may be the case, it is important to examine how this particular task is conducted. The sorting portion of this task involves the identification of a pig or group of pigs in a pen, and then moving only those particular pigs out of the pen. The selecting portion of this task involves crouching down close to the pig(s), to a height of about 0.6 meters, to evaluate the physical characteristics of each pig. Higher dust levels are expected to be present at this height, since workers are closer to the source. The high level of pig activity that ensues during the sorting and selecting activity, stirs up a lot of dust, which is reflected in the higher exposures seen for this activity. In addition, since the sorting/selecting activity took over 30 min, on average, to conduct, it is likely that during this high animal activity task, dust was continually re-entrained, contributing to the higher dust exposures seen.

Respirable dust exposures were also evaluated for moving and non-moving activities. The results indicated a slight trend towards higher exposures among workers conducting the moving task. Dust re-entrainment from the barn floor, as a result of the hoof actions of many pigs, likely contributed to the slightly higher dust exposures seen during this activity.

Dry Sow/Breeding and Nursery/Grower-Finisher workers conducting dry feeding and barn checking activities, workers conducting the pig sorting and selecting activities, and workers conducting pig moving tasks are exposed to higher respirable dust exposures

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during these tasks. Until such time that engineering and administrative controls can be established and implemented for the reduction of respirable dust exposures, the wearing of respiratory protection (specifically N95[4] respirators) should be considered. A recent study by Dosman et al. (2000), supports these recommendations. Study participants in the Dosman et al. study, who had no previous exposure to pig barns, were asked to wear N95 respirators during an exposure episode in a typical grower-finisher swine facility. The wearing of N95 respirators were shown to significantly decrease acute respiratory symptoms among these participants (Dosman et al., 2000). The long term health effects of respirable dust exposures are not known, but the wearing of properly fitting N95 respirators will help reduce the exposures of workers in the pig barn environments.

One of the more interesting results from this study, was the worker's exposures during their daily coffee and lunch breaks (average 107 minutes). CO_2 concentrations were less than 1300 ppm, on average, in these areas, indicating that coffee/lunch rooms tended to have "fresher" air. Contrary to expectations, the respirable dust exposures in the coffee/lunch areas were comparable to those of other workplace activities evaluated in this study. There are two possibilities why higher particle concentrations were present in the coffee/lunch room. Firstly, monitoring equipment was not worn by workers during breaks. Instead, it was placed along the wall, on the floor of the coffee/lunch area, so as to be out of the way. With the equipment now positioned low to the ground, and with workers walking past the equipment, any dust on the floor may have been stirred up, and

[4] N95 is a NIOSH designation that stipulates that this "mask" can be used in a non-wet environment, and will filter out 95% of particulates of an aerodynamic size of >0.3 μm.

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then measured by the dust counter. As well, since some coffee/lunch areas allowed smoking, some of the particulate present in tobacco smoke would have contributed to the respirable dust exposures monitored in these areas. These results highlight the importance of barn cleanliness, especially dust removal in all areas of the pig barn, including the coffee/lunch room.

4.4.1.3 **Hydrogen sulfide**

Pig barn workers in this study were exposed to low (< 4 ppm) overall H_2S concentrations (Chapter Three). However, the maximum H_2S concentrations differed among workers of different specialties when conducting different workplace activities. Since agitation results in H_2S release from manure (Zhang et al., 1990), as expected, the highest H_2S exposures were during pit pump repair and pit work activities, involving the agitation and removal of liquid manure from underfloor pits. Pig barn workers conducting the pit work tasks were found to be 21 times more likely to be exposed to H_2S concentrations exceeding the recommended 15 ppm ceiling limit, than workers not conducting pit work tasks (Chapter Five). It was interesting to note that not all workers conducting the pit work task had high peak H_2S exposures, indicating that H_2S release from pits is not predictable (Chénard et al., 2003). Other activities conducted by pig barn workers in this study resulted in H_2S exposures ≥15 ppm, the newly proposed ceiling limit for this contaminant in Alberta (Alberta Human Resources and Employment, 2002). These included: artificial insemination, piglet processing, dry feeding, liquid feeding, creep feeding, barn checking, pig treatments, moving older pigs and weighing activities. Among the Dry Sow/Breeding, Farrowing and Nursery/Grower-Finisher workers

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participating in this study, approximately 40% of workplace activities showed activity-specific H_2S exposures of greater than 15 ppm. Why such high H_2S exposures were seen for non-pit work activities is not clear. It is possible the workers had just previously conducted the pit work activity and the exposures seen were remnants of the previous task conducted, or that co-workers were conducting the pit work task nearby. H_2S liberation from pit work activities appears to have implications not only to the workers who are conducting the pit work tasks, but also to the exposures of co-workers.

These findings suggest that we should look at H_2S exposures among pig barn workers in a new light. Traditionally, the focus has been on protecting only those workers who primarily conduct the pit work task, from potentially high H_2S exposures, and did not include co-workers nearby. We need to re-focus our attention on protecting all workers in pig barns from H_2S exposures exceeding government established ceiling limits.

4.4.2 Workplace Activity and Activity Diaries

The use of time activity diaries in this study resulted in a precise quantification of actual time spent by specialty workers in conducting different activities within this occupational cohort (Sexton and Ryan, 1988). Worker diaries themselves did not provide the depth and detail of data necessary for accurate activity-exposure linkage. This was likely due to the comprehensive nature by which activity data were recorded by observers, since many workers felt that additional activity data recording on their own behalf was redundant. Furthermore, given that career pig barn workers already had busy workdays, prompting them to record additional information in worker diaries may have reduced

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their level of cooperation (Sexton and Ryan, 1988), such that they either did not have the time, or were unwilling to stop and record additional information for the benefit of the study (Kains, 1994). However, even without the presence of observers, we believe that more substantial data would not have been provided by the workers themselves, since worker diaries from a parallel study, where worker diaries were distributed to other workers in the study barns, showed a similar low level of data recording. Even though the use of trained observers recording unbiased data made this study more expensive, it significantly improved the quality of data collected in this study.

In a number of previous studies, pig barn owners or workers were asked to keep a record of each activity conducted, in a 15-min time block, over the entire workday (Kains, 1994; Preller et al., 1995b; Vogelzang et al., 1998a). In contrast, open-ended diaries were chosen for this study, to provide a complete listing of all specialty-area activities conducted by workers, and to allow for a calculation of the amount of time spent on these tasks every time they were conducted (Sexton and Ryan, 1988). Since observers could record an unlimited amount of data, they were able to capture information on even the shortest-interval workplace activities. Even though this resulted in the collection of greater volumes of data, the studies' results show that 15-min time block intervals are too long, since information on activities of shorter durations would not be captured.

Despite conducting a wide range of different activities including break activities (Olsen, 1994), the amount of time spent on the majority of tasks did not vary by specialty pig barn worker type. This study found that Farrowing workers spent the most amount of time dry feeding, and the least amount of time moving older pigs, while Nursery/Grower-

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Finisher workers spent the most amount of time barn checking and vaccinating, when compared with the other workers specialties. These differences reflect the nature of work in the different specialty areas in modern pig barns, and are dependent on the pig management priorities within the different specialty areas. For example, a priority in the Farrowing area is to feed each individual sow based on the sow's body condition and the size of litter she is nursing. Therefore, Farrowing workers will spend more time conducting the dry feeding activity. Conversely, in the Nursery/Grower-Finisher area, pigs are primarily self-fed, using automated feeding systems, resulting in more available time to conduct other activities (Attwood et al., 1987). Workers in the Nursery/Grower-Finisher area will spend more time conducting the barn checking activity because they are responsible for significantly more animal rooms (Chapter Three).

In contrast, it was surprising to the author to see how little time was spent by some workers on some workplace activities. Most noteworthy, was the short amount of time spent on the pit work activity. This particular task was of a short duration because workers tended to pull (lift them up so that manure from the pit can drain out) only one or two pit plugs at one time, leaving them open, until they returned later in the day, or even the next day, to close the pit by replacing the pit plug (Chapter Five).

An interesting finding from this study was that, for some workplace activities, less than 30% of study participants within a given specialty were seen to conduct specific activities, even though some of the tasks are deemed essential by managers of a pig barn. The weighing activity, for example, is an essential activity in all pig barns with finishing components, given that packing plants require market pigs be shipped in the proper

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weight ranges. Since visits were only made to the study barns on Tuesdays, Wednesdays and Thursdays, it is possible that some workplace activities (including weighing) were conducted on days, or times of the day, when the study team was not present. Moreover, since barns with larger herd sizes, and therefore a greater number of employees, were visited in this study, non-study participants may have had a greater opportunity to conduct these workplace tasks. Within larger pig barns employing greater numbers of workers, there is a trend to a greater degree of work-task specialization within specialty areas. An example of this was seen in the Farrowing area of one of the study barns, where one worker spent the majority of the day feeding sows and piglets, which allowed the other workers in the area to spend the bulk of their workdays conducting animal care and management activities (farrowing assistance, animal treatment, piglet processing).

An important finding from this study, was that workers from one specialty area crossed over to work in other specialty areas, to conduct tasks on behalf of, or in conjunction with, co-workers. The consequences of this crossover, highlights the importance of tailoring area-specific safety training to *all* workers in a pig barn, not just to those whose job description it is to conduct specific job tasks. H_2S awareness and safety training is one such example. All workers must be made aware of the likelihood of high H_2S exposures during the manure pit work task (Zhang et al., 1990; Chapter Five).

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4.5 Study Limitations

The intense scrutiny of the observers may have introduced bias into this study since it may have affected how the workers conducted their daily activities. We believe this bias was minimized due to the confidential nature of observer diaries, and the establishment of a comfortable and rapid rapport between the worker and the observer. However, given the way in which this study was conducted, there is a possibility that serious risk-takers were not enrolled in this study. Therefore this study likely does not capture the full range of exposures that may have been possible.

Even though self-reported activity recording compliance was an issue in this study, it is not anticipated that compliance would have improved among study participants even if observers had not been present, since worker diaries from a parallel study, where worker diaries were distributed to other workers in the study barns, showed a similar amount of data recording.

Placing the PESB II monitoring equipment on the floor during breaks is seen as a limitation of this study. If the monitoring equipment cannot be worn during these activities, then attempts should be made to have the equipment positioned close to the worker(s) at breathing height.

4.6 Summary

The results of this study highlight the importance of tailoring safety training to *all* workers in a pig barn, since workers were seen to cross-over from one specialty to another to conduct tasks on behalf of, or in conjunction with co-workers. Observer-

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recorded time activity diaries allowed data of high quality to be collected in this study, and showed that specialty pig barn workers conducted individual workplace tasks in accordance with the management priorities within a given pig barn specialty area. Even within these specialty pig barn areas, there was a trend towards task specialization, such that one worker may only feed pigs, and another worker has more time for animal-care activities.

Mean winter CO_2 exposures were generally < 3000 ppm for activities evaluated in this study. Farrowing workers had the lowest respirable dust count exposures during dry feeding and barn checking activities. However, Farrowing workers were 3 times more likely than Dry Sow/Breeding and Nursery/Grower-Finisher workers to be exposed to high (> 20 particles/mL) respirable dust exposures when conducting workplace activities. Interestingly enough, in Chapter three, Farrowing workers where shown to have significantly lower overall respirable dust mass exposures, when compared to Nursery-Grower/Finisher workers. This result highlights the importance of activity monitoring. Evidence of pervasive exposures suggests that all pig barn workers should consider wearing personal respiratory protection (N95 respirators) when working with pigs, especially for activities involving barn checking, dry feeding, sorting, selecting and animal movements.

In 79% of workplace activities examined in this study, workers were exposed to concentrations of H_2S exceeding the proposed 15 ppm ceiling limit. Such levels do not conform to Alberta Government regulations.

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4.7 Conclusion

- For research purposes, self-reported time activity diaries among the pig barn worker occupational cohort do not contain sufficient information to reliably and accurately link to real-time continuous air contaminant exposures.

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Chapter Five

Peak Hydrogen Sulfide Exposures of Career Pig Barn Workers

5.1 Introduction

Hydrogen sulfide (H_2S) is a colorless, flammable, toxic gas which is heavier than air, and at low concentrations (< 1 ppm) (O'Donoghue, 1961) smells like rotten eggs (Lewis, 1997; Fuller and Suruda, 2000; ACGIH, 2001). It is primarily absorbed through inhalation (Glass, 1990). At higher concentrations (150 to 200 ppm), the distinctive smell is no longer discernable due to olfactory nerve paralysis, thereby making the presence/absence of smell, undependable as an early warning detection system (ACGIH, 2001). A brief exposure of 500 to 1000 ppm of H_2S, with as little as one breath, can result in a condition referred to as "knockdown", meaning "a sudden loss of consciousness" (Guidotti, 1994). During the study, pig barn workers confided to the author about knockdown situations they themselves, and other pig barn workers across Canada had experienced. However, at concentrations >1000 ppm, H_2S is fatal (Costigan, 2003).

Occupational exposure limits for H_2S are based on protecting workers from eye and respiratory tract irritation, headache and fatigue conditions (Ammann, 1989; ACGIH, 2001). The threshold-limit-value (TLV), eight-hour time-weighted-average (TWA) exposure limit for H_2S has been set at 10 ppm, while the 15-minute short-term-exposure-limit (TLV-STEL) is set at 15 ppm (ACGIH, 2001). The Alberta regulations follow the ACGIH (2001) TWA guidelines, however, the Alberta Government Chemical Hazards

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Regulation Task Force opted to set a ceiling rather than a TLV-STEL level for H_2S given the hazardous nature of this gas (personal communication, Radnoff, September 23, 2003). Recently, the Alberta regulation ceiling limit (a concentration above which workers cannot be exposed for *any* length of time) was lowered from 20 ppm to 15 ppm (Alberta Human Resources and Employment, 2002).

In modern pig barns, manure is stored in underfloor pits in liquid form (Janni et al., 1981). Manure, urine, spilled feed, and wastewater from pig waterers and room/floor washing are added on a continual basis to the liquid slurry (Zhang et al., 1990). Anaerobic microbial decomposition of the manure results in the formation of H_2S (Arogo et al., 2000), which remains trapped in the manure until it is released when the manure is agitated (Zhang et al., 1990). In many pits, a solid "crust" layer often forms on the surface of the manure, and together with other solids in the manure, necessitates manure agitation prior to removal to outdoor storage lagoons.

While pig barn workers are typically exposed to low concentrations of H_2S during workshifts (Chapter three), following manure agitation and pit plug pulling, H_2S concentrations can reach 1000 ppm or higher (Chénard et al., 2003; Costigan, 2003). Therefore workers who conduct liquid manure-related activities, such as draining pits, repairing the manure pump, or work inside a manure transfer room (a specialized room in some barns in which a sump pit is used to collect manure from adjacent barn gutters), may be subject to exposures exceeding the occupational exposure guidelines for H_2S.

Little has been published to date on the personal peak H_2S exposures of pig barn workers conducting different workplace tasks. Therefore, the purpose of this study was

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to investigate the short-term peak exposure levels (maximum H_2S exposures ≥15 ppm) of pig barn workers in large intensive pig barns, and to evaluate the causes of these high exposures among workers. Recommendations for the reduction of such exposures are also outlined.

5.2 MATERIALS AND METHODS

5.2.1 Study design

This study was part of a larger study evaluating the workplace contaminant exposures of specialty-area pig barn workers. The full research methodology protocols are reported previously (Chapters 3 and 4).

Briefly, the study used a cross-sectional design that followed specialty-area pig barn workers (Dry Sow/Breeding, Farrowing, Nursery/Grower-Finisher) and was conducted over the winter (February to April) and summer (June to August) of 2000, in Alberta, Canada. This paper reports the peak H_2S exposure results from the winter data only, since activity data were only readily available for the winter season. Ethical approval for this study was obtained from the Health Research Ethics Board (B: Health Research) of the Faculty of Medicine, University of Alberta.

5.2.2 Research Setting

5.2.2.1 The barns

Pig barns were eligible for this study if they were Farrow-to-Finish or Farrow-to-Wean farms and if the barns employed a minimum of four full-time workers. Priority was given to Farrow to Finish operations since employees in such facilities represented

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the broad range of worker specialities and activities of interest. A total of 20 barns, met the inclusion criteria, and 15 were randomly selected to be contacted. Ten barns (8 Farrow-to-Finish; 2 Farrow-to-Wean) agreed to participate and allowed the study team access to their facilities. Barn herd sizes averaged 1310 sows, ranging from 350 to 2400 sows.

5.2.3 **Study Sample**

5.2.3.1 **The workers**

Career pig barn workers were asked to participate in this study (Wenger, 1999). Employees were excluded if they were maintenance workers[1] or summer students. Three workers from each of the 10 barns (one worker from each of the Dry Sow/Breeding, Farrowing and Nursery/Grower-Finisher specialty areas) were randomly selected to be followed by a study team member (trained observer) and to wear a Personal Environmental Sampling Backpack (PESB II). Of the 38 randomly selected workers, 36 (95%) agreed to participate in the study. Written informed consent was obtained from all participating workers.

The number of workers who worked exclusively in the Nursery area were too small to evaluate on their own (3 workers in winter), and approximately half of the workers who were responsible for the Nursery area, were also responsible for the Grower area or the combined Grower/Finisher areas (47% in winter and 57% in summer). This made it impossible to separate out only the Grower/Finisher exposures for these workers.

[1] Maintenance workers in the study barns were not involved in the repair of the manure system

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For these reasons, the Nursery area and Grower/Finisher areas, were combined into one specialty area for this study.

5.2.4 Data Collection

5.2.4.1 The study team

The field team was comprised of the project manager (IIW), two full-time assistants, and an agricultural research engineer, who calibrated and maintained the equipment in the field. The trained observers (project manager and assistants) were randomly assigned to follow a worker for 3 consecutive days, recording all activities conducted over each full workshift. Activities were recorded by the observers every time a worker changed activities or changed zones (such as moving from a hallway into a room, or moving from an alleyway into a pen, for example).

5.2.4.2 Exposure monitoring

Personal contaminant exposures were monitored for 3 pig barn workers in each of the 10 barns, throughout their entire workshifts (including breaks), over 3 consecutive days of a work week (Tuesday through Thursday). Sampling was not conducted on Mondays and Fridays due to shift changes and scheduled days off. If a participating worker either declined further participation or was away on subsequent study days, another worker from the same barn and specialty area was recruited to the study. During coffee and lunch breaks, workers took their backpacks off, so the monitoring equipment was not worn during these break activities. Instead, the equipment was placed along the

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wall, on the floor of the coffee/lunch area, so as to be out of the way.

Personal sampling for airborne constituents was accomplished in this study with second generation Personal Environmental Sampling Backpacks (PESB II's), a modified version of the PESB (Ouellette et al., 1999). In addition to other monitoring equipment (Chapters 2 and 3), each PESB II also contained an in-line real-time H_2S gas monitor (Toxi Ultra, Biosystems, Inc., Middletown, CT). The H_2S monitor sampled continuously at 1 s intervals, over the 20 s data logging period. At the end of the 20 s, the highest H_2S reading was stored by the data logger. Barn air drawn from within the worker's breathing zones (through an inlet affixed to the cloth backpack of the PESB II), passed through all in-line air contaminant sensors using a personal air sampling pump. The calibrated flow rate of 2.8 L/min ± 5% was chosen as the dust count sensors were factory calibrated to this flow rate. The Toxi-Ultra H_2S was capable of monitoring H_2S concentrations from 1 to 100 ppm ± 5% or 1 ppm (whichever was greater). H_2S concentrations were recorded every 20 seconds throughout the entire workday, including breaks, and data were stored in an on-board data logger.

5.2.4.3 **Diary Data**

All workplace activities, recorded by the observers, were grouped into analogous activity categories and assigned 3-digit activity codes (Table 5.1). Each activity performed by a worker was then coded using the specific code assigned to that activity. Activity data were entered into a spreadsheet (Microsoft Excel®), and the data were

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Table 5.1. Outline of activity coding

Activity Code	Activity Code	Activity Code
100 - Breeding	500 - Health	900 - Other/Miscellaneous
110 - Stimulating heat	510 - Barn/Health Check	910 - Breaks
120 - Heat checking	520 - Animal Identification	920 - Rest
130 - Natural breeding	530 - Treatments	930 - Smoking
140 - Semen collection	540 - Vaccinating	940 - Study requirements
150 - Artificial insemination	550 - Repair ruptures	950 - Checking/looking
160 - Pregnancy checking	560 - Animal restraint	960 - Driving
170 - Backfat probing	570 - Animal Euthanasia	970 - Handling other animals
180 - Boar testing	580 - Tender Loving Care	
200 - Cleaning	600 - Maintenance	
210 - Solid manure removal	610 - Construction	
220 - Spreading bedding	620 - Building structure	
230 - Sweeping/dust removal	630 - Equipment	
240 - Pressure washing	640 - Environment adjustment	
250 - Dead pig removal	650 - Machinery and tools	
260 - Washing and garbage	660 - Manure system repair	
270 - Pit work	670 - Welding	
280 - Biosecurity	680 - Pest control	
290 - Household chores		
300 - Farrowing	700 - Moving pigs	
310 - Farrowing preparation	710 - Gate adjustments	
320 - Inducing farrowing	720 - Weaning/moving piglets	
330 - Assisting farrowing	730 - Moving/herding pigs	
340 - Checking sows	740 - Sorting/selecting pigs	
350 - Piglet care	750 - Weighing pigs	
360 - Processing litters		
370 - Cross-fostering piglets		
400 - Feeding	800 - Work preparations	
410 - Feeding preparations	810 - Work clothing on/off	
420 - Feed delivery	820 - Walking	
430 - Dry feeding	830 - Get/return supplies	
440 - Liquid feeding	840 - Talk with co-workers(s)	
450 - Watering	850 - Record-keeping	
460 - Creep feeding	860 - Finding co-workers(s)	
470 - Checking feed system	870 - Waiting	
480 - Cleaning feeders		

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rigorously checked for both coding and data entry errors[2].

Start and finish times for activities conducted by each study participant during a full workshift were identified by one of the investigators (IIW), with extensive knowledge of pig barn environments and activities. Workplace activities were included in the analysis if they were ≥ 1 min in duration. Activities were excluded if the activity was: less than 1 min in duration; limited to walking from zone to zone or area to area; talking or meeting with co-workers; looking for co-workers; looking for, getting or returning supplies; or assembling supplies required for a particular activity in a location (such as in the shop, hallway, office area, or medicine room) other than where the included activity took place.

The H_2S exposure files and activity data files were linked by worker ID, day of visit and time of day using a Quick Basic 4.5 computer program (Microsoft Corporation®, Redmond, WA). The program calculated the maximum H_2S contaminant exposures for each study activity conducted chronologically over the work day. The overall time spent on each activity and the corresponding overall daily maximum H_2S contaminant exposures were calculated.

Eighty observer activity diary data files were linked to 80 corresponding H_2S exposure data files for the analysis. Four H_2S exposure files were missing due to unavailable H_2S sensors at the beginning of the winter study, and one was missing due to

[2] The project manager (IIW) and a study team member responsible for data entry, would read each line of data to each other to check for data entry errors. These were then corrected in the data set. When IIW was making the determinations of the start and finish times for activities conducted by each study participant, coding errors were identified and subsequently corrected. This ensured the consistency of activity diary coding.

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a data logger malfunction.

5.2.4.4 **Statistical analysis**

The daily exposure data represent the total duration of, and maximum H_2S exposures ≥ 15 ppm for, each activity conducted by an individual worker during each day of the 3-day barn visit. The total duration of H_2S exposures ≥ 15 ppm was calculated for each peak exposure event. The specific time of the exposure infraction, and the corresponding H_2S peak were identified. The times were then totaled over the intervals where the concentrations were ≥ 15 ppm. Descriptive statistics are reported as the highest peak H_2S exposures of ≥ 15 ppm encountered by workers during workplace activities conducted on each day of the visit. So, for example, if liquid manure removal (pit work) was conducted by a participating worker three times during one workshift, then the peak H_2S exposure reported was the highest H_2S exposure encountered by that worker during the three manure removal procedures conducted that day. A Chi-square test (r by c table) was used to test differences in peak H_2S exposures between worker specialties, and to test differences in peak H_2S exposures between pit work and non-pit work activities. Where differences were found, an odds ratio was calculated to determine the likelihood of the over-exposure occurrence for workers conducting different activities. If the assumptions for the Chi-square test (80% of the expected cell counts should be > 5) were not met, then Fisher's exact test was used. Non-parametric analyses were used in the analysis of the data due to small sample sizes and the non-normal distributions of peak exposures during workplace activities. Data were analyzed using SPSS, version 10.0 software (SPSS Inc.,

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Chicago, IL). Resultant p-values were considered statistically significant at $p \leq 0.05$.

5.3 RESULTS

5.3.1 Study Participants

Thirty six career pig barn workers participated in this study (22 men; 14 women), with an average age of 34.3 years. Thirty workers were enrolled on the first day of the barn visits. An additional 6 workers were recruited to the study thereafter, as a result of workers being unavailable due to sick day(s), scheduled day(s) off, or vacation (N=6), unwilling to wear the instrumentation for more than one day (N=2), and coveroff workers (N=7). Cover-off workers were specialty pig barn workers from the same barn who met the inclusion criteria, were recruited to the study, and were usually from the same specialty work area (83%) as the workers they were replacing. Of the 36 study participants, 13 worked in the Dry Sow/Breeding area, 13 in the Farrowing area, and 10 in the combined Nursery/Grower-Finisher area. The average workshift duration in this study was 9.4 h.

5.3.2 Activity diaries and workplace activities

5.3.2.1 Observer diaries

Observer diaries were used as the primary time activity data source since worker diaries did not contain sufficient information to develop an adequate time activity profile (Chapter 4). Activity diary data from a total of 85 full workshift observer diaries, out of a possible 90, were collected in this study. Five observer diaries were excluded. Three

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(representing data from one study participant) were excluded because of incomplete time-activity profiles; one was excluded because the worker was not working in one defined specialty area, and one was excluded because an observer diary was lost.

5.3.2.2 **Worker activities**

Worker activities were coded into 68 different tasks, ranging from barn checking to breaks (Table 5.1). While a small number of workplace activities are pig barn area specific (heat checking and artificial insemination conducted by Dry Sow/Breeding workers in the Dry Sow/Breeding area; farrowing assistance, piglet care, piglet processing and creep feeding conducted by Farrowing workers in the Farrowing area; and sorting, weighing and marking pigs conducted by Nursery/Grower-Finisher workers in the Nursery/Grower-Finisher area), the majority of activities were conducted by workers in all specialty areas. There were instances, however, where workers from one specialty area were seen to cross over to another specialty area(s) to conduct tasks on behalf of, or in conjunction with, co-workers (Chapter 4).

Only two of the 68 workplace activities (2.9%), were related to pit work (activity code 270), and repairing the manure system including manure pump repair (activity code 660). Less than half of the study participants (42%) were seen to conduct these tasks, and when conducted, these activities were of a short duration, 11 to 31 min on average, over the 3-day workshifts (Chapter 4).

5.3.3 **Peak H_2S Exposures**

Table 5.2 presents the peak ($\geq$15 ppm) H_2S exposures for pig barn workers conducting different workplace activities in the winter of 2000. There were 27 such peak

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Table 5.2. Peak (>15 ppm) hydrogen sulfide gas exposures of specialty pig barn workers (Dry Sow/Breeding, Farrowing and Nursery/Grower-Finisher) conducting workplace activities.

	Contaminant: Peak H_2S exposure (ppm)					
	Specialty					
ACTIVITY	Dry Sow/ Breeding ppm [proportion]	*Duration ≥ 15 ppm (minutes)	Farrowing ppm [proportion]	*Duration ≥ 15 ppm (minutes)	Nursery/Grower-Finisher ppm [proportion]	*Duration ≥ 15 ppm (minutes)
100 - Heat checking & breeding						
150 - Artificial insemination	24.4 [1/25]	5.7	—	—	31.6 [1/3]	< 1.0
200 - Other manure removal & cleaning						
270 - Pit work	47.5 [1/9]	5.0	32.5 [1/3]	16.6	17.4; 26.7; 57.0; 94.0 [4/11]	< 1.0; 1.0; 8.0; 4.9
300 - Other farrowing & piglet care						
360 - Processing piglets	—	—	21.2 [1/21]	< 1.0	—	—
400 - Other feeding & feed delivery						
430 - Dry feeding	—	—	61.5 [1/17]	2.0	18.7 [1/17]	< 1.0
440 - Liquid feeding	16.4 [1/8]	< 1.0	18.7 [1/6]	< 1.0	—	—
460 - Creep feeding	—	—	67.0 [1/16]	2.0	—	—
470 - Checking feed system	—	—	—	—	53.1 [1/5]	1.3
500 - Other barn check & treatments						
510 - Barn check	43.5 [1/23]	< 1.0	16.2; 17.8 [2/16]	< 1.0; < 1.0	15.9 [1/18]	< 1.0
530 - Pig treatments	15.7 [1/12]	< 1.0	—	—	—	—
600 - Other barn maintenance						
610 - Construction	30.9 [1/1]	< 1.0	—	—	—	—
660 - Repairing manure system	19.1; 23.1 [2/2]	< 1.0; < 1.0	—	—	18.1 [1/2]	1.0
700 - Other moving & weighing piglets						
730 - Moving older pigs	29.1 [1/29]	1.0	55.0 [1/15]	1.3	—	—
750 - Weighing	—	—	—	—	25.0 [1/6]	2.0
†Total number of peak exposure events	9/358		8/322		10/208	27/888

Numbers in [brackets] for the different activities depicts the number of occurrences of H_2S exposures > 15 ppm over the total number of times a particular activity was conducted. † These are the total number of peak exposure events occurring over all activities conducted by the different worker specialties. A "-" in the body of the text indicates that no peak H_2S exposures occurred.

* Duration of exposures refers to the length of time workers were exposed to H_2S concentrations exceeding 15 ppm during the workplace activity.

exposure events, nine in the Dry Sow/Breeding area, eight in the Farrowing area, and ten in the Nursery/Grower-Finisher areas. Of the 36 workers participating in this study, these exposure events corresponded to 11 workers (5 Dry Sow/Breeding, 4 Farrowing, 2 Nursery/Grower-Finisher). The majority of the events (70%), occurred in two of the study barns, with 2 workers in each of these barns contributing to 9 and 8 of the exposure events, respectively. No differences in peak ($\geq$15 ppm) hydrogen sulfide exposure events were found between the area specialty worker groups ($\chi^2 = 2.88$, df=1, p=0.24).

Of the 27 peak exposure events, over half (52%) were < 1 min in duration, 30% were between 1 and 2 min, while 18% of the peak exposures were found to be > 3 min in duration. One Nursery/Grower-Finisher worker was exposed to $\geq$15 ppm H_2S for almost 17 min during liquid manure removal activities conducted on one of the study days. The activities which resulted in the longest exposures to H_2S above the ceiling limit in this study included pit work activities, and one artificial insemination activity.

Pit work activities, including the repair of the manure pump conducted by the workers themselves, accounted for 29 out of the 888 activities (3%) conducted by workers in this study. Yet, despite the small number of overall pit work activities conducted, 9 out of 29 (31%) of those resulted in exposures to H_2S of $\geq$15 ppm (Table 5.3). The highest overall peak exposure of 94 ppm was measured on a Nursery/Grower-Finisher worker during one of the pit work activities. This exposure approached the upper detection limit of 100 ppm for the H_2S sensor used in this study.

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Table 5.3. Number of pit work and non-pit work related workplace activities conducted by pig barn workers in which peak H_2S exposures either exceeded and did not exceed 15 ppm

H_2S exposures > 15 ppm	Workplace Activities		
	Pit work and manure system repair activities	Non-pit work activities	Total
Yes, H_2S exposures > 15 ppm during activity	9 (31%)	18 (2%)	27 (3%)
No, H_2S exposures ≯ 15 ppm during activity	20 (69%)	841 (98%)	861 (97%)
Total	29 (100%)	859 (100%)	888 (100%)

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The proportion of peak H_2S exposures among pit work-related activities, was found to be significantly greater, 9 out of 29 (31%), than those of non pit work activities, 18 out of 859 (2%) ($\chi^2 = 79.7$, df=1, $p<0.0001$). This means that workers in this study conducting pit work-related tasks were 21 times more likely to be exposed to H_2S concentrations equal to or exceeding 15 ppm, compared to workers conducting other non-pit work activities [OR=21.0, 95% CI (8.4, 52.5)].

Of the 27 peak ($\geq$ 15 ppm) H_2S exposure events recorded in this study, 18 (67%) occurred when workers were not engaged in pit work or manure pump repair activities. For Dry Sow/Breeding workers (N=6), these activities included artificial insemination, liquid feeding, barn checking, pig treatments, construction, and moving older pigs. Farrowing workers had unexpectedly high peak H_2S exposures (N=7) while performing processing piglets, dry, liquid and creep feeding, barn checking and moving older pig activities. The high peak H_2S exposures for Nursery/Grower-Finisher workers (N=5), were recorded in non pit work activities of artificial insemination, dry feeding, checking the feed system, barn checking and the weighing of pigs.

Table 5.4, presents the circumstances surrounding each of the 27 peak exposure events found in this study. In order to further investigate the causes of these events, peak exposures were classified as being *direct* (if the worker was found to be conducting a pit work or manure pump repair activity), *indirect* (if the exposure was related to a job activity of a co-worker), or of an *unknown cause* (if it was not possible to determine why the worker had such high H_2S exposures). This categorization revealed that of the 27 peak exposure events, 13 (48%) were attributable to a direct cause (agitating or flushing

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manure; pulling pit plug; checking pits; repairing the manure pump). Nine events (33%) were categorized as having an indirect cause (getting assistance from, or standing beside a co-worker who was agitating pits; in same room where manure agitation was being conducted; in room where pit plugs had been pulled earlier; in room where pressure washing was conducted; working in an area adjacent to, or walking past the manure transfer room; pit plug pulled beside worker). Five events (18.5%) were of an unknown cause (in a room treating sows, dry feeding sows, processing piglets, or checking pigs; walking in main hallway of barn where smell of H_2S was detected).

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Table 5.4. Case reports for workers whose H_2S exposures were ≥15 ppm at some point during individual workplace activities

*Exposure category	Specialty	Activity	Commentary
Indirect	Dry Sow/Breeding	Barn check (511)	H_2S peak 43.5 ppm. Worker went to get the assistance of a co-worker who was agitating manure pits.
Indirect	Dry Sow/Breeding	Moving older pigs (731)	H_2S peak 29.1 ppm. During moving older pigs activity, this worker went to stand beside a worker who was agitating pits "to see what the exposures would be like".
Indirect	Dry Sow/Breeding	Artificial insemination (150)	H_2S peak 24.4 ppm. Worker was conducting artificial insemination activities in a barn adjacent to, but sharing the same airspace, with a Dry Sow breeding barn in which the manure pits were being agitated.
Direct	Dry Sow/Breeding	**Pit work (agitating pit/flushing manure) (273)**	H_2S peak 47.5 ppm. During the time of the peak exposure, this worker was pushing manure with a scraper to make it move and then proceeded to flush the manure gutters .
Unknown	Dry Sow/breeding	Animal treatments (532)	H_2S peak 15.7 ppm. Worker was in one of the breeder barns treating sows. Not clear why high H_2S exposures occurred.
Direct	Dry Sow/breeding	Liquid feeding (440)	H_2S peak 16.4 ppm. Just prior to the peak H_2S exposure, the worker used water to spray out the manure pit (manure agitation), and then during the liquid feeding activity the work took time out to watch the manure pit drain.
Direct	Dry Sow/breeding	Construction (610)	H_2S peak 30.9 ppm. During the time of the exposure, the worker was in the pump (transfer) room checking out the manure transfer pit and measuring plywood needed to cover a portion of the pit.
Direct	Dry Sow/breeding	**Repair manure pump (663)**	H_2S peak 23.1 ppm. At the time of the exposure, the worker was working with a co-worker helping to repair the manure pump in the pump (transfer) room.

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Table 5.4. Case reports for workers whose H_2S exposures were ≥15 ppm at some point during individual workplace activities (continued)

*Exposure category	Specialty	Activity	Commentary
Direct	Dry Sow/Breeding	**Repair manure pump (663)**	H_2S peak 19.1. Worker looking at, winching up, and shutting off the separator pump at the time of the peak exposure
Direct	Farrowing	**Pit work (pull pit plugs) (272)**	H_2S peak 32.5 ppm. Worker actively looking for pit plugs and checking pits during time of exposure.
Indirect	Farrowing	Barn check (511)	H_2S peak 17.8 ppm. At the time of the peak H_2S occurrence, the worker was in a weaner room talking with a co-worker. The co-worker was pressure washing in the room.
Unknown	Farrowing	Dry feeding (432)	H_2S peak 61.5 ppm. Not readily obvious why this worker was exposed to high H_2S concentration. Earlier in the morning a co-worker had started pumping out manure from the transfer station/shop, however the farrowing barn hallway, where this high H_2S exposure occurred, was located some distance away. Were H_2S gases travel down the hallway system?
Indirect	Farrowing	Creep feeding (464)	H_2S peak 67.0 ppm. At the time of peak exposure, the worker was walking in the hallway close to the transfer station/shop where manure was actively being pumped out. It is likely that H_2S from the transfer station/shop moved down the hallway.
Indirect	Farrowing	Moving older pigs (732)	H_2S peak 55.0 ppm. This worker was moving sows from a dry sow barn close to the transfer station/shop where manure was actively being pumped out.
Unknown	Farrowing	Processing piglets (360)	H_2S peak 21.2 ppm. This worker was in one of the farrowing rooms processing piglets at the time of the peak exposure event. Not readily obvious why H_2S exposures were high during this activity.
Indirect	Farrowing	Barn check (511)	H_2S peak 16.2 ppm. Worker was checking sows and a pit plug was pulled beside where the worker was working.

Table 5.4. Case reports for workers whose H_2S exposures were ≥ 15 ppm at some point during individual workplace activities (continued)

*Exposure category	Specialty	Activity	Commentary
Unknown	Farrowing	Liquid feeding (440)	H_2S peak 18.7 ppm. At the time of the exposure, the worker was waking in the main hallway of the farrowing barn. The observer following the worker recorded that there was a high H_2S smell in the main hallway at the time that the peak exposure was recorded. No further information was available to determine the source of the gas.
Indirect	Nursery/Grower-Finisher	Artificial insemination (150)	H_2S peak 31.6 ppm. This Nursery/Grower-Finisher worker was assisting a co-worker in artificially insemination sows. The location of this activity was in a pen close to the transfer station/shop where manure was being actively pumped.
Direct	Nursery/Grower-Finisher	**Pit work (checking pits) (271)**	H_2S peak 57.0. Worker was in the pump room checking the flush and pit pump. Observer recorded that she could smell H_2S in the room.
Direct	Nursery/Grower-Finisher	Feeding (431)	H_2S peak 18.7 ppm. This worker was quickly checking on a manure pump in a grower room during the feeding task.
Unknown	Nursery/Grower-Finisher	Barn check (511)	H_2S peak 15.9 ppm. Worker was in one of the finisher rooms checking pigs. It was not obvious why H_2S exposures were high. There was no record of high H_2S odours.
Direct	Nursery/Grower-Finisher	Weighing pigs (750)	H_2S peak 25.0 ppm. During the weighing activity, this worker quickly went to check on manure that was being pumped in the same finisher room. At the same time, this worker also pulled a pit plug, watched the manure drain and closed the pit plug, prior to resuming the weighing activity.
Direct	Nursery/Grower-Finisher	**Pit work (agitating manure) (273)**	H_2S peak 17.4 ppm. Worker was checking manure pump and was using water to mix/agitate manure.

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Table 5.4. Case reports for workers whose H_2S exposures were ≥15 ppm at some point during individual workplace activities (continued)

*Exposure category	Specialty	Activity	Commentary
Direct	Nursery/Grower-Finisher	**Pit work (pull pit plugs) (272)**	H_2S peak 94.0 ppm. Just prior to the peak exposure, the worker started the manure pump and separator in the pump room and then pulled two pit plugs in one of the nursery rooms. During the exposure, the worker was in another nursery room re-plugging pits that had been pulled the day previous.
Indirect	Nursery/Grower-Finisher	Checking feeders (470)	H_2S peak 53.1 ppm. This worker was checking feed hoppers in the room in which two pit plugs had been pulled earlier.
Direct	Nursery/Grower-Finisher	**Repairing manure pump (663)**	H_2S peak 18.1 ppm. During the peak exposure event, the worker was in the pump room checking the manure pump that required repairs.
Direct	Nursery/Grower-Finisher	**Pit work (check manure pumping) (274)**	H_2S peak 26.7 ppm. Worker was in the pump room checking on the manure being pumped at the time of the peak exposure event.

*For exposure categories, exposures were assigned as: (1) Direct, if exposures were as a result of workers conducting pit work and pump repair activities at the time of the peak H_2S exposure event; (2) Indirect exposures were those in which workers were not conducting the pit work or pump repair activities themselves, but were exposed to H_2S as a result of activities conducted either by a co-worker or by an activity they conducted themselves early in the day or prior to the peak exposure event; and (3) An exposure was assigned "unknown" if it was not possible to determine, from activity diaries or supplemental comments made by observers, why the worker was exposed to high H_2S concentrations.

5.4 DISCUSSION

This study investigated the peak H_2S exposures (≥ 15 ppm) of pig barn workers for different activities conducted during the workshift. This concentration was selected because it is the new proposed ceiling limit for this contaminant in the Province of Alberta (Alberta Human Resources and Employment, 2002). Twenty seven peak exposure events were recorded in this study. The highest peak H_2S exposure recorded was 94 ppm. The results show that the proportion of peak exposure events among pit work and manure pump repair activities was significantly greater than the proportion among non-pit work activities. Furthermore, workers conducting pit work and manure pump repair tasks were found to be 21 times more likely to be exposed to H_2S concentrations exceeding the 15 ppm ceiling limit, than workers conducting non-pit work tasks. Approximately half (48%) of the peak exposure events were attributable to direct pit work activities, while 33% were attributable to H_2S emanating from the manure transfer room or as a consequence of pit work activities conducted by co-workers, and 19% were of an unknown cause.

Only during relatively few (3%) workplace activities, were pig barn workers exposed to concentrations of H_2S equal to or exceeding the newly revised ceiling limit of 15 ppm set by the Province of Alberta (Alberta Human Resources and Employment, 2002). Not surprisingly, one third of the peak (≥ 15 ppm) exposure events in this study occurred during pit work and manure pump repair activities where such exposures are expected (Zhang et al., 1990).

Workers in the present study, who conducted pit work and manure pump repair

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activities, were found to be 21 times more likely to be exposed to H_2S concentrations above the 15 ppm ceiling limit compared to workers who conducted non-pit work activities. However, conducting the pit work task alone does not automatically mean that H_2S exposures will be exceeded. The unpredictable nature of gas release following pit plug pulling[3] activities (Chénard et al., 2003), is demonstrated by the fact that in 67% of such events in the present study, and 52% of the events in the Chénard et al. (2003) study, ceiling exposure limits were not exceeded following pit plug pulling tasks.

The highest peak exposure recorded in this study was 94 ppm, for a worker who, following the pulling of two pit plugs, replaced pit plugs that had been left open the day before. In this situation, H_2S present in the sewer line escapes through the open pit plugs. Higher room ventilation rates, encourages more air to come up the sewer/discharge pipe. Chénard et al. (2003) have identified that H_2S concentrations can reach 1000 ppm, the lethal exposure concentration for this contaminant (Costigan, 2003). Consequently, the potential exists for workers who pull pit plugs to be exposed to lethal concentrations of this gas. The low peak exposures recorded in the present study are reflective of the personal exposures of workers, and the short amount of time spent on job activities in areas of high H_2S concentrations. The < 30 second lag time of the H_2S sensor may have also played a contributory role. Study results indicate that it took workers an average of 8.4 min to conduct one pit work task. Therefore, workers in this study were in the vicinity of the open manure pits for 5 to 15 min following pit plug pulling, when the

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[3] Pit plug pulling involves lifting the pit plug from its seat in the floor, allowing liquid manure from the pit to drain out. This is part of the pit work activity that has been discussed in this chapter.

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highest peak exposures are likeliest to occur (Chénard et al., 2003). However, workers in the present study, were not bent over the pit for any length of time, and were therefore not exposed to potential peak concentrations as high as those seen in the Chénard et al. (2003) study. Simply moving away from the site of pit plug pulling however, does not guarantee safe exposures for workers, since Chénard et al. (2003) found that concentrations were higher at some locations in the barn airspace other than the site where the pit plug had been pulled.

In the majority of cases, workers were exposed to H_2S concentrations in excess of 15 ppm, for only short periods of time, typically two min or less. However, there were a few instances, where workers were exposed for longer periods of time. One such event, was an artificial insemination task conducted by a Dry Sow/Breeding worker. This worker was exposed to unacceptably high H_2S concentrations for almost 6 min, which was the amount of time it took for this worker to complete the artificial insemination task. Some job tasks in pig barns require that workers stay in one place for extended periods of time. If H_2S concentrations are high in these locations, such as was the case for this one worker, a worker may be exposed to unacceptably high H_2S concentrations. The way that workers conduct a particular job activity may contribute to their H_2S exposures as well. For example, observers recorded that workers would stop to "watch manure drain". Given the results of this study, watching manure drain would increase a worker's chances of being over-exposed to H_2S.

Exposures for *any* length of time above the ceiling limit indicates non conformance with the law, which states that *no* worker can be exposed to H_2S

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concentrations exceeding 15 ppm, *at any time*, during the workday (ACGIH, 2001). In the event of an exposure greater than the limit, a worker must immediately vacate the work area, and should return only when H_2S concentrations are below the ceiling limit. However, under the observed circumstances, pig barn workers do not know that they have been exposed to unacceptably high H_2S concentrations. The results of this study support the recommendation that pig barn workers should wear H_2S monitors (Chénard et al., 2003), given that H_2S is a poisonous gas (Lewis, 1997), and has a narrow safety margin (Guidotti, 1994). The use of such monitors would show the presence of high levels of H_2S, as well as the conditions and workplace activities where high concentrations occur. Furthermore, given that lethal H_2S concentrations are possible, especially during pit plug pulling activities, the use of monitors would alert workers to life-endangering gas levels (Fuller and Suruda, 2000). It has been suggested that almost all of the 80 H_2S-related fatalities in the United States from 1984 to 1994, could have been prevented had workers worn an H_2S gas monitor (Fuller and Suruda, 2000).

The wearing of monitoring equipment alone does not make an environment safe. Workers need to have clear understanding of what to do in the event the monitor warns them of high H_2S levels. Where should the worker go? Clearly it is unlikely to be safe to move to another location in the same room, so alternate areas such as the coffee/lunch room, where H_2S concentrations were found to be low (Chapter 4), should be designated for evacuation. The length of time a worker should stay out of the contaminated airspace must also be determined. Standard Operating Procedures (SOP) must be developed prior to the use of personal H_2S monitors by pig barn workers. Furthermore, it is

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recommended that an in-barn reporting scheme be implemented for every H_2S exposure infraction, identifying the worker, location of high exposure (room number), worker task(s) conducted, other workers present, and whether pit work tasks were being conducted in the area. Every incident should be investigated by the manager of the barn and supplemented by interviewing other workers who were, or may have been, working in the area. Results of such investigations will help to pinpoint problem area(s) in barns, protect workers from future exposures, and help engineers pinpoint manure pit and plumbing design deficiencies.

An unanticipated finding from this research, and one that causes greater concern from an occupational exposure perspective, was that 18 out of 27 (67%) of the peak H_2S exposure events occurred during workplace activities not associated with pit work or manure pump repair activities. Further examination from observer-recorded data revealed, however, that despite not being coded as pit work activities, almost one quarter of the events (4 of the 18 events) were in fact attributable to direct liquid manure work. In other words, these 4 activities (liquid feeding, construction, dry feeding, and weighing of pigs) had a pit work component (workers either watching manure drain, working in the manure transfer room where H_2S exposures are expected to be high, checking on a manure pump, or quickly pulling or replacing pit plugs). While an attempt was made to code pit work tasks separately from other activities, it was not always possible to do so, since during such circumstances the pit work activities occurred for such short amounts of time. Although this finding reflects the ability of some workers to multi-task, it also highlights the challenges of managing activity-specific exposure diary data. Furthermore,

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it demonstrates the importance of observer-recorded activity diary data for personal worker exposure studies, since workers themselves would not have recorded the short time spent conducting individual pit work tasks.

Of the remaining passive H_2S exposures, four were attributable to the manure transfer room. Manure transfer rooms are rooms in which a sump pit is used to collect liquid manure from local barn pits, prior to pumping the manure outside to a lagoon. The workers who were exposed to H_2S emanating from the manure transfer rooms were either working in a room or walking in the hallway adjacent to the manure transfer room. While not all barns have a designated manure transfer room, the results of this study show that transfer rooms require a better design, including an independent ventilation system, and improved management to prevent passive H_2S exposures. Given the greater likelihood of high H_2S levels in this room, manure transfer rooms must be single-use rooms only, not shared spaces with a shop or storage area. The door to this room must always be kept closed, so that gases are vented from the room and not drawn into other rooms and hallways. Proper negative pressure or isolated ventilation systems need to be installed in these rooms to ensure that all gases are removed. This is also important for workers who conduct tasks in this room. However, a cautionary note here. With increased ventilation rates, there is the potential to pull H_2S into the room from the manure discharge pipe. An observation from this study pertinent to the manure transfer room that bears mentioning here, is that if there is a requirement to remove slats over the pit in this area, to gain better access to the pit pump (such that the opening to the pit is now large enough for a worker to fall in), then it is absolutely imperative that workers wear safety harnesses. In the

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event of a "knockdown", the worker will be prevented from falling into the pit, making the incident more dangerous and rescue more hazardous. The "buddy system" and other confined space procedures, used routinely in other industries, should be investigated for implementation in pig barns.

The remaining five passive indirect exposures were attributable to co-workers either walking into a room in which pressure washing was being conducted, or working in a room in which pit plugs had been pulled or left open earlier. While one of these events occurred as a result of the research study (a worker stood beside a co-worker pulling pits to "see what the concentration was like"), workers communicate frequently with one another, and such an exposure situation may have occurred even without the presence of the researchers in the barn. The remaining exposures could have been prevented if the timing of pit pulling is altered in barns. One suggestion would be that plugs be pulled and then re-plugged prior to breaks (coffee/lunch) to allow the H_2S levels in the airspace to be diluted. Chénard et al. (2003) found that once a pit plug was pulled in the Dry Sow/Breeding room (and replaced shortly afterwards), the H_2S concentration reached a maximum of $\geq$850 ppm, but returned to concentrations of < 15 ppm in approximately 20 to 25 min. Given that breaks are at least 30 min in duration, this allows H_2S levels to be diluted to < 15 ppm prior to re-entry of workers into the airspace. The worker who was exposed to H_2S as a result of walking into a room in which pressure washing occurred is not unexpected, given that manure agitation occurs when pens are washed. Chénard et al. (2003) found that exposures during such activities approached 100 ppm in some specialty areas.

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In this study, 19 per cent of peak H_2S exposures were of an unknown cause. This is a concern, particularly because it is not possible to find a remedy for such exposure situations. These H_2S exposures could have resulted from burst releases from the manure pits, in the absence of manure agitation (Ni et al., 2000), or from poorly seated drain plugs or drain plugs that popped open when other pits in the barn were pulled (Chénard et al., 2003). Use of H_2S monitors will assist in identifying other site-specific sources of H_2S releases and resulting human exposures.

With the greater likelihood of high H_2S exposures during pit work, manure pump repair activities or work in the manure transfer room, workers should consider wearing a self contained breathing apparatus (SCBA) for these activities. While such a unit would make the working environment safer, SCBA gear have their drawbacks. Intensive training is required in the proper use of SCBA gear. The workers must feel comfortable with, and have practiced sufficiently with this equipment so that it does not impair work performance (Poda, 1966). However, even when worn, over-exposures can still occur for a variety of reasons. These include "mask knocked off, hose pinched off, and valve frozen" (Arnold et al., 1985) or that the "equipment had a leaking hose, (or) the air cylinder was empty..." (Poda, 1966). If such equipment is accessible in pig barns, it should be used regularly, it must be checked prior to use and maintained in between uses. Unfortunately, for the short duration pit work activities in barns, it may take longer to put the SCBA gear on properly, than to conduct the tasks. Workers therefore may not comply with its use. One suggestion is to conduct all pit work activities at one time, making the wearing of SCBA gear more practical. The limiting factor to its use under such situations

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will be the 30-min air supply.

The notion of the development of SOPs were introduced earlier in relation to the wearing of H_2S monitors. However, SOPs are equally important in emergency "knockdown" situations. If a "knockdown" situation(s) were to occur in a pig barn, would pig barn workers or managers know what to do? This is clearly a situation that requires immediate attention. Rescue efforts must not be initiated without the proper self-contained respiratory devices. Over an eleven year time span, almost one quarter of the reported H_2S-related fatalities were workers trying to save their co-workers, most without wearing the proper safety equipment (Fuller and Suruda, 2000). Pig barn workers should receive extensive H_2S training, including a thorough understanding of H_2S and its effects. This should include "an abbreviated first aid course with emphasis on artificial respiration, splinting, hemorrhage control and care for shock, and instruction in the proper method of transporting a victim of overexposure to H_2S" (Poda, 1966).

A final comment about H_2S over-exposure. We know that H_2S can cause knockdowns, with a brief exposure, at concentrations of 500 to 1000 ppm. We know that at concentrations of ≥ 1000 ppm H_2S is lethal. We know that liquid manure stored in under-floor pits in pig barns provides a high concentration source of emitting H_2S. We know that H_2S concentrations have been measured at lethal concentrations of 1000 ppm following manure agitation and pit plug pulling (pit work) activities. Even though the author has been told about knockdown situations, fortunately, as far as the author is aware, no pig barn workers have died as a result of conducting routine pit work activities. However, this is the classic case of waiting for the rare unfortunate circumstance where

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all of these "knowns" align and a pig barn worker may die. It is the responsibility of the barn owners and managers to provide a safe working environment for workers in their barns, and to provide an H_2S training course. This may involve mandating the use of safety equipment and procedures so that there are no lethal H_2S exposures risks to the employees. It may be up to the pork industry to be the driving force in this regard; to be pro-active in preventing needless H_2S over-exposure death(s) from occurring.

5.5 Study Limitations

Liquid manure removal activities were of such a short duration in this study, and because workers moved away from the open pits, the potential maximum H_2S exposures were not recorded. The lag time of 30-s for the H_2S monitoring equipment (Chapter two) may have also contributed to the lower exposures recorded in this study.

5.6 Summary

The results of this study demonstrate that activities involving pit work and the repair of manure pump, increase the likelihood of exposure to H_2S above the 15 ppm ceiling limit. However, other workers in barns can also be exposed to high H_2S concentrations as a result of pit pulling activities of co-workers. Managers and workers need to be aware of the toxicity of H_2S and take precautions to eliminate the risk from such exposures. The use of H_2S monitors, and perhaps, SCBA gear is warranted under certain circumstances.

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5.7 Conclusions

- Workers are at the greatest risk to high H_2S exposures when conducting manure pit work activities. Workers conducting this task, were 21 times more likely than workers not conducting the pit work activities, to be exposed to H_2S concentrations exceeding the proposed 15 ppm ceiling exposure limit in Alberta for this contaminant.

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Chapter Six

Summary, Conclusions, and Recommendations

6.1 Summary and implications of findings

The purpose of this research project was to evaluate the full workshift and activity-specific air contaminant exposures of specialty-area career pig barn workers. The chapters of this dissertation: summarized the research on measuring the air contaminant concentrations and work exposures in pig barns; evaluated the use of time activity diaries; and described the development and use of the Personal Environmental Sampling Backpack (PESB II) System. Data collected from pig barn workplaces were analyzed to: evaluate the workplace exposures of specialty-area pig barn workers during winter and summer; examine the activity-specific air contaminant exposures of specialty-area workers; and investigate the activity-related H_2S exposures of specialty-area workers when conducting specific workplace tasks.

The literature review on contaminant exposures of pig barn workers, presented in chapter one, showed that while some studies identified the potential for exposures to be greater in certain pig barn specialty areas, no one study provided a convincing conclusion of where air contaminant concentrations might be the highest. Most air contaminant concentration assessments were based primarily on area-monitoring reflecting the earlier time period of these studies. Relatively few studies used personal sampling for air contaminants, and none performed continuous (as opposed to cumulative) personal monitoring for the major air contaminants likely to contribute to potential health effects

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(dust, endotoxin, CO_2, NH_3, H_2S). It is essential to use personal monitoring for the determination of the air contaminant concentrations of workers in the complex pig barn workplace. Area monitoring has application in some engineering studies but will not be acceptable for worker exposure assessments. Workers conduct activities in all areas of the barns (including coffee/lunch rooms, medicine rooms, shop areas), as well as in the multiple rooms making up each individual specialty area in modern pig barns. It is impossible to choose one representative location for a single-site monitoring station that would accurately represent the exposures of workers as they conduct all workplace activities. Another body of literature, also presented in chapter one, showed that time activity diaries have been used to a limited extent to evaluate the types and duration of activities conducted by workers in pig barns. However, activity diaries have not been used to link real-time continuous air contaminant exposures of pig barn workers to specific workplace tasks undertaken. No studies were found which monitored the activity-specific H_2S exposures of workers and compared these exposures to established ceiling limits.

The PESB II System, developed for this study, is described in chapter two. There was no one "off the shelf" personal monitoring instrumentation system available that could capture all relevant contaminants in a configuration compatible with current biosecurity requirements in modern pig barns. In the preliminary phase of this study, the PESB II was developed and utilized successfully. It was designed to be portable (of reasonable weight and size for workers to wear over full workshifts), meet stringent biosecurity requirements of modern barns (easy to disinfect, HEPA filtration of the

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sampling air stream), and capable of capturing an accurate measurement of all contaminants of interest simultaneously in the breathing zone of the worker. A Personal Environmental Sampling Backpack-type instrumentation works well for actively mobile workers in complex pig barn environments. This study demonstrated that pig barn workers are willing to wear personal instrumentation while conducting activities over the full workshift and the full range of workplace activities.

The full personal workshift exposures of specialty-area pig barn workers during winter and summer are presented in chapter three. Winter exposures were consistently higher than summer exposures for all air contaminants monitored. This result supports previous research and is consistent with pig barn ventilation system management. Using appropriate contaminant measurement technology and a personal monitoring approach, this study confirmed that exposure differences exist for specialty-area workers. In particular, Nursery/Grower-Finisher workers were shown to have the highest gravimetric respirable dust exposures in both winter and summer, the highest respirable dust count exposures in the size fraction > 5.0 μm in summer, and the highest endotoxin exposures in summer when compared to Farrowing workers. For the majority of airborne contaminants monitored, there were no differences in concentrations by day of visit (Tuesday, Wednesday, or Thursday). However, for Nursery/Grower-Finisher workers, higher respirable dust mass (mg/m^3) and endotoxin exposures were found for exposures on Tuesday's when compared to Thursday sampling days. Further analysis showed that significantly greater pig movement activities occurred on Tuesdays relative to Thursdays. While none of the worker exposures in the study exceeded the 3 mg/m^3 Threshold Limit

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Value (TLV) for respirable dust (ACGIH, 2001), specialty-area worker exposures did exceed a more conservative guideline of 0.28 mg/m^3 for personal-sampled respirable dust, proposed by Donham et al. (1989). According to the lower TLV guidelines, more than 25% of workers from all worker specialties were over-exposed to respirable dust. Furthermore, a larger proportion of Nursery/Grower-Finisher workers were over-exposed compared with Dry Sow/Breeding or Farrowing workers in both winter and summer. The presence of solid flooring was found to be predictive of higher endotoxin and lower H_2S exposures. All specialty-area workers were exposed to low (< 3 ppm) TWA H_2S exposures. However, TWA H_2S exposures give a false sense of security. This study found that 54% (winter) and 30% (summer) of the workers experienced short-term H_2S exposures that exceeded the proposed 15 ppm H_2S ceiling limit for Alberta.

In chapter four, the activities of workers and duration of activities (using time activity diaries from the winter season) were analyzed and linked to real-time respirable dust and gas air contaminant concentrations recorded with the PESB II instrumentation. The purpose of this portion of the study was to determine whether the types and duration of activities conducted by Dry Sow/Breeding, Farrowing and Nursery/Grower-Finisher specialty-area workers varied by specialty, and to determine whether airborne contaminant exposures differed by workplace activity. This study found that the types and duration of activities as well as activity-specific air contaminant concentrations did differ by area-specialty. Farrowing-area workers spent the most time dry feeding and had the lowest respirable dust (>0.5 μm) count exposures during this and the barn checking activities. Nursery/Grower-Finisher workers spent the most time barn checking,

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vaccinating and moving older pigs and also had the highest respirable dust (>0.5 μm) count exposures during dry feeding and barn checking activities. Farrowing-area workers were 3 times more likely to be exposed to high respirable dust count exposures when conducting workplace activities. There was also a trend to higher respirable dust exposures for pig moving activities. In 79% of workplace activities, workers were exposed to concentrations of H_2S exceeding the proposed 15 ppm ceiling limit. Not surprisingly, peak exposures ($\geq$15 ppm) were found during pit work and manure system (pump repair) activities. However, peak exposures were also found among activities not associated with liquid manure removal from barns. Analysis of the time activity diary data showed that workers' self-reported diaries did not contain sufficient information to develop an adequate and reliable time activity profile of the workday. This necessitated the use of observer-recorded diary data. While the use of trained observers recording unbiased data made this study more expensive, it proved invaluable to the quality of the activity data that was collected.

In chapter five, the peak H_2S exposure levels ($\geq$15 ppm) of pig barn workers during winter in large intensive barns were analyzed, and the causes of these high H_2S exposures were evaluated. Twenty-seven peak exposure events were recorded. Results showed that the proportion of peak exposure events during manure pit work activities was significantly greater than the proportion during non-pit work activities. Furthermore, workers conducting pit work tasks were found to be 21 times more likely to be exposed to H_2S concentrations exceeding the 15 ppm ceiling limit compared to workers conducting other tasks. Approximately half (48%) of the peak exposure events were attributable to

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direct pit work activities. Of the remaining exposure events, 33% were attributable to H_2S emanating from the manure transfer room, or as a consequence of pit work activities conducted by co-workers. Nineteen per cent of the events were of an unknown cause.

Results from this study can be generalized to the exposures of career pig barn workers in modern pig barns in Alberta and likely more generally in Canada and the Northern USA. A representative sample of 15 barns were randomly selected from barns in Alberta. Of the workers asked to participate in the study, 95% agreed to wear the PESB II, which represented 18% of career pig barn workers in Alberta. This is an exceptionally large sampling rate for this kind of occupational exposure study. The barns that were selected represented a wide range of herd sizes, barn design and management, and were representative of the modern pig industry in general. In previous research, most workers were owner-operators and had often worked less than a full workshift in the pig barn environment. By contrast, in the current study, all of the workplaces involved hired employees, ranging from 3 to 16 workers per barn. Thus, this study is more representative of the modern pig industry and the results and interpretations are more likely to be useful for predicting workplace exposures.

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6.2 Conclusions

From this study, the following conclusions can be drawn:

1. Pig barn workers should be enrolled in studies based on the specialty-area in which they work, not on their status of 'just' being a pig barn worker.
2. Personal monitoring is more appropriate than area monitoring for measuring air contaminant exposures of pig barn workers in modern pig barns. This allows the *actual* exposures of the workers to be monitored as they conduct their varied workplace activities in the many rooms and areas throughout the modern confinement pig barn.
3. Workplace exposure differences exist for specialty-area pig barn workers. Nursery/Grower-Finisher workers have higher exposures to respirable dust and endotoxin compared to Farrowing workers.
4. Solid floor in pig barns are associated with higher endotoxin exposures than slatted floors.
5. Workers are at the greatest risk to high H_2S exposures when conducting manure pit work activities. Workers conducting this task, were 21 times more likely than workers not conducting pit work activities to be exposed to H_2S concentrations exceeding the proposed 15 ppm ceiling exposure limit in Alberta for this contaminant.
6. For research purposes, self-reported time activity diaries for pig barn workers do not contain sufficient information to reliably and accurately link to real-time continuous air contaminant exposures.

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6.3 Recommendations and Future directions

The following recommendations are drawn from this study.

1. This study found that air contaminant exposures are highest in winter. The result has been supported by numerous other studies reported in the literature and is consistent with pig barn ventilation management. However, the winter-summer exposure differences were suppressed in the present study given the mild winter conditions experienced. The choice of season to conduct a particular study will be dependent on the purpose of the study (compliance study; health effects study). From a risk-management perspective, a study may be conducted to determine exposure/health outcomes during a 'worst case scenario' season. Such a study may be able to confine exposure and health assessment of specialty-area career pig barn workers to the winter season in climates like Alberta.
2. It is most appropriate to select a sampling day for future exposure studies on the basis of types of activities likeliest to be conducted on a specific day, rather than randomly selecting a day of the week. For example, in studies of maximum exposures of Nursery/Grower-Finisher workers, the researcher might want to select those days where sorting, weighing or moving activities will occur. It is easy to obtain information on expected worker activities given the predictable nature of work in modern pig barns.
3. While some previous studies identified the potential for workplace exposures to be highest in the Nursery area of pig barns (because of higher

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temperatures, humidity and dust levels), these assessments were based primarily on area-monitoring. It was not possible to evaluate separately the exposures of specialty-area Nursery workers in the present study, but future studies should test the hypothesis that Nursery workers are at the highest air contaminant exposure risk. Such research will be possible in the future given the trend toward the establishment of separate-site specialized nursery barns. Similarly, it will also be possible to further evaluate the exposures of specialized Grower-Finisher workers as a separate population given the trend to specialized Grower-Finisher facilities.

4. While it may be more convenient for some worker health and exposure studies to use näive study participants, with the PESB II system, researchers can monitor the exposures of actual workers. However, in order for studies with actual workers in private barns to be successful, it is essential to communicate well with the barn owners and managers to ascertain which day(s) workers are likeliest to be conducting either higher exposure activities (such as pig moving activities), or activities where they will be performed in a particular room for extended periods of time, such as for studies that are evaluating room-specific pit or dust control technologies.

5. Future studies in pig barns must incorporate stringent biosecurity protocols encompassing both research equipment and personnel. A level of

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cooperation and trust needs to be established between the researcher(s), owner(s)/manager(s) of the barns, and herd health veterinarians to accomplish this.

6. Ideally, personal monitoring equipment should be worn throughout the workshift, including during breaks (coffee/lunch). If workers must shed the equipment during rest periods, the equipment may be positioned at breathing zone height (on a table for example), as close to the worker as possible to approximate as best as possible, actual personal exposures during such break activities. In pig barn environments, workers do not completely leave the workplace during breaks and contaminant exposures may continue at significant levels even while not working.

7. The choice of sensors/instrumentation used in future studies should be carefully considered given the environmental contaminants found in pig barn environments. The experiences from this study suggest that NH_3 sensors should be thoroughly tested for cross-sensitivity to H_2S prior to use. NH_3 is an important barn contaminant, and specialty-area personal worker exposure data has yet to be reported in the literature.

8. The observation that workers from one specialty area work in other specialty areas to conduct tasks on behalf of, or in conjunction with co-workers, highlights the importance of tailoring area-specific safety courses to *all* workers. For example, a particular worker may not conduct the pit work task. However, this worker may, at some time in the future, be

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required to conduct this task. Therefore, if a H_2S safety course is offered to barn staff, all workers should be required to take this course.

9. In this study, more than 25% of all specialty-area workers were exposed to respirable dust exceeding Donham et al.'s (1989) proposed 0.28 mg/m^3 exposure guideline for this contaminant, in both winter and summer. Furthermore, even with routine complete room washing in the Farrowing area, this study found that Farrowing-area workers were 3 times as likely to be exposed to high respirable dust count exposures when conducting workplace activities. Given these results, and until other engineering and administrative controls can be successfully implemented, there is merit in recommending that workers wear proper respiratory protection when conducting work within animal rooms, to reduce their exposures to airborne dust.

10. Pig barn workers should consider wearing H_2S monitors. However, to gain maximum benefit from their use, a proper feedback mechanism needs to be in place to inform each individual about H_2S exposure. At a minimum, the use of these monitors would help to raise the awareness of the presence of occasional high levels of H_2S, as well as the conditions and workplace activities where high concentrations may occur. As well, the use of monitors would alert workers to life-endangering gas levels. The author cautions, however, that the wearing of an H_2S gas monitor alone does not make an environment safe. Pig barn environments are relatively

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unregulated and the awareness of exposures and potential health risks in this relatively new class of workplace are still quite rudimentary. Procedures and practices for routine calibration and testing of monitors in the environment have yet to be developed. The author recommends that Standard Operating Procedures be developed in concert with the use of personal H_2S monitors in pig barns. They should include information on where workers go following an exposure infraction (i.e. area designated for evaluation); how long they are to remain out of the area where the exposure infraction occurred, or more appropriately, how they will know whether it is safe to return to the area. An in-barn reporting scheme should also be developed for every H_2S exposure infraction. This will help pinpoint problem area(s) in barns, help to protect workers from future exposures, and help engineers pinpoint manure pit and plumbing design deficiencies.

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6.4 References

ACGIH. 2001. Documentation of the Threshold Limit Values and Biological Exposure Indices. 7th Edition ed. Cincinnati OH: ACGIH.

Donham, K.J., Haglind, P., Peterson, Y., Rylander, R., Belin, L. 1989. Environmental and Health Studies of Farm Workers in Swedish Swine Confinement Buildings. British Journal of Industrial Medicine 46: 31-37.

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Appendices for Chapter Two

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Appendix 2.1. Procedure to determine the level of cross-sensitivity of hydrogen sulfide (H_2S) on the ammonia (NH_3) sensor, and to determine whether a cross-sensitivity exists for NH_3 gas on the H_2S sensor.

A. Procedure for determining cross-sensitivity of the NH_3 sensor to H_2S

1. Set the date, time and sampling interval on each NH_3 monitor.

2. Record all sensor identification numbers.

3. Turn the NH_3 monitors on to allow them to stabilize for 3 min.

4. Hook up all NH_3 monitors in series using teflon-lined vinyl tubing.

5. Flow a certified 100% nitrogen gas (N_2) past all of the sensors in series for 5 min to zero the NH_3 monitors. If the monitors do not read zero, then they are manually adjusted to read zero. The procedure for this is described in the operator's manual.

6. Flow a certified 50 ppm NH_3 gas mixture, balanced with N_2, past the sensors for 5 min. This procedure checks and sets the span of the units. Record the readings.

7. Adjust all monitors to read 50 ppm. This procedure is described in the user's manual.

8. Flow the certified 100% N_2 gas past the sensors in series again, for 5 min, to re-zero the monitors.

9. Flow a certified 9 ppm Hydrogen sulfide (H_2S) gas mixture, balanced with N_2, past the sensors for 5 min. Record the readings.

10. Steps 8 and 9 are repeated twice more. Three replications for each sensor were conducted in total.

11. Cross-sensitivity readings for each sensor were averaged over the three replications.

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B. Procedure for determining cross-sensitivity of the H_2S sensor to NH_3

1. Set the date, time and sampling interval on each H_2S monitor.

2. Record all sensor identification numbers.

3. Turn the H_2S monitors on to allow them to stabilize for 3 min.

4. Hook up all H_2S monitors in series using teflon-lined vinyl tubing.

5. Flow a certified 100% nitrogen gas (N_2) past all of the sensors in series for 5 min to zero the H_2S monitors. If the monitors do not read zero, then they are manually adjusted to read zero. The procedure for this is described in the operator's manual.

6. Flow a certified 9 ppm H_2S gas mixture, balanced with N_2, past the sensors for 5 min. This procedure checks and sets the span of the units. Record the readings.

7. Adjust all monitors to read 9 ppm. This procedure is described in the user's manual.

8. Flow the certified 100% N_2 gas past the sensors in series again, for 5 min, to re-zero the monitors.

9. Flow a certified 50 ppm NH_3 gas mixture, balanced with N_2, past the sensors for 5 min. Record the readings.

10. Steps 8 and 9 are repeated twice more. Three replications for each sensor were conducted in total.

11. Readings for each sensor were averaged over the three replications.

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Appendix 2.2. Disassembly and calibration of PESB II monitoring equipment:

a) The boxes are taken out of the cloth backpacks and are individually wiped down with 97% isopropyl alcohol
b) Keeping the box intact, download the PESB II data using a laptop. The PESB II data is visually checked to ensure that downloading was completed successfully and to see if there were any problems with the monitoring equipment
c) Check the pump flow rates after a five minute warm-up period (refer to DryCal flow meter manual for instructions)
d) Open up the PESB II boxes by loosening the 4 bolts
e) Remove the Toxi Ultra (NH_3 and H_2S) units and associated tubing. Download the Toxi Ultra units and double check the data to ensure that downloading was successful and to see if there were any problems with the monitoring equipment (see below)
f) Clean the dust sensor
g) Conduct the post calibration of the Toxi Ultra units (see below)
h) Return the dust sensor and Toxi Ultra units to the PESB IIs
i) Close the box. Conduct the post-calibration and checks of the CO_2, RH and temperature sensors (see below)
j) Repair (if required) and recalibrate the PESB II monitoring equipment (see below)
k) Re-assemble the PESB II boxes
l) Pre-calibrate and adjust the pump flow rates. The adjustment is done manually on the pumps themselves and may require opening and closing the enclosure boxes.
m) Re-charge the PESB II re-chargeable batteries. This will take approximately 4-6 hours but will be dependent on the charge left in the batteries.

Specific downloading and calibration procedure details:

i. **Removal and downloading of Toxi Ultras (NH_3, H_2S).** Turn the units off. Take the flow caps off. Place the Toxi Ultra into the downloading cradle and download the data via laptop/desktop PC. Double-check that the data downloaded properly and that there are no monitor/sensor problems. Clear the memory and re-set the clock. Turn the Toxi Ultra Units back on.

ii. **Post-calibration of the Toxi Ultras.** Zero calibrate the Toxi Ultras using 100% certified N_2 gas. Flow this gas passed the sensors for 5 minutes. Record the zero readings. For the span calibration use the appropriate certified gas mixture, either 50 ppm NH_3, balanced with N_2, or 9 ppm H_2S, balanced with N_2, depending on the sensor. Again, flow this span gas passed the sensor for 5 minutes. Record the span readings for the post-calibration. Flush the units with 100% N_2 gas until the H_2S units read zero and the NH_3 readings are below 10 ppm. Put the NH_3 Toxi Ultra units aside with their caps removed while you conduct the pre-calibration of the H_2S units. Re-do the zero and spans for the H_2S units for which zero is not zero. Conduct the zeros and spans on the NH_3 units if they are reading below 10 ppm.

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If they are not reading below 10 ppm then continue on with another task until the NH_3 units are ready for zeroing and spanning. Follow the same calibration procedures as for H_2S. Once completed, attach the caps and place the units back into the PESB II. Attach all appropriate tubing.

iii. **Personal pump calibration procedure.** For post or pre-calibration, allow the pumps to run for 5 minutes before taking any readings with the Drycal flow meter. Procedures for using the Drycal flow meter are presented in the owner's manual. Note that these pump calibrations should take place with the box tightly closed. If necessary, the pump flow rates can be adjusted to achieve the target flow rates (1.7-2.0 L/min and 2.8 L/min).

iv. **Post-calibration and check of CO_2 and RH sensors.** Flow 100% certified N_2 gas passed the sensors for 5 minutes to check and record CO_2 and RH zero readings. Compare the readings with past readings to ensure that the sensors are working OK. Flow CO_2 span gas (9000 ppm), balanced N_2, passed the sensors for 5 minutes and check and record the span reading after the 5 minutes. Again compare the span readings with past readings to make sure that the sensor is working OK. Turn on the pumps and review the ambient readings for CO_2, RH and external temperature. Again compare these readings with past readings to confirm that the sensors are working OK.

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Appendices for Chapter Three

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Appendix 3.1. PESB II Pack Card used in this study

Visit Date:__________ Barn Name: ____________ Barn ID:____

Participant Name:______________ Participant ID:_______

Worker Specialty Area:___________

PESB II #:________ Endotoxin Cassette #:________

Time Pack On:_________

Pump Running Time:__________

Time Pack Off:____________

Calculated Running Time:__________

Comments:____

This Pack Card, printed on thicker card stock, measured 13 cm by 10 cm, and was placed into a zippered pocket of the cloth backpack prior to entry into the barn.

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Appendix 3.2. Example Barn Management Questionnaires used for the Farrowing Area. Supplemental questions for the Dry Sow/Breeding, Nursery, Grower and Finisher specialty areas of the study pig barns are attached.

Barn Management Questionnaires

Today's Date: ________________ Sherpa Name:______________ Farm Name:_____________ Farm I.D:_______

Farrowing:

	Room 1	Room 2	Room 3	Room 4, etc.
Are the rooms:	❒ continuous flow ❒ All-in, All-out ❒ __________	❒ continuous flow ❒ All-in, All-out ❒ __________	❒ continuous flow ❒ All-in, All-out ❒ __________	❒ continuous flow ❒ All-in, All-out ❒ __________
Room dimensions:				
length (ft)				
width (ft)				
ceiling height (ft)				
Lighting:	❒ incandescent ❒ fluorescent ❒ __________	❒ incandescent ❒ fluorescent ❒ __________	❒ incandescent ❒ fluorescent ❒ __________	❒ incandescent ❒ fluorescent ❒ __________
Is the lighting sufficient to easily read a newspaper while sitting on the floor?	❒ yes ❒ no	❒ yes ❒ no	❒ yes ❒ no	❒ yes ❒ no
Number of animals:				
# sows				

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avg sow weight				
# piglets				
average age of piglets (d)				
avg piglet weight				
Size of farrowing crates	❒ 5' x 7' ❒ 6' x 8' ❒ ______	❒ 5' x 7' ❒ 6' x 8' ❒ ______	❒ 5' x 7' ❒ 6' x 8' ❒ ______	❒ 5' x 7' ❒ 6' x 8' ❒ ______
Farrowing crate flooring	❒ partially slatted ❒ fully slatted	❒ partially slatted ❒ fully slatted	❒ partially slatted ❒ fully slatted	❒ partially slatted ❒ fully slatted
Is the flooring in the farrowing crate:	❒ different piglets/sows ❒ same for piglets/sows	❒ different piglets/sows ❒ same for piglets/sows	❒ different piglets/sows ❒ same for piglets/sows	❒ different piglets/sows ❒ same for piglets/sows
Manure Management:				
Depth of pits (ft)				
How often are the pits drained?	❒ weekly ❒ every 2 weeks ❒ every 3 weeks ❒ ______	❒ weekly ❒ every 2 weeks ❒ every 3 weeks ❒ ______	❒ weekly ❒ every 2 weeks ❒ every 3 weeks ❒ ______	❒ weekly ❒ every 2 weeks ❒ every 3 weeks ❒ ______
How is manure removed from the room?	❒ pull plug ❒ underfloor scraping	❒ pull plug ❒ underfloor scraping	❒ pull plug ❒ underfloor scraping	❒ pull plug ❒ underfloor scraping
Room Cleanliness:				
How often is this area scraped?	❒ daily ❒ twice daily ❒ ______	❒ daily ❒ twice daily ❒ ______	❒ daily ❒ twice daily ❒ ______	❒ daily ❒ twice daily ❒ ______

How often is this area swept?	☐ daily ☐ weekly ☐ __________ ☐ never	☐ daily ☐ weekly ☐ __________ ☐ never	☐ daily ☐ weekly ☐ __________ ☐ never	☐ daily ☐ weekly ☐ __________ ☐ never
How often is this area washed?	☐ daily ☐ weekly ☐ every 3 weeks ☐ __________	☐ daily ☐ weekly ☐ every 3 weeks ☐ __________	☐ daily ☐ weekly ☐ every 3 weeks ☐ __________	☐ daily ☐ weekly ☐ every 3 weeks ☐ __________
Is disinfection part of the washing procedure?	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no
If yes, name of disinfection product used				
Is the room clean and are the crates clean?	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no
If the area is not clean, please specify whether area is wet/dust on floor/etc.				
Is there evidence of corrosion / rust in the area?	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no
Is there dust on the penning material or ducts?	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no
Are there cobwebs on the ceiling?	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no
Are there flies?	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no	☐ yes ☐ no
If yes, name of fly control product used				

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Feeding System:				
Method	❑ hand-fed once/d ❑ hand-fed twice/d ❑ hand-fed three/d ❑ liquid feeding ❑ ________	❑ hand-fed once/d ❑ hand-fed twice/d ❑ hand-fed three/d ❑ liquid feeding ❑ ________	❑ hand-fed once/d ❑ hand-fed twice/d ❑ hand-fed three/d ❑ liquid feeding ❑ ________	❑ hand-fed once/d ❑ hand-fed twice/d ❑ hand-fed three/d ❑ liquid feeding ❑ ________
Feed Type	❑ ground feed ❑ Pellets/crumbles ❑ liquid ❑ ________	❑ ground feed ❑ Pellets/crumbles ❑ liquid ❑ ________	❑ ground feed ❑ Pellets/crumbles ❑ liquid ❑ ________	❑ ground feed ❑ Pellets/crumbles ❑ liquid ❑ ________
How is water supplied to the pigs?	❑ water nipples ❑ ________	❑ water nipples ❑ ________	❑ water nipples ❑ ________	❑ water nipples ❑ ________
Is there an extra water source for the piglets?	❑ yes ❑ no	❑ yes ❑ no	❑ yes ❑ no	❑ yes ❑ no
Gas Levels:				
Is there evidence of high gas levels (NH_3 and/or H_2S)? If yes, please specify type of gas you can smell and whether this smell is strong or weak				
Heating / Ventilation:				
Ventilation type	❑ fans, exhaust ❑ natural ❑ ________	❑ fans, exhaust ❑ natural ❑ ________	❑ fans, exhaust ❑ natural ❑ ________	❑ fans, exhaust ❑ natural ❑ ________
# fans				
# fans running				

Re-circulation type	❑ ducts/tubes ❑ stirring fans ❑ none	❑ ducts/tubes ❑ stirring fans ❑ none	❑ ducts/tubes ❑ stirring fans ❑ none	❑ ducts/tubes ❑ stirring fans ❑ none
Type of room heating	❑ hot water ❑ un-vented furnace ❑ heated floors ❑ ___________	❑ hot water ❑ un-vented furnace ❑ heated floors ❑ ___________	❑ hot water ❑ un-vented furnace ❑ heated floors ❑ ___________	❑ hot water ❑ un-vented furnace ❑ heated floors ❑ ___________

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Dry Sow / Breeding: supplemental questions

	Room 1, etc.		Room 1, etc.
Lighting:	❑ incandescent ❑ fluorescent ❑ metal halide ❑ sodium ❑ ____________	Is the pen flooring:	❑ partially slatted ❑ fully slatted
Number of animals:		Is the slat flooring material:	❑ concrete ❑ plastic ❑ metal
# sows		**Room Cleanliness:**	
avg sow weight		Are the solid portions of the floor:	❑ dry / clean ❑ dry / dirty ❑ wet / dirty
# boars		If the area is not clean, please specify whether area is wet/dust on floor/etc.	
avg boar weight		**Feeding system:**	
# gilts		Method (check all that apply)	❑ self feeder ❑ drop feeder (1/day) ❑ drop feeder (2/day) ❑ liquid feeding ❑ ____________
avg gilt weight		Feed type	❑ ground feed ❑ pellets/crumbles ❑ liquid ❑ ____________

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Type of dry sow housing	❑ stalls ❑ pens ❑ mix of both of above ❑ group/loose housing	How is water supplied to the pigs?	❑ water nipples ❑ water trough ❑ ___________

Nursery, Grower and Finisher: Supplemental Questions

	Room 1	Room 2	Room 3	Room 4, etc.
Number of animals:				
# pigs				
avg pig weight				
Type of housing (nursery):	❑ floor pens ❑ raised pens ❑ multi-level ❑ ___________	❑ floor pens ❑ raised pens ❑ multi-level ❑ ___________	❑ floor pens ❑ raised pens ❑ multi-level ❑ ___________	❑ floor pens ❑ raised pens ❑ multi-level ❑ ___________
Size of pens				
Pen flooring	❑ partially slatted ❑ fully slatted	❑ partially slatted ❑ fully slatted	❑ partially slatted ❑ fully slatted	❑ partially slatted ❑ fully slatted
Is the slat flooring material:	❑ concrete ❑ plastic ❑ metal ❑ ___________	❑ concrete ❑ plastic ❑ metal ❑ ___________	❑ concrete ❑ plastic ❑ metal ❑ ___________	❑ concrete ❑ plastic ❑ metal ❑ ___________
Is the penning:	❑ open between pens ❑ solid between pens	❑ open between pens ❑ solid between pens	❑ open between pens ❑ solid between pens	❑ open between pens ❑ solid between pens
Manure management:				

Is there any bedding material on the floor	❑ yes ❑ no if yes:__________	❑ yes ❑ no if yes:__________	❑ yes ❑ no if yes:__________	❑ yes ❑ no if yes:__________
Feeding system:				
Method	❑ self feeder ❑ liquid feeding ❑ __________	❑ self feeder ❑ liquid feeding ❑ __________	❑ self feeder ❑ liquid feeding ❑ __________	❑ self feeder ❑ liquid feeding ❑ __________
Feed type	❑ pellets/crumbles ❑ liquid feed ❑ ground feed ❑ __________	❑ pellets/crumbles ❑ liquid feed ❑ ground feed ❑ __________	❑ pellets/crumbles ❑ liquid feed ❑ ground feed ❑ __________	❑ pellets/crumbles ❑ liquid feed ❑ ground feed ❑ __________
How is water supplied to the pigs?	❑ water nipples ❑ __________	❑ water nipples ❑ __________	❑ water nipples ❑ __________	❑ water nipples ❑ __________
Heating / Ventilation:				
Type of room heating	❑ hot water ❑ un-vented furnace ❑ heated floors ❑ infrared tubes ❑ __________	❑ hot water ❑ un-vented furnace ❑ heated floors ❑ infrared tubes ❑ __________	❑ hot water ❑ un-vented furnace ❑ heated floors ❑ infrared tubes ❑ __________	❑ hot water ❑ un-vented furnace ❑ heated floors ❑ infrared tubes ❑ __________

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Appendix 3.3. Biosecurity and Farm Entry / Exit Protocol

Scheduling:

For biosecurity reasons, only one pig barn will be visited per week. This will allow for the proper disinfection of the hiker's backpacks housing the Personal Environmental Sampling Backpacks (PESB IIs) and associated research equipment between visits, and will adhere to the 48 hour minimum "pig free" requirement that the majority of minimal disease facilities in Alberta require. At all times, the study personnel will adhere to the specific biosecurity protocols for the participating study farms. Scheduling the order of pig barn visits will be negotiated in consultation with veterinarians who work with the participating study farms.

Research Supplies:

All paperwork including questionnaires and activity diary booklets, and all associated research equipment including watches, dust collection cassettes, pens, and Ziploc® bags will be brand new and will be placed inside the backpack garbage bags prior to entrance into the pig barn (please refer to detailed entrance protocol below).

Twelve hiking backpacks, cyclones and other equipment will be purchased for this study so that no external equipment disinfection is required while the study team is "on the road". The cleaning and disinfection of all equipment will take place in Edmonton, the washing of the backpacks at a laundromat and the tubing and equipment disinfection in designated rooms in the Agriculture, Food and Nutritional Sciences (AFNS) building on the University of Alberta campus.

Entrance and Exit Protocol:

1. Once the re-chargeable batteries in the PESB II are fully charged, each battery charger is disconnected from the instrumentation case. The plastic instrumentation cases are then wiped down with 97% isopropyl alcohol and each instrumentation case is placed into a clean and disinfected hiker's backpack. All external tubing and cyclone cassette holders are attached and connected to the instrumentation cases. The hiker's backpacks are zippered shut and each backpack is triple-bagged. Prior to sealing the inside garbage bag with a twist tie, watches, pack cards, pens and other associated research materials are placed inside the garbage bag. Note, once the PESB II instrumentation is placed inside the hiking backpack and zippered shut, the hiking backpack will not be permitted to be zippered opened again until the end of the data collection day when the study team is off the pig barn property.

2. The barn manager of each farm shall be contacted prior to arrival to determine the best route of entry for the study equipment and supplies. Upon arrival at the pig farm, the

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outside garbage bag will be opened and the inner garbage bags lifted out so that the garbage bags containing the instrumentation box and associated equipment can be carried through the biosecurity zone(s). The outer garbage bag will remain in the vehicle and will serve as the bag that encloses the dirty packs (one garbage bag per hiking backpack) and associated equipment requiring cleaning and disinfection. While being carried to the barn from the vehicle, the inner garbage bags will not be allowed to contact the ground. Generally speaking, each particular barns' protocol will require travel through more than one biosecurity zone, so the equipment should be triple-bagged, meaning that successive outer garbage bag(s) are discarded prior to entry into the next biosecurity zone. At the entrance to the pig barn, the PESB IIs will be handed to workers (who have already showered into the barn), left sealed in the innermost garbage bag. Once in the barn, each garbage bag enclosing one PESB II will be opened and the instrumentation lifted out.

3. For barns where entrance showering is not required (N=3 barns), study personnel will shower at the motel prior to departing for the barn. At the barn, the study team members will change into 'in barn' clothing. This will include socks specifically purchased for this study, and clothing supplied by the study team members, which have previously never been in a pig barn, including underwear, t-shirts and shorts/sweat pants. For the return trip to the motel each evening, where possible, the study team will shower at the barn and change into 'traveling clothing'. Washable traveling shoes will be worn by the study team members when traveling to and from the pig barns. Where showering is not possible, the study team members will wash their hands prior to departure from the pig barn. At the end of the 3-day winter and summer visits, the "in-barn" clothing worn in these non shower-in barns will be removed from the study barn in a garbage bag. These along with the 'traveling shoes' worn for this barn will be washed with Tide™ with Bleach and dried at the laundromat. Specific clothing for these barns will be placed in individual new garbage bags and stored for the next season's visit to that particular barn and/or until the end of the study, by the project manager. This was done to ensure that no article of clothing would mistakenly be taken into a different pig barn. Coveralls and boots will be supplied by the farms.

4. For the seven barns in which "showering at the barn prior to entry" is part of the barn's biosecurity protocol, towels and all in-barn clothing (underwear, t-shirts, socks) will be supplied by the barn. Coveralls and boots will also be supplied by these farms. In the event that towels are not provided by the barns, brand new towels will be purchased for the project.

5. At the end of the data collection day, all monitoring equipment will be shut off, using an external toggle switch. Each PESB II will be placed into a garbage bag that was taken into the barn and sealed with a twist tie. The individual garbage bags containing the instrumentation backpacks will be taken out of the barn by research personnel or by workers from the barn who have already showered out of the facility. At the vehicle, the garbage bag containing the hiking backpack and monitoring instrumentation, will be

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placed in individual garbage bags which have remained in the vehicle. This procedure will occur outside the vehicle to prevent contamination of the inside of the vehicle from barn dust. Each bag will then be sealed with a twist tie, and placed on a disinfected cover sheet inside the vehicle to prevent contamination of the inside of the vehicle. Study team members will then use WetOnes® with disinfectant to "wash" their hands in the vehicle prior to departure from the farm. These moist toilettes are discarded in a travel garbage bag which is then discarded upon arrival in Edmonton at the end of the study week. The equipment will be transported to the field maintenance office for data downloading and equipment calibration and maintenance.

6. The equipment is handled slightly differently on the last day of the study visit (Thursday) due to travel logistics. During the winter and summer study, for barns that are located within an appropriate driving distance from Edmonton, the equipment will not be touched until the study team has arrived back in Edmonton. There, the garbage bags containing the hiking backpacks will be opened. The endotoxin cassettes will be individually removed from the cyclone holders, attached to desiccant cassettes, placed in individual Ziploc bags, and placed in a small cooler. The garbage bags are then re-sealed and the equipment is delivered to the U of A. For study barns that are located greater than 300 km from Edmonton, the endotoxin cassettes will be removed upon arrival back to the motel (following the procedure outlined above). The instrumentation cases are then individually removed from the hiking backpacks and are wiped down with 97% isopropyl alcohol. The data from the data loggers are then downloaded using a laptop computer. The equipment is then transported back to Edmonton and delivered to the U of A.

7. University of Alberta fleet vehicles will be rented for this field project. Each vehicle is thoroughly cleaned after each use, inside and outside, by University of Alberta fleet vehicle maintenance staff. An attempt will be made to rent a different vehicle each consecutive week. Sheets will be used to cover the vehicle's seats and the storage compartment of the van. The sheets will then be washed at the laundromat using Tide with Bleach. Paper floor mats were secured from a local car dealership, and they will be placed on the floor of the van (driver and passenger) when the van is picked up from vehicle pool. At the end of the week, these floor mats are discarded.

Lunches and snacks for barn staff and the research team: Types, contents and modes of transport of lunches into the participating pig barns will be discussed with the managers of the pig barns.

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Appendix 3.4. Equipment Disassembly, Cleaning and Disinfection Protocol

1. Upon arrival in Edmonton at the Department of Agriculture, Food and Nutritional Sciences (AFNS) Building on the University of Alberta Campus, the bags containing the instrumentation boxes will be carried to the outside door to our designated "dirty room". Outside this room, the instrumentation boxes will be removed from the backpacks, and placed on a metal trolley. The garbage bags containing the dirty backpacks and the plastic storage container containing the other equipment requiring disinfection will be sealed again with twist ties.

2. The instrumentation boxes will be wiped down with 97% isopropyl alcohol using shop towels. The instrumentation boxes will be taken into the "dirty room" and the disassembly, calibration and maintenance procedures followed as outlined in Appendix 3.5.

3. Our home base of Edmonton will be the site of all equipment cleaning and disinfection between separate pig barn visits. There will be three designated sites: Site 1 (backpack cleaning); Site 2 (equipment cleaning and disinfection of equipment and backpacks); Site 3 (storage and backpack assembly).

Backpack cleaning and Disinfection. The individual backpacks requiring disinfection will be taken to a neighborhood Laundromat. This will occur either immediately on return to the city of Edmonton, or the next day. There, each backpack will be individually removed from the garbage bags and placed into a quintuple- or triple-load automatic washing machines (6 backpacks per quintuple and 2 backpacks in each of 3 triple front-load washing machines). A commercial laundry detergent (Tide™ with bleach) will be used in the pre-wash and wash cycles. Each wash cycle has 5 complete water changes per cycle. The used dirty garbage bag(s) and anti-microbial filters will be discarded in a garbage bin located outside the laundromat. Once the full wash cycle is complete and after the project manager has washed her hands with disinfectant soap, the backpacks will be placed inside new garbage bags, sealed shut and taken to Site 2. At Site 2, the clean backpacks are hung to dry, since drying is a form of disinfection in itself. The following day, the backpacks will be soaked in a 2% Virkon disinfectant solution in a large tub for 20 minutes, 4 backpacks at a time. Throughout this 20 minute time period, the backpacks will be agitated in the tub every 5 minutes to ensure complete contact with the Virkon solution. Following this, the backpacks will be thoroughly rinsed with cold water to remove as much of the Virkon solution as possible. The backpacks will then be hung to thoroughly dry overnight. Once dry, the backpacks are placed in new garbage bags and transported to Site 3 in the Agriculture and Forestry Building at the University of Alberta.

Other Equipment cleaning and disinfection: The other equipment such as cylones, isokinetic probes, external tubing and velcro requiring thorough cleaning and disinfection will be taken to Site 1. These items will first be washed by hand twice in water, using

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Sunlight™ dish detergent. A syringe will be used to propel water through the cyclones, probes and tubing. The items are then transported to Site 2 where the equipment is thoroughly rinsed (inside and out) under a stream of water from the tap to remove soap residue. The cyclones and other equipment will then be transferred to a separate large disinfecting tub containing a Metricide solution). Metricide is an alkaline gluteraldehyde solution, which is a high level disinfectant used at a concentration of 2% in hospitals for scopes and the disinfection of other equipment including breathing tubes. We found that Virkon was too corrosive for the respirable dust cyclones and isokinetic probes. The equipment is soaked in this solution for 20 minutes, agitated ever 5 minutes to ensure the all parts of the equipment make contact with the disinfectant solution. After the disinfection process is complete, this equipment is thoroughly rinsed under flowing water. A high pressure air hose is then used to blow water out of the tubes, cyclones and isokinetic probes. Following this, the equipment is allowed to thoroughly dry.

Equipment Transport: All clean and disinfected hiking backpacks, tubing, cyclones, isokinetic probes, velcro and study paperwork and associated supplies are placed in a large plastic travel container, sealed with duct tape and transported to the motel.

Backpack Assembly: At the motel, two study team members spend a portion of the evening on the first night (usually the Monday night before the Tuesday AM visit) triple-bagging garbage bags, and attaching tubing, cyclones, velcro and a new antimicrobial filter to the 12 clean and disinfected backpacks. These items are then delivered to the project manager's room in the large plastic tub, in preparation for the 3-day barn visits. Meanwhile, the PESB II instrumentation is charging in the project managers room. In early morning, prior to each days' barn visit, the project manager assembles the PESB II instrumentation, following the protocol discussed under item 1, Entrance/Exit protocol in Appendix 3.3.

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Appendix 3.5. Categorical barn management variables. Category collapsing decisions

Original Barn Management Categories

Type of manure system:	1 = no pit 2 = pit	Type of flooring:	1 = solid 2 = partially slatted 3 = fully slatted
Frequency of pit draining:	1 = daily 2 = weekly 3 = every 1.5 weeks	Animal Flow:	1 = continuous 2 = All-in, All-out (AIAO)
	4 = every 2 weeks 5 = every 3 weeks 6 = once monthly	Area washed:	1 = no 2 = yes
	7 = every 2 months 8 = every 3 months 9 = no pits; scraping / hauling manure	Area disinfected:	1 = no 2 = yes
Feeding method:	1 = self-feeding 2 = drop feeding (1/day) 3 = drop feeding (2/day) 4 = hand feeding 5 = wet/dry self feeding 6 = liquid feeding 7 = drop feeding (3/day)		
Feed Type:	1 = ground feed 2 = pellets/crumbles 3 = liquid 4 = ground feed / pellets and crumbles 5 = pellets / crumbles / liquid feed		

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Recoded Barn Management Categories

Type of manure system:	1 = no pit 2 = both pit and no pit 3 = pit	Area washed:	1 = no 2 = some of both 3 = yes
Frequency of	1 = every 2-3 mo. (includes pit draining, no pits & daily flushing) 2 = every 3 - 4 weeks 3 = every 1 - 2 weeks	Area disinfected:	1 = no 2 = some of both 3 = yes
Feeding method	1 = drop and hand feeding 2 = Self feeding (some liquid feeding) 3 = liquid feeding		
Feed Type:	1 = Ground feed (some pellets/crumbles and/or liquid feed) 2 = Pellets/crumbles (some liquid feed) 3 = Liquid feed		
Type of flooring	1 = solid 2 = partially slatted 3 = fully slatted		
Animal flow:	1 = continuous 2 = continuous & AIAO 3 = AIAO		

Data categories were developed prior to barn management data coding, based on responses captured on the barn management questionnaire. As can be seen, many of the categories are not necessarily mutually exclusive. For some of the variables, like categories were combined to create mutually exclusive categories, while some categories were expanded to account for areas in which more than one type of system was present (particularly as a result of combining the Nursery area with the Grower/Finisher area).

Individual category decisions:

In all cases, the reference category received the highest ranking number in the collapsed and re-numbered barn management categories. The reference category is considered to be the best condition within a category, the one that others are compared to.

Type of manure system. An additional category was added, a catch-all category of both pit and no pit. The category "pit" was considered to be the best, so it received the highest ranking number (is the reference category).

Frequency of pit draining. The original 7, 8 & 9 categories were combined and became the first category (considered the "worst"). The original categories 5 and 6 were combined to create the new category 2, and finally original categories 1 through 4 were combined and became the new category 3, considered to be the best, i.e. the reference category.

Feeding method. The study barns employed a lot of different feeding methods. The different categories are presented in the left text box. These 7 categories were collapsed into 3 categories. Drop and hand feeding were grouped together as the first category. Self feeding became its own category since the workers are not directly involved with this task. In this category, "some liquid feeding" was added. This was because some workers had responsibilities in more than one area of the barn, with different areas sometimes having different feeding methods. The liquid feeding category was grouped on its own and became category 3, the reference category.

Feed type. It was difficult to group feed type into distinct categories, given the different types of feed that were fed in the barns, coupled with the fact that workers have responsibilities in more than one area of the barn. Hence some overlap of feeding types was anticipated. From the 6 original categories, the categories were collapsed into 3 feed type categories. Ground feed became the first category. A second category included ground feed plus "some pellets/crumbles and/or liquid feed" reflecting the fact the workers had responsibilities in more than one area of the barn that employed different feed types. Liquid feed became its own category and again, was considered to be the reference category.

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Type of flooring. The three original categories of solid, partially slatted and fully slatted remained the same. No changes were required. Fully slatted was coded as the reference category.

Animal flow. The animal flow categories of continuous flow, and All-in, all-out, where a room is filled with pigs which remain in the room until they reach a certain age or weight, and are then all moved out of the room at the same time, allowing for the entire room to be washed, followed in most cases by disinfection. In the new re-coded barn management categories, an additional category was added, the "catch-all" category again reflecting the fact that some workers worked in areas of the barn where animals were housed in a continuous flow system, but that these workers also had to work in areas of the barn where the animals were housed in an AIAO system. The reference category was AIAO, with the catch-all category being assigned a category number of 2.

Area washed. Again, as was true for the animal flow category, area washed did not change much between the original and the new re-coded barn management categories. Added a "catch-all" category, coded as number 2, and then used "yes" washed as the reference category.

Area disinfected. This category was handled identically to that of the area washed category.

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Appendix 3.6. Winter and Summer Data Correction / Conversion Equations

Winter Data Correction / Conversion Equations

Dust Time Lag:	((Dust count reading * 10 s) / 9.8 s)*6)
CO_2:	[CO_2 (A/D) * (Avg A/D span (9140) - Avg A/D zero) / (Avg A/D span - Avg A/D zero) + Avg A/D zero].
External Temperature:	Pack #1 - Pack #3: y = (reading * 0.0988) - 25.561 Pack #4: y = (reading * 0.099) - 25.373
RH:	Pack #1: y = (reading * 0.183) - 41.616 Pack #2: y = (reading * 0.1772) - 37.66 Pack #3: y = (reading * 0.1579) - 33.474 Pack #4: y = (reading * 0.1821) - 39.38
NH_3 and H_2S:	Corrected NH_3 = [(avg NH_3 concentration - avg zero) * 50] / avg span Corrected H_2S = [(avg H_2S concentration - avg zero) * 9] / avg span

Summer Data Correction / Conversion Equations

Dust Time Lag:	((Dust count reading * 10 s) / 9.8 s)*6)
CO_2:	[CO_2 (A/D) * (Avg A/D span (9140) - Avg A/D zero) / (Avg A/D span - Avg A/D zero) + Avg A/D zero].
External Temperature:	Pack #1 - Pack #3: y = (reading * 0.0247) - 25.561 Pack #4: y = (reading * 0.02475) - 25.371
RH:	Pack #1: y = (reading * 0.04575) - 41.616 Pack #2: y = (reading * 0.0443) - 37.66 Pack #3: y = (reading * 0.039475) - 33.474 Pack #4: y = (reading * 0.045525) - 39.38
NH_3 and H_2S:	Corrected NH_3 = [(avg NH_3 concentration - avg zero) * 50] / avg span Corrected H_2S = [(avg H_2S concentration - avg zero) * 9] / avg span

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Appendix 3.7. Specialty Barn Area Differences for workers who participated in the winter portion of the study

	Worker Specialty				
	DS/B	FA	N/GF	Row Totals	p-value
Number of Workers	16	12	15	43	
Type of manure system					0.29
No pit	2	0	3	5	
Both pit and no pit	0	0	1	1	
Pit	14	12	11	37	
Column totals	16	12	15	43	
Frequency of pit draining					0.041
Every 2-3 months	4	1	4	9	
Every 3-4 weeks	4	10	7	21	
Every 1-2 weeks	8	1	4	13	
Column totals	16	12	15	43	
Type of flooring					0.0001
Solid	2	0	1	3	
Partially slatted	14	1	11	26	
Fully slatted	0	11	3	14	
Column totals	16	12	15	43	
Feed type					0.37
Predominantly ground feed	9	7	4	20	
Pellets / crumbles	4	2	7	13	
Liquid feed	3	3	4	10	
Column totals	16	12	15	43	
Feeding method					0.001
Drop/self feeding	12	2	11	25	
Hand feeding	1	7	0	8	
Liquid fed	3	3	4	10	
Column totals	16	12	15	43	
Animal flow					0.0001
Continuous	16	0	6	22	
Both continuous & AIAO	0	0	3	3	
All-in, All-out (AIAO)	0	12	6	18	
Column totals	16	12	15	43	

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Rooms in area washed					0.0001
No	16	0	5	21	
Both yes and no	0	0	5	5	
Yes	0	12	5	17	
Column totals	16	12	15	43	
Rooms in area disinfected					0.0001
No	16	1	5	22	
Both yes and no	0	0	5	5	
Yes	0	11	5	16	
Column totals	16	12	15	43	

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Appendix 3.8. Specialty Barn Area Differences for workers who participated in the summer study

	Worker Specialty				
	DS/B	FA	N/GF	Row Totals	p-value
Number of Workers	13	10	14	37	
Type of manure system					p<0.001
No pit	3	0	0	3	
Both pit and no pit	0	0	6	6	
Pit	10	10	8	28	
Column totals	13	10	14	37	
Frequency of pit draining					p=0.08
Every 2-3 months	4	1	2	7	
Every 3-4 weeks	3	8	9	20	
Every 1-2 weeks	6	1	3	10	
Column totals	13	10	14	37	
Type of flooring					p<0.0001
Solid	2	0	0	2	
Partially slatted	11	1	13	25	
Fully slatted	0	9	1	10	
Column totals	13	10	14	37	
Feed type					p=0.62
Predominantly ground feed	7	5	7	19	
Pellets / crumbles	4	2	6	12	
Liquid feed	2	3	1	6	
Column totals	13	10	14	37	

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Feeding method					p=0.007
Drop/self feeding	10	3	13	13	
Hand feeding	1	4	0	5	
Liquid feeding	2	3	1	6	
Column totals	13	10	14	37	
Animal flow					p<0.0001
Continuous	13	0	2	15	
Both continuous & AIAO	0	0	8	8	
All-in, All-out (AIAO)	0	10	4	14	
Column totals	13	10	14	37	
Rooms in area washed					p<0.0001
No	13	0	2	15	
Some yes and some no	0	0	11	11	
Yes	0	10	1	11	
Column totals	13	10	14	37	
Rooms in area disinfected					p<0.0001
No	13	1	3	17	
Some yes and some no	0	0	10	10	
Yes	0	9	1	10	
Column totals	13	10	14	37	

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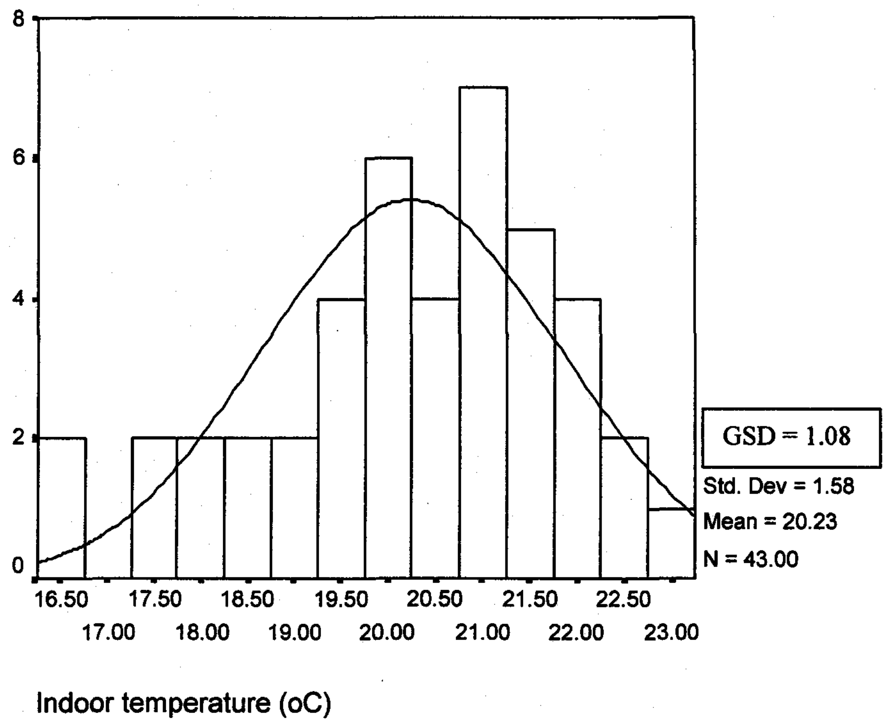
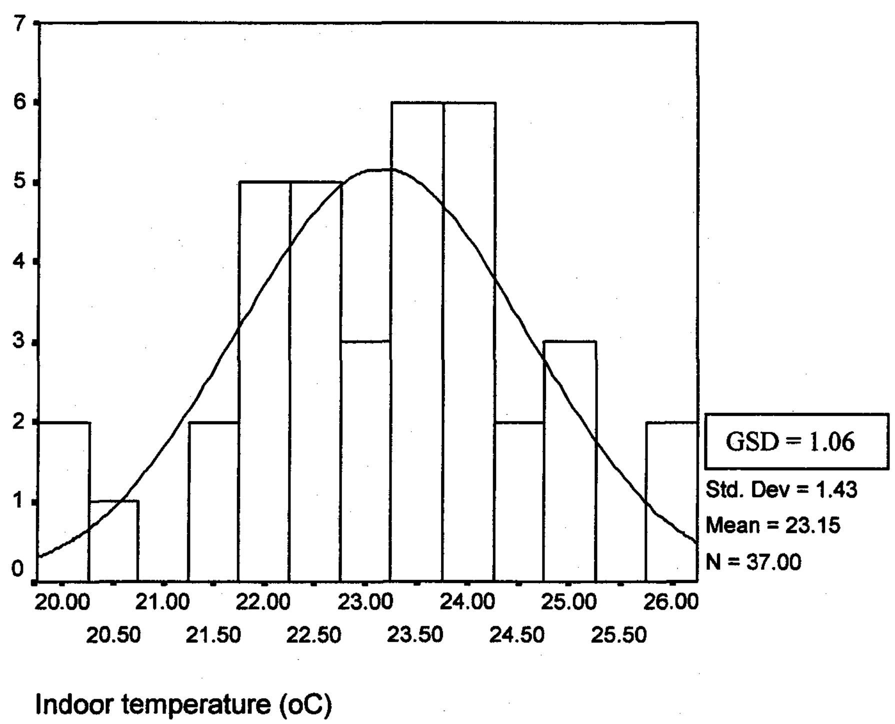
Appendix 3.9. Frequency histograms of selected variables used to make decisions on whether to transform variables prior to data analysis

Histogram: Un-transformed winter Indoor temperature (°C)



Histogram: Un-transformed summer Indoor temperature (°C)



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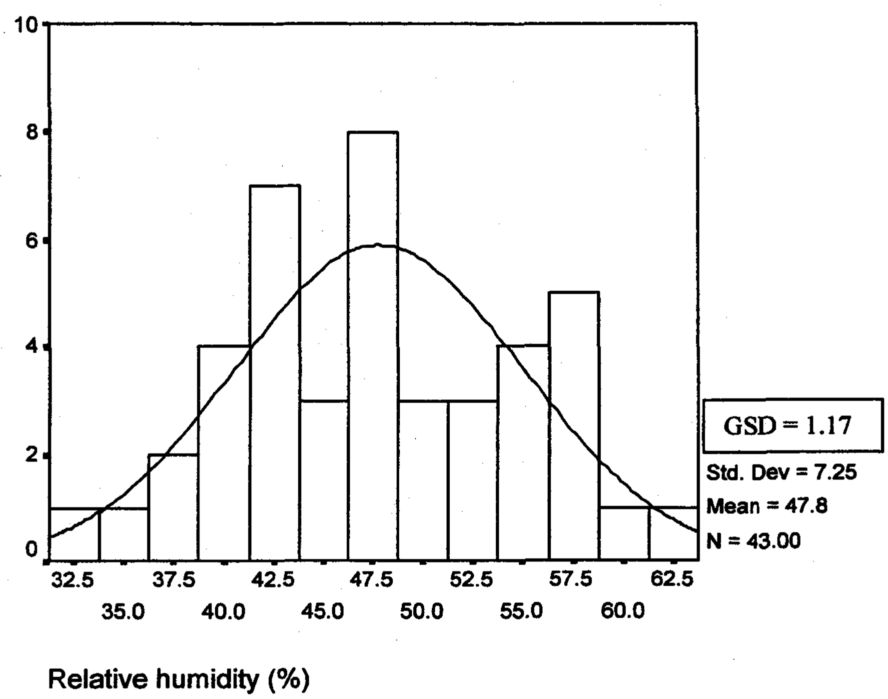
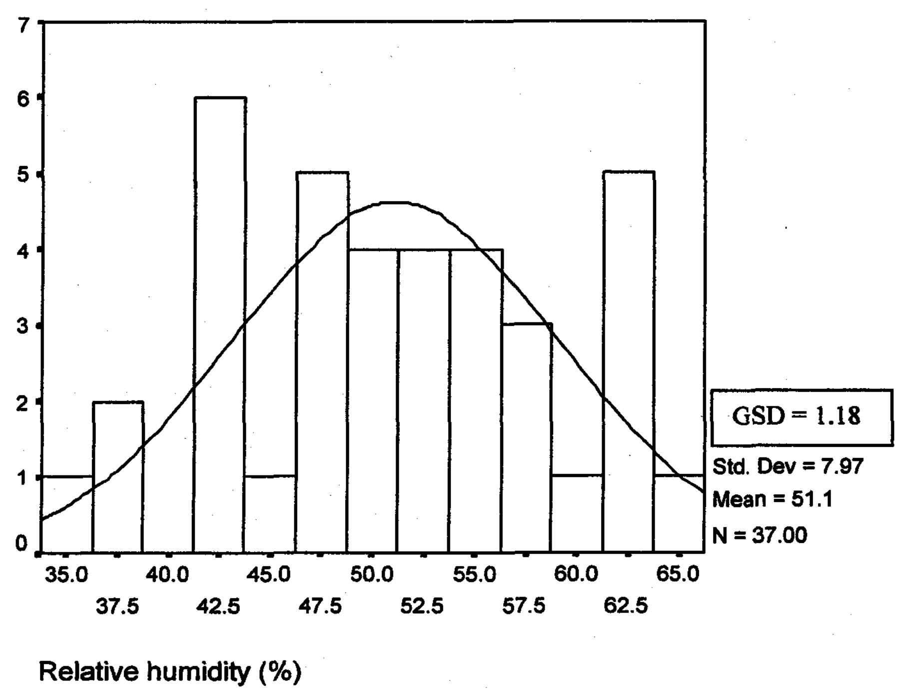
Histogram: Winter Relative humidity (%)



Histogram: Un-transformed summer Relative humidity (%)



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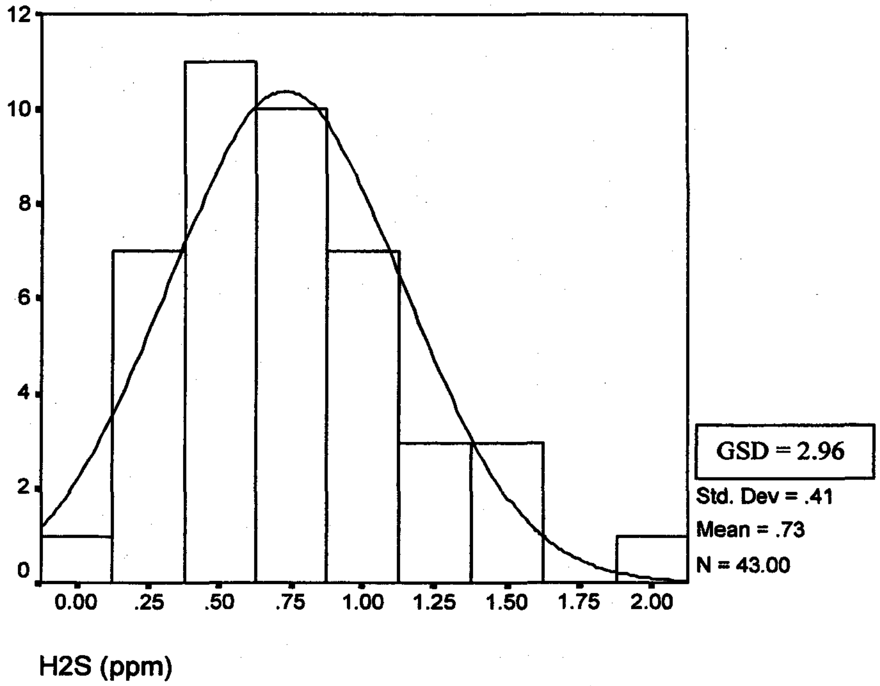
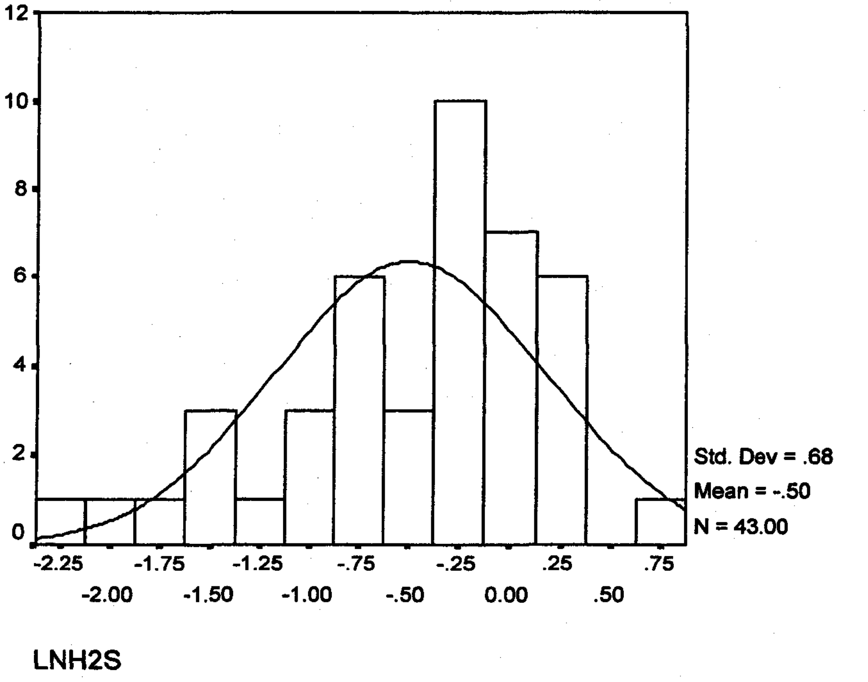
Histogram: Un-tranformed winter H_2S (ppm)



Histogram: Winter $\ln H_2S$ (ppm) following ln-transformation



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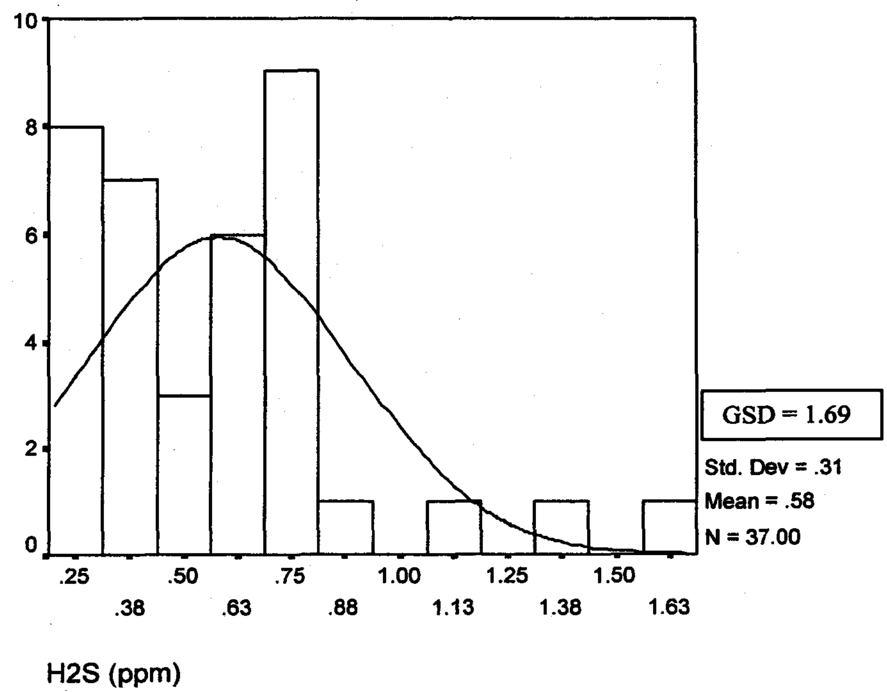
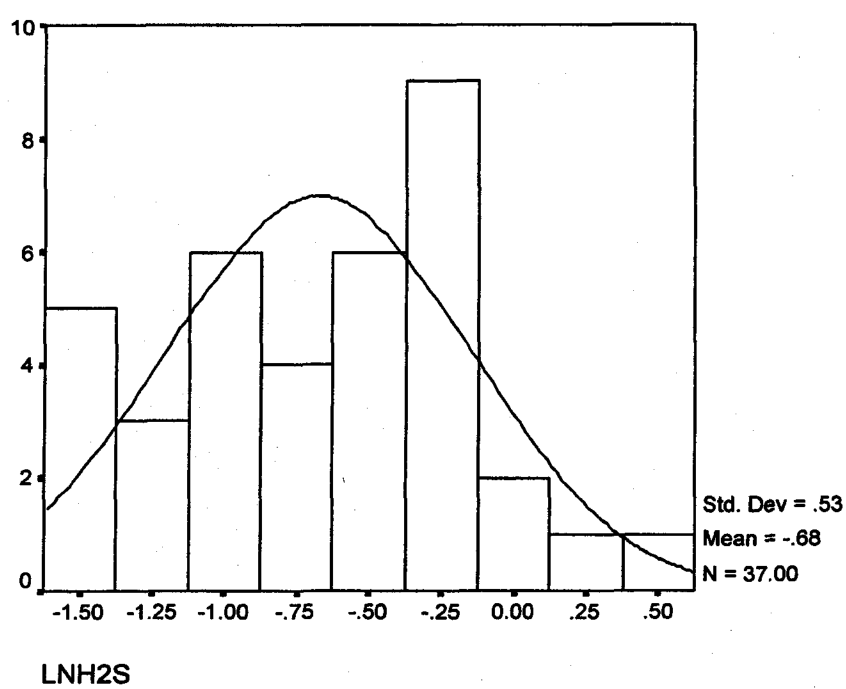
Histogram: Un-transformed summer H_2S (ppm)



Histogram: Summer lnH_2S following ln-transformation



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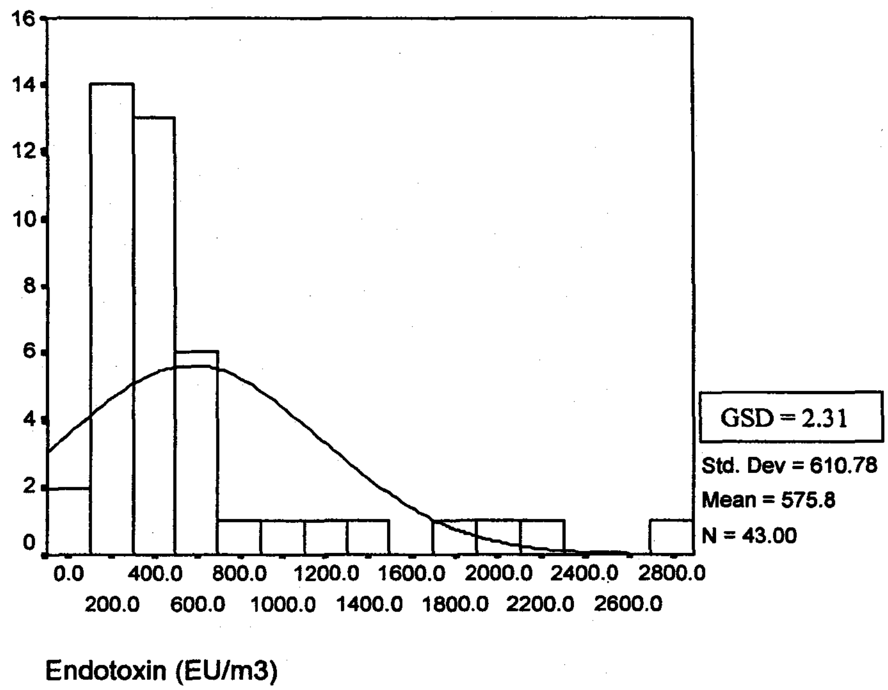
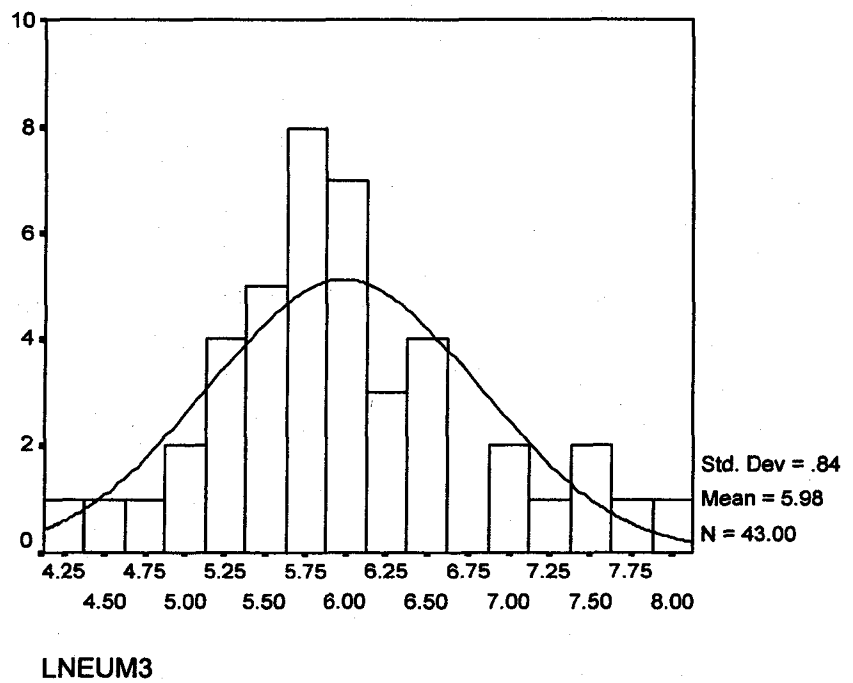
Histogram: Un-transformed winter Endotoxin (EU/m^3)



Histogram: Winter endotoxin (lneum^3) following ln-transformation



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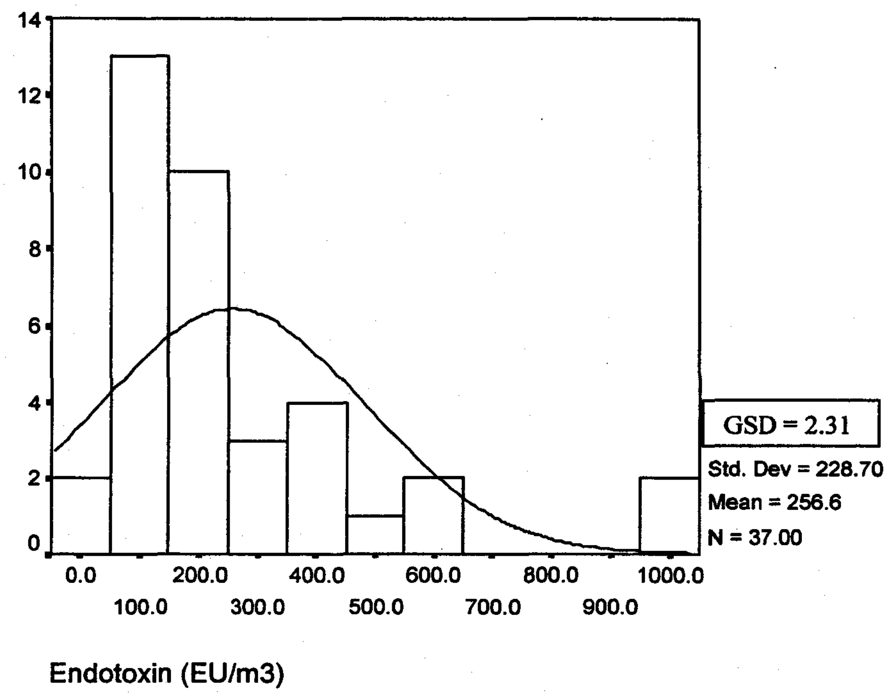
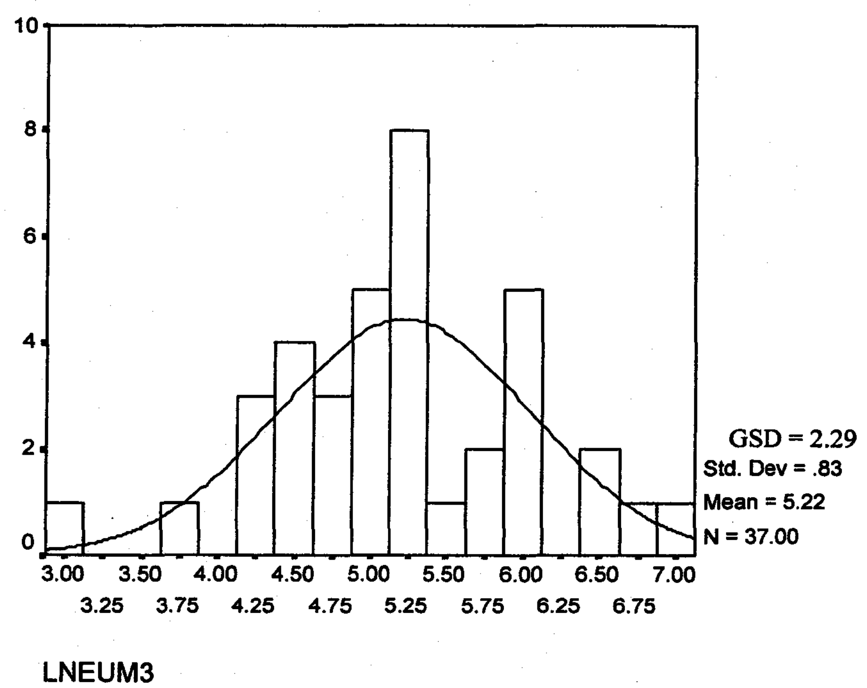
Histogram: Un-transformed summer endotoxin (EU/m^3)



Histogram: Summer endotoxin (lneu/m^3) following ln-transformation



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Appendices for Chapter Four

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Appendix 4.1. Open-ended Time Activity Diary used in the study.

For Office Use Only

Participant ID ______

Barn ID ________

Observer ID ______

Backpack ID

Name: ____________________

Farm Name: ____________________

Visit Date: ____ ____ ____
year month day

Visit Day: Tues. ❑ Wed. ❑ Thurs. ❑

Specialty Area: ____________________

Time began	Which zone?	Where are you?	What are you doing?	With who?	Time ended
			EXAMPLES		
8:39	Hallway	Farr barn	Herding sows into farr room # 3	–	8:43
8:44	Center alleyway	Farr room 3	Putting sows into farrowing crates	–	8:46
8:46	Center alleyway	Farr room 3	Calling sow numbers to co-working	Frank	8:49

Time began	Which zone?	Where are you?	What are you doing?	With who?	Time ended
:					:
:					:
:					:
:					:
:					:
:					:

Comments:

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The above diagram shows the time activity diary used in this study. Each booklet was a small (1.4 cm by 1.1 cm) coil notebook, designed to fit in the breast pocket of the worker's coveralls. Two diary types were used, one for the observer and another for the worker. The two diary types were identical in size and in the information requested (activity begin/end times, area and zone of the barn where each activity was being conducted, and who (names of other co-workers) the activity was being conducted with. The differences in the two diary types included the color of the front cover (yellow for observer and white for worker diaries), the number of pages available for data collection; the worker diary contained 20 pages (160 lines of data capability), while the observer diary contained 66 pages (396 lines of data capability), and space at the bottom of each page in the observer diary for comments.

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Appendix 4.2. Time Activity Diary Coding Manual

100 - BREEDING

110 Stimulating heat
- 111 Sow/boar mixing: mixing sows with teaser boar(s)
- 112 Stressing gilts: mixing gilts to bring on heat

120 Heat checking
- 121 Walking the boar: moving boar(s) slowly past groups of sows
- 122 Back pressure test: applying pressure on sow's back to see if in standing heat
- 123 Vulva check: checking vulva for redness and excretion as sign of heat

130 Natural breeding
- 131 Assisting boar: helping boar breed (includes watching boar with sow)
- 132 Providing footing: throwing feed on floor for grip
- 133 Removing boar: moving boar off sow that is not in standing heat

140 Semen collection/preparation
- 141 Training boar(s): training boar(s) for semen collection
- 142 Collecting semen: collecting the semen from a boar
- 143 Preparing semen extender: weighing and mixing extender powder with water
- 144 Semen preparation: weigh, test quality and mix into extender
- 145 Tube preparation: fill extended semen into tubes, seal and put in cooler
- 146 Semen transport: transporting semen to barn

150 Artificially inseminating (AI'ing) sows
- 151 Checking semen: turning semen; sorting, counting and marking tubes
- 152 AI preparation: setting up breeding equipment (pipettes, tubes, etc.)
- 153 Moving sandbags: putting on, or removing sandbags
- 154 Cleaning vulva(s): cleaning/wiping vulva(s)
- 155 Massaging sow(s): stimulating sows
- 156 Taping sow(s): putting tape on sow's back
- 157 Inserting/removing catheters: includes attaching/squeezing tubes
- 158 Moving semen tube hanging devices: includes moving semen tubes/bags

160 Pregnancy (Preg) checking
- 161 Preg check preparation: getting ready to preg check

170 Backfat probing (ultrasounding)
- 171 Probing preparations: setting up; finding/preparing/putting on equipment
- 172 Backfat probing procedures: includes putting gel on ultrasounder

180 Boar testing
- 181 On/off test: putting boars on/taking off growth test
- 182 Selecting boars: reading tattoos, tagging, checking underlines and testicles
- 183 Jump testing boar(s): checking boar's penis
- 184 Ejaculating the boar(s): tests willingness to breed

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200 - CLEANING

210 Manure removal and pen clean-out

- **211** Scraping pen floor: pushing, shoveling, scraping solid manure in pens
- **212** Scraping crates/alleys: scraping behind sows in farrowing crates
- **213** Shoveling manure: out of crates; scooping manure into wheel barrow
- **214** Piggy box clean-out: drain piggy box manure
- **215** Washing gutters: washing down dunging area and gutters in pens
- **216** Bobcat scraping: scraping manure with a bobcat
- **217** Spreading manure: dump manure onto pile; dump onto field

220 Bedding down (the pigs)

- **221** With shavings: getting and bedding down pens with shavings
- **222** With feed: throwing feed on floor as bedding and for footing

230 Sweeping / dust removal

- **231** Alleys/pens: sweeping of alleys
- **232** Stalls: banging dust off bars over stalls

240 Pressure washing and disinfecting

- **241** Set up: moving, hooking up pressure washer hose
- **242** Washing: turning on pressure washer and water; washing walls, pens, floors
- **243** Disinfecting: disinfect rooms/alleys

250 Remove dead pits/afterbirth

- **251** Checking for and removing dead pigs
- **252** Recording weights: weighing dead pigs and recording weights
- **253** Moving dead pigs: in barn
- **254** Disposal: moving dead pits out of barn

260 Washing/garbage removal

- **261** Washing boxes: washing holding boxes
- **262** Washing equipment: water filters, light covers, tattooer, instruments
- **263** Garbage removal: collect garbage, put in bags and throw out garbage
- **264** Clean clothing: wash manure off coveralls, wash glasses
- **265** Clean milk feeding equipment: wash troughs, dispose of old milk replacer
- **266** Clean blackboards: wipe off blackboards
- **267** Sterilize catheters: fill sterilizer with water; place catheters inside sterilizer
- **268** Washing sows: washing sows before moving to farrowing barn

270 Pit Work

- **271** Checking pit(s): checking manure levels in pit(s)
- **272** Pulling pit plug(s): looking for and pulling pit plug
- **273** Agitating manure in pit: agitating by moving plug up/down; flushing gutters
- **274** Pumping out manure: turn pump on/off; putting hose down pit; watching
- **275** Sump pump on/off: plugging in sump pump

280 Biosecurity

- **281** Boot dip: check and change boot dip solution
- **282** Footwear: washing shoes between rooms

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283 Equipment: spraying ties of forklift with disinfectant

290 Household chores

291 Laundry: wash and dry barn clothes

292 Bathrooms: cleaning bathrooms

293 Washing dishes

300 - FARROWING

310 Farrowing preparation

311 Room/crate set-up: set up newly cleaned room and crate

312 Heat lamp set-up: plug in/un-plug heat lamps; hanging/taking down lamps

313 Sow/piglet comfort: setting up mats for farrowed sows; adjust stall width

314 Setting up creep area: put shavings in creep area; rip up paper for creep

315 Creep disassembly: taking off/putting on creep lids; removing creep boards

316 Piggy deck: open piggy boxes; moving piggy deck

320 Inducing farrowing

321 Inducing sows: to farrow

322 Giving oxytocin: injection to sows

330 Assisting farrowing

331 Pulling piglets: putting on arm glove; checking for stuck piglets

332 Supervising farrowing: checking on and watching sows farrowing

340 Checking sows

341 For colostrum: checking sows of colostrum; collecting colostrum

342 For sufficient teats: looking at and counting teats

343 For weaning potential: looking for sows that are ready for weaning

344 For induction potential: checking sows that are overdue

350 Piglet treatment/care and weaning preparation

351 Locking piglets in creep area: moving piglets under heat lamp for warmth

352 Rescuing piglets: rescuing a piglet from under sow

353 Assisted suckling and tube-feeding: helping runt suckle; tube-feeding

354 Reviving piglet(s)

355 Splay-legged piglets: taping/removing tape (from) splay legged piglets

356 Warming piglets: getting bucket of warm water; warming chilled piglets

357 Weaning preparation: opening crate divider; moving piglets into one crate

360 Processing piglets / litters

361 Confining piglets: moving piglets into creep area or feed cart

362 Set-up for processing: getting instruments ready

363 Processing: tooth clipping; injecting iron; tail docking; castrating; marking

364 Umbilical cords: clipping umbilical cords

370 Cross-fostering piglets

371 Checking for runt piglets: checking for undersize piglets and/or foster sows

372 Catching piglets: putting piglets into cart

373 To new sows: put piglets in with foster sows

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400 - FEEDING

410 Feeding preparations

- 411 Turn feed system on/off: turn auger/feeder on/off
- 412 Mixing preparation: getting feed ready; opening up bags of feed
- 413 Mixing feeds: adding ingredients to feed mixer
- 414 Feed amount check: check to see how much feed pigs require

420 Feed Delivery

- 421 Filling/Moving feed: setting up auger; fill feed cart/bucket
- 422 Moving bagged feed: getting bagged feed; put on trolley; carrying feed bags
- 423 Feeder set-up: set up feeder and lower water nipple

430 Dry Feeding (excludes piglets)

- 431 Feeding (general): feeding pigs; filling self feeder(s)
- 432 Scoop feeding: scooping feed into feeders/troughs
- 433 Filling drop feeders: filling feed auger
- 434 Drop feeding: pulling drop feeder(s); checking and dropping feed
- 435 Adjusting feeders: closing drop feeders; unlock/lock feeders
- 436 Top dressing: dump top dress into boar troughs

440 Liquid feeding

- 441 Mixing soup: stirring soup with a metal rod
- 442 Watching feed system: watching feed being delivered to pigs
- 443 Checking feed and troughs: checking troughs for fullness/flooding
- 444 Adding water: adding water to liquid feed troughs

450 Watering

- 451 Watering (general): watering piglets/sows; getting sow(s) to drink
- 452 Turn water on/off: turn water taps on/off; adjust water timer
- 453 Check water levels: check water levels in troughs
- 454 Check/adjust water nipple drinker(s): raise/lower and check nipple drinkers

460 Creep feeding (piglets only)

- 461 In Farrowing crates: check creep feeder(s) and fill up accordingly
- 462 Milk replacer: mixing milk replacer; put milk replacer in trough
- 463 Supplements: giving energy booster; mixing electrolytes for poor-doers
- 464 Milk bits: getting, opening and pouring bag of milk bits into feeding troughs

470 Checking feed system

- 471 Checking augers/feeders: checking augers and feeders
- 472 Unplug feeders/feed system: unplug feed system; snake feeders
- 473 Alarms: check on feed mill alarm

480 Clean-up

- 481 Scrape/spread feed: scrape feed into water trough; cleaning out feeders
- 482 Emptying feeders: vacuuming out feeders; tip feeder to empty it
- 483 Removing feeders: taking out dirty feeders from pens

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500 - HEALTH

510 Barn / Health Check

- 511 Checking pigs: tapping sow to get her up; check sow(s), gilts, piglets, pigs
- 512 Health check: taking sow's temperature; check tails; examining pigs closely
- 513 Lights on/off: turn room lights on/off

520 Animal Identification

- 521 Ear tagging: ear tagging boar/sow/gilt; check ear tag number; removing tag
- 522 Ear notching: ear notching; reading notches
- 523 Tattooing: tattooing; checking/reading tattoos; change number in tattooer
- 524 Marking: marking pigs/sows with spray marker

530 Treatments

- 531 Getting ready to treat pigs: move sick pig out of pen; organize medications
- 532 Animal treatments: treating pigs and recording information
- 533 Injection preparation: fill/re-load syringe; putting needles on syringe(s)
- 534 Giving injections: giving injections and recording information
- 535 Topical treatments: spray sores with antiseptic
- 536 Prepare medications: mixing water medications
- 537 Oral treatments: giving medicine orally; putting vitamins into trough

540 Vaccinating

- 541 Vaccination preparation: mixing up vaccine; filling syringes with vaccine
- 542 Vaccinating sows: vaccinating sows
- 543 Vaccinating pigs: vaccinating nursery pigs

550 Surgery

- 551 Surgery preparation: getting instruments ready
- 552 Repair ruptures: repairing cryptorchid piglets
- 553 Repair prolapse: fixing prolapse
- 554 Castrating: castrating older pigs

560 Animal restraint

- 561 Holding: holding pigs
- 562 Snaring: snare pig(s)

570 Animal Euthanasia

- 571 Animal euthanasia: preparing for and conducting animal euthanasia

580 Tender loving care (TLC)

- 581 Petting pigs: scratching/petting piglets, boars and sows
- 582 Playing with pigs: talking to and playing with pigs
- 583 Helping pigs: pour water on sow to cool her down; help stuck pig

600 - MAINTENANCE

610 Construction

- 611 Measuring: measuring plywood; measuring crate/floor
- 612 Moving materials: moving plywood; checking if plywood fits
- 613 Woodworking: cutting plywood; sawing plywood

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614 Assembly: put plywood in place; screw pieces together

620 Building structure maintenance and repair

621 Check/repair barn: check(ing) roof for leaks; fix wall between pens
622 Check breaker box: looking at fuse box
623 Check/repair electrical system: checking electrical system; fixing wire
624 Door lubrication: spray door with WD40
625 Replace insulation: putting styrofoam back into ceiling

630 Building equipment maintenance and repair

631 Check/repair dry feed system: check/fix feed system/trough
632 Check/repair liquid feed system: repair/maintenance of liquid feed system
633 Check/repair water system: fix broken water line and pipes
634 Check/repair lights: change/repair/clean light bulb fixtures
635 Fixing gate: fixing (bent gate); repairing gate by grinding metal

640 Environmental Adjustments(s) and Repair

641 Check temperatures: checking thermostats and checking temperatures
642 Adjust ventilation rates: turn fans on/off; take louvers off fans
643 Adjusting air intakes: adjusting air intakes
644 Adjust micro-environment(s): raising/lowering hoods over pens
645 Check/repair ventilation wires: check ventilation and wires and adjust
646 Check boiler/pump: check boiler and pump; let moisture out of pressure tank
647 Check/adjust sprinkler system: turn sprinklers on/off; check/clean sprinklers
648 Installing/removing fan: installing/removing fan

650 Machinery/Tools Maintenance and Repair

651 Repair processing equipment: fixing tattooer
652 Check/repair pressure washer: check pressure washer leak; fix pump breaker
653 Fix heat lamp: check/ fix heat lamp
654 Check/repair pregnancy checker: fix preg checker; replace battery
655 Fix water medicator: fix water medicator

660 Manure System Repair

661 Check/repair pit plugs: check plugs; fixing pit plug
662 Repair/unplug manure pipe/system: stick pressure washer hose to flush drain
663 Check/repair flush pump: taking pump apart/putting back together
664 Checking manure valves: checking manure valves

670 Welding

671 Moving welder: push cart with welder
672 Set up welder: check welder; set up welding cords
673 Getting bars/gates ready: getting bars ready for welding; remove rust
674 Repairing feed deliver tube: welding feed delivery tube

680 Pest Control

681 Spraying pesticide: spray(ing) pesticide/fly spray
682 Check/replace fly bait: emptying old bait and putting new bait in containers
682 Mosquito repellant: put on bug spray

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684 Mice bait: grab mouse bait; fill container with mouse bait

700 - Moving Pigs

710 Gate Adjustment

711 Opening/closing gates: opening stalls and gates; adjusting gates
712 Setting up gates/doors: setting up gate(s); block(ing) off hall
713 Securing gates: holding gate(s) as sows move out
714 Adjusting stalls: adjusting stalls
715 Set up load out area: getting loadout organized

720 Weaning pigs/piglets

721 Prepare for weaning: setting up boards; set up pen
722 Catching piglets: take piglets out of crate; move piglets into cart
723 Moving piglets: moving piglets; carrying piglets
724 Moving weanling pigs into pen: moving weanling pigs into pen
725 Sorting/sizing piglets: sorting female/male piglets

730 Moving/herding pigs

731 Moving pigs from one place to another: herding pigs
732 Moving sows into/out of farrowing crates: moving sows into/out of crates
733 Moving boars/sows into/out of stalls: letting boar/sow out of/into stall
734 Shipping: shipping pigs/gilts/boars; moving pigs onto truck
735 Calling pigs: calling sow
736 Separating pigs: separating boars
737 Pulling pigs: Move pig out of feeder/out of pen
738 Move sows around: move sows around

740 Selecting/Sorting/Marking pigs

741 Sorting/marking pigs: sorting pigs; marking pigs
742 Selecting gilts: crouching down with flashlight, checking underline

750 Weighing pigs

751 Set up weigh scale: setting up scale; disassembling weigh scale
752 Calibrate scale: worker weighing himself to calibrate scale
753 Herd pigs to/from scale: herding pigs to scale; herding pigs back to pen
754 Moving pigs into/out of scale: raising gate at end of scale; move pigs in/out
755 Weighing and selecting boars: weighing boars
756 Weighing and marking pigs: checking weights and marking pigs
757 Visual weight check: looking at boars to judge weights

800 - Work Preparations

810 Putting on/removing work clothing

811 Coveralls: put coveralls on/take off
812 Footwear: put on/take off boots; tie shoes
813 Special clothing: putting on hat; putting on taking off coat

820 Method of travel (from one zone to another)

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821 Walking: walking from place to place
822 Jump divider: jump divider into next pen

830 Get/return supplies

831 Cleaning supplies: get scraper/squeegie; grab broom; get disinfectant
832 Feeding supplies: get/return scoop; get/return bucket; looking for feed cart
833 Herding supplies: getting plywood boards; put ramp away
834 Maintenance supplies: get/return extension cord; getting ladder; get flashlight
835 Breeding supplies: getting breeding mats; getting AI supplies
836 Health supplies: getting injection equipment; get sore foot medication
837 Animal ID and marking supplies: getting a marker/spray marker
838 Personal protection supplies: get dust masks; getting earplugs; grab gloves
839 General supplies (not otherwise specified): pick up something that dropped

840 Communication

841 Talking: talking to co-worker
842 Meeting(s): meeting with co-worker(s)
843 Phone call(s): making phone calls

850 Record-keeping

851 Recording information with minimal pig contact: write on sheet/chart
852 Recording information with direct pig contact: writing on sow cards
853 Sorting/filing paperwork: check paperwork; sorting paperwork
854 Collecting/identifying/moving sow cards: putting up/taking down sow cards
855 Computer/office work: entering farrowed sows into computer; photocopying
856 Inventory: counting pigs

860 Finding co-worker(s)

861 Looking for co-worker(s): trying to find co-worker; looking for co-worker
862 Getting co-worker(s): going to get co-worker

870 Waiting

871 With non associated activity: waiting for co-worker to move pigs
872 During an activity: waiting for boar to finish breeding

900 - Other/Miscellaneous

910 Breaks

911 Coffee/lunch
912 Bathroom
913 Drink of water: getting tissue and drink of water; making coffee
914 Washing hands: wash hands
915 End of day

920 Rest

921 Rest after strenuous activity: stopping for a rest after strenuous activity
922 Rest between tasks: resting between tasks

930 Smoking

940 Special study requirements

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941 PESB II: PESB II on/off; adjusting backpack straps
942 Worker book: writing in worker time activity diary book
943 Barn management questionnaire: measuring pens/rooms; counting pigs

950 Checking/looking
951 Something (not otherwise specified): giving something to co-worker
952 Job quality: check pressure washing job of co-worker
953 For truck arrival: checking time of truck arrival

960 Driving
961 Vehicle to transport pigs: (going) to get bus; driving bus
962 To different barn: drive to other barn
963 For feed pickup: drive truck to fill with feed
964 Tractor: putting tractor back

970 Handling "other" animals
971 Preparing feed containers for cats: making new fee/water container
972 Feeding/watering cats: getting cat food; fill water container
973 Moving cats: moving cats to next room
974 Play with cats: petting cats
975 Dog: petting the dog

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Area Code

1 **Dry Sow/Breeding**
2 **Farrowing**
3 **Nursery**
4 **Grower**
5 **Finisher**
6 **Main hallway**
7 **Support areas**: boot area; med room; maintenance room; manure transfer room
8 **Office/computer areas**: coffee room/lunch room; laundry room; office; kitchen
9 **Other**: load ramp; in truck/bus; outside

Zone Code

1 **Main hallway**
2 **Alleys**
3 **In pen**
4 **In crate**
5 **In stall**
6 **Support areas**: boot area; med room; maintenance room; manure transfer room
7 **Office/computer areas**: coffee room/lunch room; laundry room; office; kitchen
8 **Outside**
9 **Other**: load ramp; in truck/bus; outside

With Who Code

1 **Working with one co-worker**
2 **Working with two co-workers**
3 **Working with three co-workers**
4 **Working with four or more co-workers (team)**
5 **Working with co-workers but number unspecified**
6 **Working alone**
7 **Working with non-barn workers**: truck driver; construction workers; veterinarian
8 **Co-worker(s) working in same area but not directly with worker**

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