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SUDBURY AREA RISK ASSESSMENT
Volume II

Appendix M:

Indoor Dust Survey – Data Report

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INDOOR DUST SURVEY DATA REPORT

FINAL REPORT

Prepared by:

SARA
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HHRA Document
Indoor Dust Survey Report
August, 2005

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FINAL REPORT

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SUDBURY RISK ASSESSMENT
INDOOR DUST SURVEY DATA REPORT

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EXECUTIVE SUMMARY

One of the most important pathways to consider for the current HHRA is potential exposures to concentrations of the chemicals of concern (COCs) present as part of indoor dust within Sudbury homes. The INCO and Falconbridge smelters release atmospheric emissions containing chemicals and particulate matter, including the COCs. Gradually, wet and dry deposition causes the COCs to settle onto local soils and other surfaces. Both the settled material and the airborne chemicals may be transferred into residential homes *via* human and local meteorological activity.

Outdoor yard soil can be transported indoors on clothing or shoes of humans or by animals, and combines with other sources to form household dust (U.S. EPA Region VIII, 2001). Studies have reported that between 20 and 30% of indoor contamination comes from outdoor soil sources (Rutz *et al.* 1997). Exposure to concentrations of COCs present in indoor environments is an important pathway of exposure for human health, especially for children.

During the problem formulation phase of the HHRA, it was recognized that there was no information on the concentrations of the COCs in indoor dust in Sudbury. Therefore, an indoor dust survey was developed to fill this significant data gap. The primary objectives of this survey were as follows:

1. Measure concentrations of COCs in indoor dust in the Greater Sudbury area (GSA);

2. Measure concentrations of the COCs in co-located outdoor soil samples to identify a relationship (if any) between indoor dust and outdoor soil concentrations;

3. Compare the data collected in Sudbury with other information and relationships reported in the literature;

4. If a relationship exists between COCs concentrations in outdoor soil and indoor dust, use this relationship to predict indoor dust levels in indoor living spaces over the range of COCs levels reported in the 2001 soil survey; and,

5. Generate data that can be utilized to estimate human exposure to COCs in indoor environments in the HHRA.

Homes and schools from five regions throughout the GSA were selected for sampling. The five areas represent the primary Communities of Interest (COIs) identified for the HHRA. A total of 91 homes participated in the survey, including: Copper Cliff (20); Coniston (20); Falconbridge

(21); Sudbury centre (19); and, Hanmer (11). Analyses of 86 indoor dust samples were completed, as five of samples were unable to be analysed. Soil samples were collected from a total of 87 of the residential properties sampled for indoor dust. The field team was unable to collect soil samples from four (4) of the residential properties in the study due to inclement weather conditions (1 property) or a lack of yard or soil in the yard (3 properties). One soil sample was analysed but was unable to be considered in the assessment due to a transcription error. The remaining 86 soil samples were evaluated in the current assessment.

All dust and soil samples were analysed for a total of twenty (20) elements. However, the current study focused on the indoor dust and outdoor soil concentrations of the six COCs being evaluated as part of the HHRA (*i.e.*, arsenic, cobalt, copper, lead, nickel and selenium).

Dust was collected using a high volume surface vacuum sampler (*i.e.*, an HVS3) by vacuuming a composite of at least three 1 metre^2 carpeted quadrants in each home. Sample quadrants were selected from high-traffic areas and areas most frequented by children (*e.g.,* floor areas in front of the main television, in a child's bedroom, in a playroom or family recreation room). Each sample quadrant was measured using meter sticks and marked on the carpet/rug with tape. Concurrent surface soil samples (*i.e.*, a composite grid in the front yard) were also collected at each house to assist in evaluating the potential relationship between indoor dust and outdoor soils.

Tables E.1 and E.2 provide summaries of mean indoor dust and outdoor soil concentrations, respectively, from each community.

Table E.1   Summary of Mean Indoor Dust Concentrations by Community of Interest

Community	INDOOR DUST (µg/g)					
	Arsenic	**Cobalt**	**Copper**	**Lead**	**Nickel**	**Selenium**[1]
Coniston (19)	19.65	32.16	916.21	202.31	768.47	2.57
Copper Cliff (19)	27.32	70.10	1307.90	379.24	1543.68	10.52
Falconbridge (21)	32.06	101.12	624.19	132.38	781.57	2.28
Hanmer (10)	15.56	17.86	374.90	94.20	297.40	1.76
Sudbury (centre) (17)	14.80	29.68	662.29	107.66	428.00	4.08
Total Residential Dataset (86)	22.94	55.23	818.30	193.04	820.86	4.46

[1] using ½ MDL for all non-detect samples (< 0.8 µg/g)
( ) denotes number of samples

Table E.2   Summary of Mean Outdoor Yard Soil Concentrations by Community of Interest

Community	YARD SOIL (µg/g)					
	Arsenic	Cobalt	Copper	Lead	Nickel	Selenium[1]
Coniston (19)	7.26	11.56	166.63	37.82	212.88	0.69
Copper Cliff (18)	15.36	28.99	1047.83	88.09	610.39	5.76
Falconbridge (21)	100.05	61.20	1065.23	93.26	1130.29	3.36
Hanmer (11)	3.06	4.24	31.52	10.61	38.32	0.4[2]
Sudbury (centre) (17)	6.54	8.98	141.54	27.20	121.09	1.05
Total Residential Dataset (86)	30.93	25.89	548.25	56.30	479.62	2.44

[1] using ½ MDL for all non-detect samples (< 0.8 µg/g)
[2] all samples were less than the detection limit
 ( ) denotes number of samples

Results of the residential survey indicated that the concentrations of the COCs in dust and soil differed between the five Communities of Interest, which is consistent with the 2001 Sudbury soils survey. For examples, arsenic levels in soil and dust tended to be higher in the town of Falconbridge relative to the other communities examined. In dust, the levels of Cu, Pb and Ni were higher in Copper Cliff compared with the other communities.

Lead concentration trends in dust do not appear as consistent as those for the other COCs, suggesting that an alternate source of lead may be present in some homes. Based on conservative screening criteria used in the study, several homes in the GSA exceed U.S. regulatory standards and were referred to the Sudbury & District Health Unit (SDHU). Following a review of the study data, the SDHU and Medical Officer of Health concluded that there was a very low potential for health risk, if any, expected from the lead levels detected in homes across the GSA. As such, preliminary analyses of this data indicated no cause for immediate concern for any of the COCs, and the data underwent further analyses as part of the HHRA.

Indoor dust was also collected from eight (8) elementary schools in the Rainbow District School Board, across the GSA: five (5) in the core of the City of Greater Sudbury; one (1) in Hanmer; one (1) in Copper Cliff; and, one (1) in Garson, which is attended by children living in Falconbridge.

Table E.3   Concentrations of Metals in Indoor Dust from Elementary Schools

Parameter	Arsenic (μ/g)	Cobalt (μg/g)	Copper (μg/g)	Lead (μg/g)	Nickel (μg/g)	Selenium (μg/g)
			ALL SCHOOLS (n=8)			
Min	6.6	13.6	119.0	54.0	138.0	1.6
Max	17.4	45.1	600.0	100.0	700.0	8.4
Mean	10.9	28.8	391.1	78.3	464.7	4.8
Standard Deviation	3.9	9.4	171.6	17.6	198.7	2.4

Preliminary analyses of this data indicated no cause for immediate concern.

Concentration ratio (CR) values can be defined as the concentration of a specific metal observed in indoor dust (μg/g) divided by the concentration observed in co-located yard soil. CR values were calculated for each site, the results of which have been summarized in Table E.4.

Table E.4   Summary Statistics of Residential Concentration Ratio Values[a]

Variable	Mean	Std Dev	Std. Error	N	Minimum	Maximum	Median	Skewness
Arsenic	2.89	3.31	0.370	80	0.055	17.33	1.61	2.29
Cobalt	3.27	2.50	0.279	80	0.318	10.61	2.56	1.30
Copper	0.28	0.27	0.030	80	0.021	1.18	0.186	1.43
Lead	5.95	6.40	0.713	80	0.326	42.76	4.68	3.10
Nickel	4.26	5.60	0.626	80	1.50	32.41	2.22	3.18

[a] CR value defined as [indoor dust μg/g] / [yard soil μg/g]

With the exception of copper, all median CR values (n =80) were greater than 1.0. This indicates that indoor dust levels were 2.8 to 5.9 times higher than corresponding soil levels. However, the data also indicates that the CR values do not remain constant over a large range of yard soil concentrations. As the concentration in outdoor yard soil concentrations increases, CR values decrease, suggesting that indoor dust concentrations do not simply increase (in a linear fashion) with increasing soil concentration.

Initial analyses suggest that at lower outdoor soil concentrations, other non-soil related sources become a more dominant source of indoor COCs (*e.g.* lead paint, household sources, *etc.*). This leads to the higher CR values observed in typical urban settings, and is consistent with results observed in other dust studies. As outdoor soil concentrations increase, soil appears to become a more significant contributor to ambient dust concentrations of the COCs and indoor concentrations no longer match or exceed outdoor concentrations. This results in much lower CR

values observed in metal-impacted areas, such as is present in some areas of Sudbury. As such, CR values do not provide an accurate reflection of potential indoor dust concentrations given the full spectrum of COC soil concentrations observed in Sudbury.

To establish a more statistically-sound comparison, linear regression equations were developed for each COC to predict indoor dust concentrations as a function of outdoor soil concentrations. Table E.5 provides the linear regression equations (*i.e.*, *ln*-transformed) which provided the best-fit based upon the paired outdoor soil and indoor dust concentration sets obtained from this study.

Table E.5   Summary of Best Fit Linear Regression Equations for each COCs

Chemical of Concern	Equation ($\ln[\text{indoor dust}] = \text{\ss}_0 \pm SE \times \ln[\text{soil}] + C \pm SE$)	r^2	P model fit	N
Arsenic	$\ln[\text{indoor dust}] = 0.22 \pm 0.06 \times \ln[\text{soil}] + 2.27 \pm 0.15$	0.148	0.0004	79
Cobalt	$\ln[\text{indoor dust}] = 0.57 \pm 0.07 \times \ln[\text{soil}] + 2.09 \pm 0.21$	0.441	<0.0001	81
Copper	$\ln[\text{indoor dust}] = 0.21 \pm 0.05 \times \ln[\text{soil}] + 5.22 \pm 0.26$	0.203	<0.0001	81
Lead	$\ln[\text{indoor dust}] = 0.26 \pm 0.06 \times \ln[\text{soil}] + 3.82 \pm 0.23$	0.182	<0.0001	80
Nickel	$\ln[\text{indoor dust}] = 0.36 \pm 0.06 \times \ln[\text{soil}] + 4.32 \pm 0.33$	0.317	<0.0001	82

It is important to note that the slope of the best fit linear regression line and the mean concentration ratio (CR) value for any COCs are not equivalent. The slope of the regression line was determined by the method of least squares and represents the rate of change (over a specific concentration range) in the indoor dust level as a function of yard soil concentration, while CR values are defined as the concentration of metal in indoor dust (μg/g) divided by the concentration observed in co-located yard soil (μg/g).

In general, outdoor soil could not account for a large percentage of the variance observed in indoor dust concentrations. The regression models presented in Table E.5 were able to explain approximately 15 to 44% of the variation observed in indoor dust concentrations. Levels of cobalt and nickel in yard soils explained approximately 32 and 44% of the variance observed in indoor dust levels, respectively. The variation observed in arsenic, copper and lead dust levels were explained by co-located outdoor soil levels to a lesser extent. That said, all regression equations were statistically significant and considered appropriate for the development of Sudbury-specific dust-to-soil relationships. These relationships were used to generate dust exposure values for the Sudbury HHRA.

Additional analyses were conducted to evaluate whether the age of the residence had any impact on indoor dust levels. While, significant correlations between the two were observed for lead and cobalt, these correlations were very weak with *r* values of 0.26 and 0.27, respectively. The multiple regression analysis for lead and cobalt (*i.e.* the addition of a second explanatory variable, house age) did not explain any additional variance in the dependant variable (*i.e.* the indoor house dust concentration). In both cases, the age coefficient was not significantly different from zero and was removed from the model during the backward elimination process. Based on this preliminary examination, age was not considered a significant explanatory variable.

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1.0   INTRODUCTION

A general introduction to the Sudbury Soils Study and Human and Ecological Risk Assessments is provided in Section 1.1 below. The objective and scope for the Indoor Dust Survey described in this report are provided in Section 1.2.

1.1   Background

In recent years, several studies have shown there are areas in Sudbury with elevated metal levels in the soil. These areas are generally close to the historic smelting sites of Coniston, Falconbridge and Copper Cliff. Although these metals do occur naturally in all soils, studies indicate that higher concentrations in surface soil (top 5 cm) are the result of local mining, smelting and refining operations.

In 2001, the Ontario Ministry of the Environment (MOE) reported that the concentrations of nickel, cobalt, copper and arsenic exceeded the generic MOE soil quality criteria. Under Ontario legislation, this triggers the need for more detailed study. Therefore, the MOE made two recommendations: 1) that a more detailed soil study be undertaken to fill data gaps; and, 2) that a human health (HHRA) and ecological risk assessment (ERA) be undertaken.

The mining companies (INCO Ltd. and Falconbridge Ltd.) voluntarily accepted these recommendations and partnered with four other major stakeholders in Sudbury to establish what is commonly referred to as "The Sudbury Soils Study". These include the Ontario Ministry of the Environment, the City of Greater Sudbury, the SDHU, and the First Nations and Inuit Health Branch of Health Canada.

A comprehensive soil sampling and analysis program was undertaken in 2001 by the MOE and the mining companies. Approximately 9 000 soil samples were collected from urban and remote areas and analyzed for 20 elements. These data form the basis for the study. Early in 2003, a consortium of consulting firms working together as the SARA (Sudbury Area Risk Assessment) Group was retained to undertake the risk assessment portion of the study.

Based on a review of the results of the 2001 soil survey, six COCs were identified for the detailed risk assessment. These were arsenic (As), cobalt (Co), copper (Cu), nickel (Ni), lead (Pb) and selenium (Se).

The INCO and Falconbridge smelters release atmospheric emissions containing chemicals and particulate matter, including the COCs. Gradually, wet and dry deposition causes the COCs to settle onto local soils and other surfaces. Both the settled material and the airborne chemicals may be transferred into residential homes *via* human and local meteorological activity.

Outdoor yard soil can be transported indoors on clothing or shoes of humans or by animals, and combines with other sources to form household dust (U.S. EPA Region VIII, 2001). Studies have reported that between 20 and 30% of indoor contamination comes from outdoor soil sources (Rutz *et al.* 1997). Exposure to concentrations of COCs present in indoor environments is an important pathway of exposure for human health, especially for children.

During development of the Human Health Risk Assessment (HHRA) for the Sudbury Soils Study, it was recognized that there was no information on the concentrations of the COCs in indoor dust in Sudbury. Therefore, an indoor dust survey was developed to fill this significant data gap.

1.2 Objectives of the Study

The primary objectives of this survey were as follows:

1. Measure concentrations of COCs in indoor dust in the GSA;

2. Measure concentrations of the COCs in co-located outdoor soil samples to identify a relationship (if any) between indoor dust and outdoor soil concentrations;

3. Compare the data collected in Sudbury with other information and relationships reported in the literature;

4. If a relationship exists between COC concentrations in outdoor soil and indoor dust, use this relationship to predict indoor dust levels in indoor living spaces over the range of COC levels reported in the 2001 soil survey; and,

5. Generate data that can be utilized to estimate human exposure to COCs in indoor environments in the HHRA.

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2.0   METHODOLOGY

The focus of this dust collection study was to determine COC concentrations in indoor dust and co-located outdoor soil samples at residential properties throughout the GSA. Settled dust typically collects on hard surfaces, windowsills, carpets, *etc*. and is often sampled using a swipe method. However, swipe sampling is better suited for the measurement of COC loading (amount in a defined area), rather than COC concentrations in dust (Lanphear *et al.* 1998). For the purposes of this risk assessment, COC concentrations in household dust are required for estimating exposure scenarios, and developing indoor dust and outdoor soil concentration ratios and relationships.

2.1   Review of Methodologies

A number of possible approaches have been utilized for estimating the concentrations of COCs in indoor dust for the purpose of human health risk assessments. Studies conducted at metal-impacted sites throughout North America provide a good basis for a numerical relationship between COC concentrations in indoor dust and those measured in nearby outdoor soil. The following section provides a brief discussion of previous studies that have examined the relationship between COC concentrations in indoor dust and outdoor soil in an attempt to define a general correlation.

A number of studies were reviewed to examine potential methods for the collection of indoor dust. Lioy *et al*. (1992) found that while loadings were greater with wipe sampling than with vacuum sampling, metal concentrations within the dust samples were similar for both collection methods. Most indoor dust sampling methods (*i.e.* wipe and vacuum methods) are designed to measure loadings as the amount of toxicant per unit area (*i.e.* $\mu g/m^2$); however, in the context of exposure and risk assessment, toxicant concentrations expressed on a mass basis (*i.e.* $\mu g/g$ dust) are preferred. This type of data can be collected through the use of vacuum sampling, where vacuum contents are analyzed to determine the concentration of specific toxicants. Vacuum cleaner sampling has its own series of problems, most notably the variability in design and efficiency. That said, residential vacuum cleaner bag samples are commonly used to collect dust samples (Lioy *et al.* 2002) and have been used to collect dust during residential sampling in a number of recent studies (Colt *et al.* 1998; Hysong *et al.* 2003; Hinwood *et al.* 2004). However, this method (referred to as household vacuum cleaners-bag/dust collection method) lacks the precision of systematic designed vacuum sampling methods, and likely will not retain particles below 10 μm (Morawska and Salthammer, 2004).

Zhipeng *et al.* (2003) evaluated several different methods for the collection of indoor dust samples for a study conducted in New Jersey. Zhipeng *et al.* (2003) looked at five methods of sampling lead-contaminated dust on carpets including wipe, adhesive label, C18 sheet, vacuum, and hand rinse. The wipe and vacuum methods showed the best reproducibility and correlation with other methods. The authors concluded that surface wipe sampling was the best method to measure accessible lead from carpets for exposure assessment, while vacuum sampling was most effective for providing information on total lead accumulation (long-term concentrations).

Following a review of the literature and previous dust studies it was determined that a soft-surface vacuum collection method would be most effective to collect COC concentrations in household dust. The HVS3 (high-volume small surface sampler) provides the ability to collect dust samples of smaller particles and was selected as the most effective method for determining gross contaminant levels in indoor dust.

The methods used to collect indoor dust samples (and corresponding outdoor soil samples) are described in the Standard Operating Procedure (SOP) (Appendix A).

2.2   Selection of Sampling Locations

Homes and schools from five regions throughout the GSA were selected for sampling. The five areas sampled represent the primary Communities of Interest (COIs) identified for the HHRA. A total of 91 homes participated in the survey, including:

- Copper Cliff - 20

- Coniston - 20

- Falconbridge - 21

- Sudbury (centre) - 19

- Hanmer – 11

Residential study participants were selected from a database of GSA residents who had already had soil samples collected from their yard as part of the 2001 soil survey conducted by the Ontario Ministry of the Environment (MOE). Subsequent to this, random selections of GSA residents were contacted by a research company hired to recruit participants for the survey.

Dust samples were also collected from eight (8) schools in the Rainbow District School Board throughout the GSA.

2.3 Sample Collection

2.3.1 Indoor Dust

Dust was collected using a high volume surface vacuum sampler (HVS3) following the standard operating procedure (Appendix A). The indoor dust sample collection SOP was based on the ASTM Standard Practice for Collection of Floor Dust for Chemical Analysis (Designation: D 5438-00) (ASTM, 2004).

The process involved vacuum sampling a composite of at least three 1m^2 carpeted quadrants in each home. Sample quadrants were selected from high-traffic areas and areas most frequented by children (*e.g.* floor areas in front of the main television, in a child's bedroom, in a playroom or family recreation room). Each sample quadrant was measured using meter sticks and marked on the carpet/rug with tape.

Dust was collected directly into wide-mouth 250 ml HDPE (high-density polyethylene) sample bottles for analysis. Dust sample bottles were labelled with the date of sample collection, house identification number, and tare weight (g) of the sample bottle (with the lid on).

Following each dust sample collection, the HVS3 sampler was disassembled and cleaned as per the SOP. Each section and gasket of the sampler was removed, wiped with alcohol wipes, rinsed with methanol, and left to air dry before re-assembling for the next sample collection (see Appendix A for SOP).

2.3.2 Outdoor Soil

Concurrent surface soil samples (taken from the front yard) were also collected at each house to assist in evaluating the potential relationship between indoor dust and outdoor soils. Duplicate soil cores were collected in an "X" pattern from the front yard. Each soil core was separated into three depths: humic material, 0-5cm, and 5-10cm, and combined into three separate containers (Ziploc plastic bags) as per the SOP (Appendix A). Each composite soil sample bag was labelled with date of sample collection, house identification number and soil sample depth. Following each soil sample collection,

soil corers were decontaminated as per the procedure detailed in the SOP (Appendix A). Soil samples were collected in the same manner as samples in the 2001 soil survey.

2.3.3 Additional Information

In addition to the collection of dust, a short questionnaire was administered in order to examine confounding variables as part the analysis of results. The questionnaire was used to collect information on the following variables:

- Age of the dwelling
- Primary source of heating (*i.e.* gas, oil, electric)
- Renovation/redecoration history
- Number of occupants; adults, children, and pets
- Lifestyle factors including occupation and smoking habits
- Fireplace and/or woodstove use
- Vacuuming behaviour (*e.g.* how often? last time?)
- Type of vacuum cleaner (*e.g.* upright, central vacuum)

2.4 Laboratory Analysis of Samples

Dust sample analysis was completed by Testmark Laboratories in Sudbury, Ontario. Soil samples were analysed by Agat Laboratories in Mississauga, Ontario. Both media were analysed for 20 elements, including: aluminum, antimony, arsenic, barium, beryllium, calcium, cadmium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, selenium, strontium, vanadium, and zinc.

2.4.1 Indoor Dust

Sample Preparation

Samples were sieved using a 75 μm (sieve No. 200) stainless steel mesh. 0.1 to 0.5 g of sieved sample was used for digestion. If the sample that passed through sieve No. 200 was less than 0.1g, a 355 μm (No. 45) was used to collect additional samples for digestion.

Microwave Digestion Method

Accurately weighed samples (between 0.1-0.5 g) were mixed with 5 mL HNO_3 (concentrated trace metal grade) in a lined digestion vessel (CEM Corporation). Sample digestion was performed in a microwave oven (MDS-2000 system, CEM Corporation) with pressure control.

A laboratory blank, standard reference material and replicate sample were digested for every 9 samples or a batch. After digestion, the sample was transferred to a volumetric flask and the vessel was rinsed with 2% HNO_3. The rinses and the sample were combined and diluted to 50.0 mL with 2% HNO_3.

Sample Analysis

The diluted sample was tested directly by Inductively Coupled Plasma - Mass Spectrometry (ICP/MS) (Perkin Elmer Corporation) (further dilution may have been required for some samples depending on the concentration of the elements in the sample). For every 10 samples or less a blank and a control standard were used to verify the calibration standard and the level of instrument performance for blank detection. Every 20 samples or less had a replicated sample to verify precision.

An internal standard was added to the sample to validate instrument performance and to validate the analysis of the individual sample.

A diluted multiple element standard solution (SCP Science) was used to calibrate the ICP/MS. An additional independent diluted multiple element standard solution was used as control standard.

Data was collected by computer then calculated using an external processing program.

The MDL for each element is shown on the laboratory reports. However, the MDLs for certain samples are dependent on the weight and dilution of the sample. The MDL and quality control data for the samples are provided in the laboratory reports (Appendix C).

2.4.2 Data Processing and QA/QC

The external data processing program involved the following:

- If the concentration level of any element in a sample was over the linear range of the element, an additional dilution for the sample was performed.

- The correlation coefficient for the calibration was required to be 0.99 or greater with a forced through zero blank fit.

- Internal Standard: The internal standards were required to have values between 70 and 130% of the expected concentration. Failure to meet this standard involved re-processing samples until the quality criteria were met.

- Method Blank: Method blanks were determined every 10 samples or less. The method blank upper control limit was required to be less than 3 times the reporting limit of the method.

- Control Standard: Control standards were analysed every 10 samples or less. The measured value was required to be within 20% of the expected value.

- Replicates: One replicate sample was analysed every 9 samples or less. Replicate samples were required to be less than 20% relative difference for analyses having a concentration of 10 times the method detection limit.

- Standard Reference Materials: Internal and external standard reference materials (SRM) were analysed in order to assess the variability associated with the performance of the analytical methods and the amount of material recovered during the sample extraction. Two SRMs (external) were purchased from the National Institute of Standard and Technology (NIST) by the SARA Group and were submitted (in triplicate) for analysis. The third (internal) SRM was provided by Testmark Laboratories.

  o SRM 2583 contains trace elements in indoor dust. This SRM is composed of dust collected from vacuum cleaner bags used in the routine cleaning of interior dwelling spaces. The SRM is certified for two of the COCs (As and Pb) identified during the Sudbury Soils Study;

  o SRM 2709 (San Joaquin Soil) is a soil sample which contains baseline trace element concentrations. This SRM is certified for all elements identified as COCs;

  o SRM 2711 (Montana II Soil) is a soil sample which contains moderately elevated trace element concentrations. This SRM is certified for five of the COCs (As, Cu, Ni, Pb, and Se) identified for the HHRA.

Results of the SRM analyses and an evaluation of the quality assurance and quality control procedures for the analysis of dust samples at Testmark Laboratories are included in Appendix B of this report.

2.4.3   Outdoor Soil

Soil sample analysis was conducted by Agat Laboratories following U.S. EPA Methods 3050B (Acid Digestion of Sediments, Sludges, and Soils) and 6020 (Inductively Coupled Plasma – Mass Spectrometry) (U.S. EPA, 2005).

3.0   RESULTS

A total of 91 residential homes and 8 schools were sampled as part of the study. Dust and soil samples were analysed for 20 elements, however, the current study focused on the indoor dust and outdoor soil concentrations of the 6 COCs being evaluated as part of the HHRA: arsenic, cobalt, copper, lead, nickel and selenium.

The following section discusses the results of the laboratory analyses for the indoor dust and outdoor soil sampling. See Appendix C for the complete set of dust and soil data.

3.1   Detection Limits of Analysis

Laboratory analysis of media samples requires the use of appropriate detection limits. The detection limits achieved during the analysis of indoor dust samples varied depending on the level of dilution required for each sample. Results of the analysis (see Certificates of Analysis in Appendix C) indicated COCs were detected at concentrations greater than the MDL in each dust sample (*i.e*., none of the dust samples contained COC concentrations at or below the detection limits of the analysis). Results of the soil analysis found COC concentrations were greater than the MDLs for all COCs except selenium which was detected below a MDL of 0.8 µg/g in 33 of 87 samples analysed. The detection limit of 0.8 µg/g was considered appropriate for selenium in soil.

3.2   Results for the Standard Reference Materials (SRM)

As mentioned in Section 2.4.2, the SARA Group submitted two SRM materials, SRM 2583 dust and SRM 2709 San Joaquin soil, for analysis to Testmark Laboratories. SRM 2583 for indoor dust reported certified values for arsenic and lead only, with mean percent recoveries of 89% and 83.1%, respectively. Both recovery values are within acceptable limits.

SRM 2709 San Joaquin Soil included certified values for each of the six COCs in the HHRA. The mean percent recoveries for arsenic, cobalt, copper, lead, nickel, and selenium were 84.37, 102.24%, 86.71, 85.23, 68.78, and 106.16%, respectively. All percent recovery values are within acceptable limits.

Further discussion of the SRM analysis and QA/QC procedures conducted for the current assessment can be found in Appendix B of this report.

3.3 Indoor Dust and Outdoor Soil Results by Community

A total of 91 indoor dust samples were collected from residential homes throughout the GSA; analyses of 86 indoor dust samples were completed. Five dust samples were unable to be analysed; 3 samples were lost due to laboratory error and 2 samples, following standard collection protocol, had insufficient amounts of dust to be analysed.

Soil samples were collected from a total of 87 of the residential properties sampled for indoor dust. The field team was unable to collect soil samples from 4 of the 91 residential properties in the study due to inclement weather conditions (1 property) and a lack of yard or soil in the yard (3 properties). One soil sample was analysed but was unable to be considered in the assessment due to a transcription error. The remaining 86 soil samples were evaluated in the current assessment.

Tables 3.1 and 3.2 provide summaries of the mean indoor dust and outdoor soil concentrations, respectively, by community for all soil (n=86) and dust (n=86) samples analysed.

Table 3.1   Summary of Mean Indoor Dust Concentrations by Community of Interest

Community	INDOOR DUST (µg/g)					
	Arsenic	**Cobalt**	**Copper**	**Lead**	**Nickel**	**Selenium[1]**
Coniston (19)	19.65	32.16	916.21	202.31	768.47	2.57
Copper Cliff (19)	27.32	70.10	1307.90	379.24	1543.68	10.52
Falconbridge (21)	32.06	101.12	624.19	132.38	781.57	2.28
Hanmer (10)	15.56	17.86	374.90	94.20	297.40	1.76
Sudbury (centre) (17)	14.80	29.68	662.29	107.66	428.00	4.08
Total Residential Dataset (86)	22.94	55.23	818.30	193.04	820.86	4.46

[1] using ½ MDL for all non-detect samples (< 0.8 µg/g)
( ) denotes number of samples

Table 3.2   Summary of Mean Outdoor Yard Soil Concentrations by Community of Interest

Community	YARD SOIL (µg/g)					
	Arsenic	Cobalt	Copper	Lead	Nickel	Selenium[1]
Coniston (19)	7.26	11.56	166.63	37.82	212.88	0.69
Copper Cliff (18)	15.36	28.99	1047.83	88.09	610.39	5.76
Falconbridge (21)	100.05	61.20	1065.23	93.26	1130.29	3.36
Hanmer (11)	3.06	4.24	31.52	10.61	38.32	0.4[2]
Sudbury (centre) (17)	6.54	8.98	141.54	27.20	121.09	1.05
Total Residential Dataset (86)	30.93	25.89	548.25	56.30	479.62	2.44

[1] using ½ MDL for all non-detect samples (< 0.8 µg/g)
[2] all samples were less than the detection limit
 ( ) denotes number of samples

Arsenic levels in soil and dust tended to be higher in the town of Falconbridge relative to the other communities examined. In dust, the levels of Cu, Pb and Ni were higher in Copper Cliff compared with the other communities.

With the exception of arsenic, the mean COC concentration was higher in indoor dust compared to outdoor soil.

It is noted that selenium was found at low levels in both yard soil and indoor dust. Of the 86 yard soil samples taken, 33 were below the reported method of detection limit of 0.8 µg/g soil for selenium. Due to the large number soil samples which were reported to be less than the method of detection, selenium was not evaluated in the regression analyses (Section 3.7).

3.4   Indoor Dust Levels in Schools

Indoor dust was also collected from 8 elementary schools in the Rainbow District School Board, across the GSA; 5 in the core of the City of Greater Sudbury, 1 in Hanmer, 1 in Copper Cliff, and 1 in Garson, which is attended by children living in Falconbridge. Table 3.3 provides a summary of COC concentrations in indoor dust from 8 elementary schools across the GSA.

Table 3.3   Concentrations of Metals in Indoor Dust from Elementary Schools

Parameter	Arsenic (µg/g)	Cobalt (µg/g)	Copper (µg/g)	Lead (µg/g)	Nickel (µg/g)	Selenium (µg/g)
ALL SCHOOLS (n=8)						
Min	6.6	13.6	119.0	54.0	138.0	1.6
Max	17.4	45.1	600.0	100.0	700.0	8.4
Mean	10.9	28.8	391.1	78.3	464.7	4.8
Standard Deviation	3.9	9.4	171.6	17.6	198.7	2.4

3.5   Preliminary Screening Criteria and Lead in Dust

With the exception of lead, no screening criteria exist for COCs in dust. As a preliminary step, MOE soil screening criteria (*i.e.*, direct contact) were used as screening criteria for indoor dust, since similar pathways of exposure would be expected (*e.g.*, direct dermal contact and incidental ingestion) (MOE, 1997). Not surprisingly, exceedances of the screening criteria were consistent with the exceedances previously observed in soil.

In general, dust levels of arsenic cobalt, copper, nickel and selenium were higher than the mean community soil concentration, but were within the same order of magnitude as soil levels. These dust results were treated in a similar manner as the original soil results were handled (*i.e.* there were exceedance of the screening criteria; however there was no expected imminent health risk or need for immediate action, and this data was considered further in the human health risk assessment).

Lead concentration trends in dust do not seem as consistent as those for the other COCs, suggesting that an alternate source of lead may be present in some of the homes. Given the age of the dwellings, the presence of lead-based paints is quite likely. Concentrations of lead in dust from several homes significantly exceeded the soil screening criteria.

Some regulatory agencies in the United States have established screening criteria for lead levels in dust. Dust-lead clearance standards of 200 micrograms of lead per square foot ($\mu g/ft^2$) for bare floors, 500 $\mu g/ft^2$ for window sills, and 800 $\mu g/ft^2$ for window troughs were adopted by the U.S. Department of Housing and Urban Development (HUD) in 1990. HUD later lowered the standard for floors to 100 $\mu g/ft^2$ (HUD, 1995). In January 2001, the U.S. Environmental Protection Agency lowered the clearance standards for floors (including carpet), interior window sills, and troughs to 40, 250, and 400 $\mu g/ft^2$, respectively (U.S. EPA, 2001). These criteria are based on swipe sampling, expressed on

a surface area loading basis. While not directly comparable, the vacuum collected dust results were converted to a surface area loading and compared to these standards.

Based on comparison to these criteria, several homes in the GSA exceed the US regulatory standards. Most notable where the dust lead results in homes that exceed both the screening standard for surface area loading (40 μg/ft^2) as well as those where the concentration exceeds the soil based concentration screening criteria (200 μg/g). Several homes sampled in this survey fell into this grouping.

Since exposure to lead may cause health effects under certain conditions, SDHU and the Medical Officer of Health were asked to review the results of this study. The SDHU concluded that there was a very low potential for health risk, if any, expected from the lead levels detected in homes across the GSA. Elevated levels of lead have been observed in many cities and communities throughout Canada and are not specific to Sudbury. However, since exposure to lead is a general public health concern, the SDHU recommended simple measures to reduce exposure to indoor dust containing lead (www.sdhu.com). Concerned citizens were also encouraged to contact the SDHU and blood tests were recommended for pregnant women and children six years of age and under who live in houses with elevated lead levels.

3.6   Co-Located Indoor Dust and Outdoor Soil Results

In order to examine the relationship between COC concentrations in indoor dust and outdoor soil, residential properties where both dust and soil samples were collected and analysed were considered for further analyses. Analytical results are available for a total of 82 co-located indoor dust and outdoor soil samples from residential properties across the GSA including:

- Copper Cliff - 17
- Coniston - 18
- Falconbridge - 21
- Sudbury (centre) - 16
- Hanmer - 10

Summary statistics for the residential data, including number of samples, mean, minimum, maximum, and median concentrations, and skewness are presented in Table 3.4. More details on the statistical analyses and identification of outliers and/or influential points are provided in Appendix D.

Table 3.4   Summary Statistics of Residential Indoor Dust and Outdoor Soil Data

Variable	Mean	Std Dev	Std. Error	N	Minimum	Maximum	Median	Skewness
YARD SOIL								
Arsenic	30.91	57.01	6.30	82	1.50	262.00	7.35	2.78
Cobalt	26.30	32.62	3.60	82	2.70	159.00	12.20	2.38
Copper	542.17	666.43	73.59	82	15.40	2830.00	246.50	1.59
Lead	55.59	58.91	6.50	82	3.30	291.00	29.80	1.71
Nickel	480.34	600.81	66.34	82	21.80	3390.00	251.00	2.23
INDOOR DUST								
Arsenic	23.06	21.55	2.38	82	3.70	120.00	15.10	2.42
Cobalt	55.59	48.41	5.35	82	6.28	246.00	41.30	1.68
Copper	811.76	819.62	90.51	82	109.00	5700.00	585.00	3.56
Lead	193.87	372.03	41.10	82	25.00	3150.00	106.50	6.70
Nickel	810.17	993.20	109.68	82	104.00	7700.00	529.00	4.55

Linear regression analysis was not conducted for selenium due to the large number of non-detectable selenium concentration observed in yard soils. Of the 82 yards sampled, 33 reported concentrations of selenium in yard soil as being less than the method detection limit of 0.8 μg/g. As a result, concentration ratio (CR) values (defined as the concentration of selenium observed in indoor dust divided by the concentration of selenium in co-located yard soil) were generated for each of 82 co-located soil/dust samples. For those locations reporting less than 0.8 μg/g selenium in yard soil, the MDL of 0.8 μg/g was conservatively assumed. The arithmetic mean (n=82) and 95th percentile CR values were 0.76 and 2.05 for selenium, respectively. The 95th percentile CR value was used by the HHRA to predict selenium indoor dust concentrations.

3.7   Relationship between Indoor Dust and Outdoor Soil Metal Levels

Linear regression analysis was conducted to determine the relationship (if any) between metal levels measured in outdoor yard soil and those measured in indoor dust. The linear regression analysis was conducted using the statistical software package SAS® (for Windows, Version 8.2). Prior to conducting the regression analysis, the raw data were organized in a pair-wise fashion (*i.e.* indoor dust concentration, co-located soil concentration, community location, and age of home).

With the exception of those observations considered outliers and/or influential points (see Appendix D) simple linear regressions were constructed using the data summarized in Table 3.4. Table 3.5 provides general equations, regression coefficients, standard errors, Pearson's r^2 values, significance levels, number of observations and 95% confidence intervals of the slope and intercept.

Table 3.5   Summary of Simple Linear Regression Equations for Each COC

	Equation[1]	R^2	P model fit	N	Slope (95% C.L.)	Intercept (95% C.L.)
Arsenic	ln[indoor dust] = 0.22±0.06 × ln[soil] + 2.27±0.15	0.148	0.0004	79	0.096 – 0.325	2.01 - 2.64
Cobalt	ln[indoor dust] = 0.57±0.07 × ln[soil] + 2.09±0.21	0.441	<0.0001	81	0.426 – 0.708	1.68 – 2.50
Copper	ln[indoor dust] = 0.21±0.05 × ln[soil] + 5.22±0.26	0.203	<0.0001	81	0.118 – 0.307	4.70 – 5.75
Lead	ln[indoor dust] = 0.26±0.06 × ln[soil] + 3.82±0.23	0.182	<0.0001	80	0.138 – 0.392	3.36 – 4.28
Nickel	ln[indoor dust] = 0.36±0.06 × ln[soil] + 4.32±0.33	0.317	<0.0001	82	0.239 – 0.473	3.66 – 4.97

[1] ln[indoor dust] = β_0±SE × ln[soil] + C±SE
SE – standard error

All slope values presented in Table 3.5 were significantly different from zero (p<0.01). In general, outdoor soil could not account for a large percentage of the variance observed in indoor dust concentrations. The regression models presented in Table 3.5 were able to explain approximately 15 to 44% of the variation observed in indoor dust concentrations. Levels of cobalt and nickel in yard soils explained approximately 32 and 44% of the variance observed in indoor dust levels, respectively. The variation observed in arsenic, copper and lead dust levels were explained by co-located outdoor soil levels to a lesser extent. Figures 3-1 through 3-5 provide prediction plots for each COC. Each figure provides a scatter plot of the observed dust concentrations *versus* co-located soil concentrations, the best fit line (determined by method of least-squares) and the 95% upper and lower confidence levels.
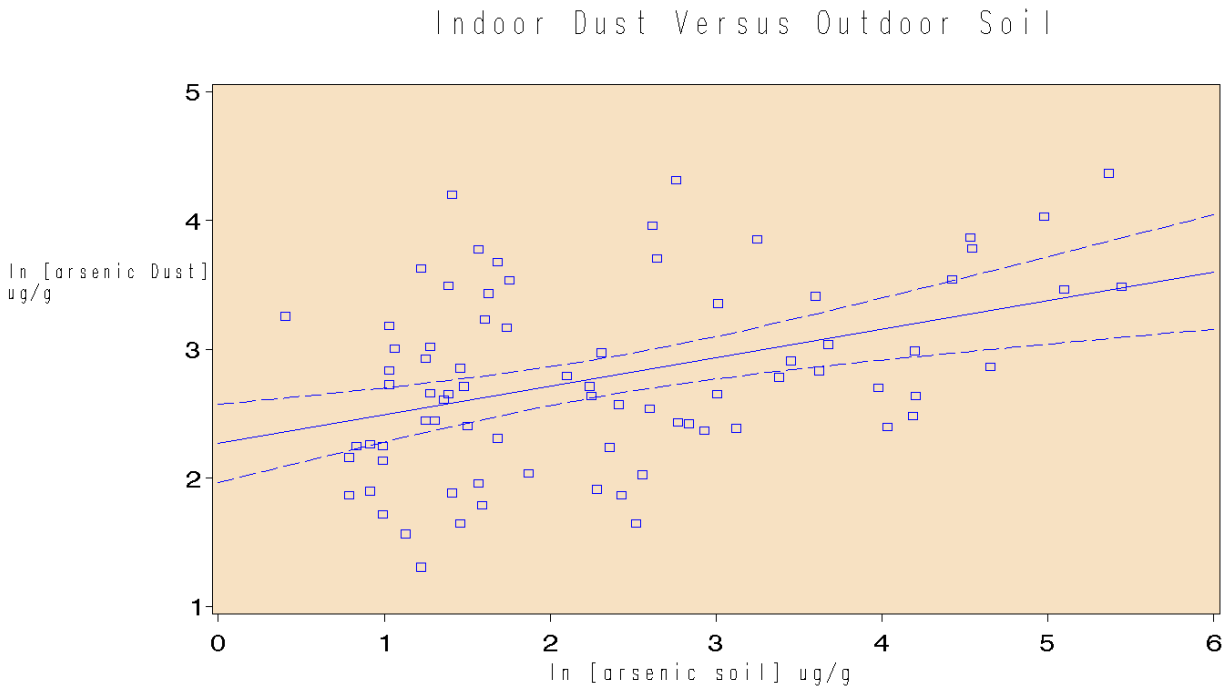
Indoor Dust Versus Outdoor Soil

Figure 3-1   Prediction Plot – ln [arsenic dust] *vs*. ln [arsenic soil]

Indoor Dust Versus Outdoor Soil
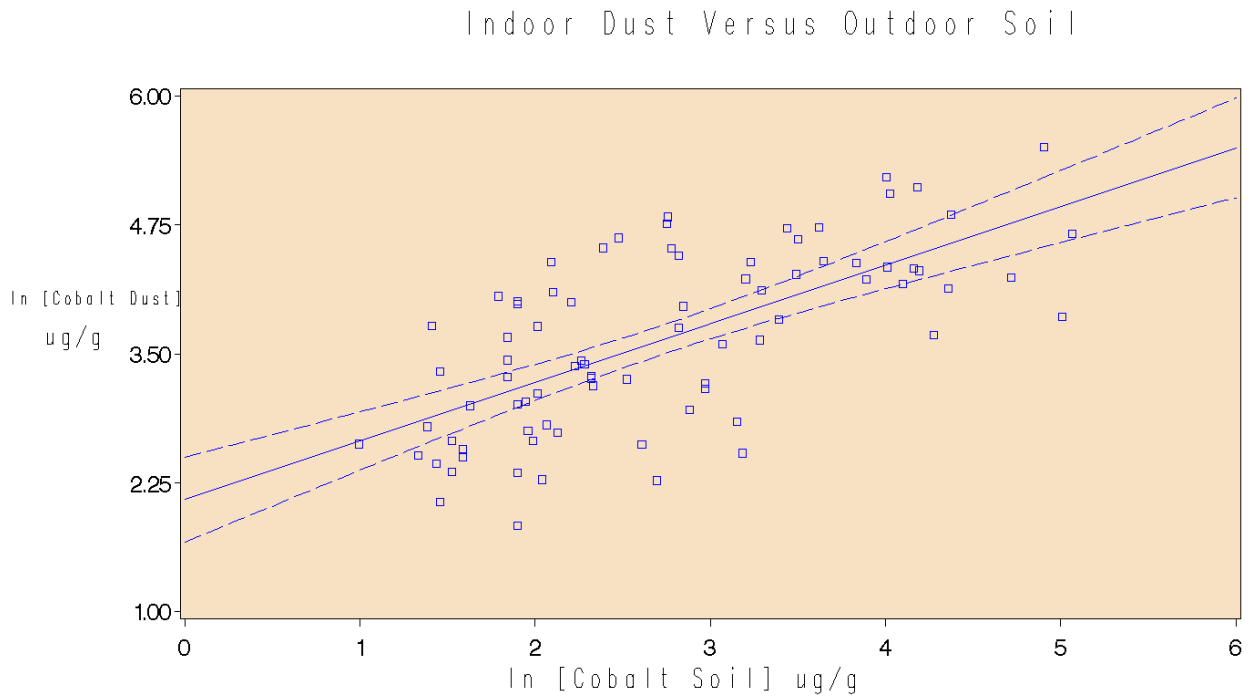
Figure 3-2   Prediction Plot – ln [cobalt dust] *vs*. ln [cobalt soil]

Indoor Dust Versus Outdoor Soil
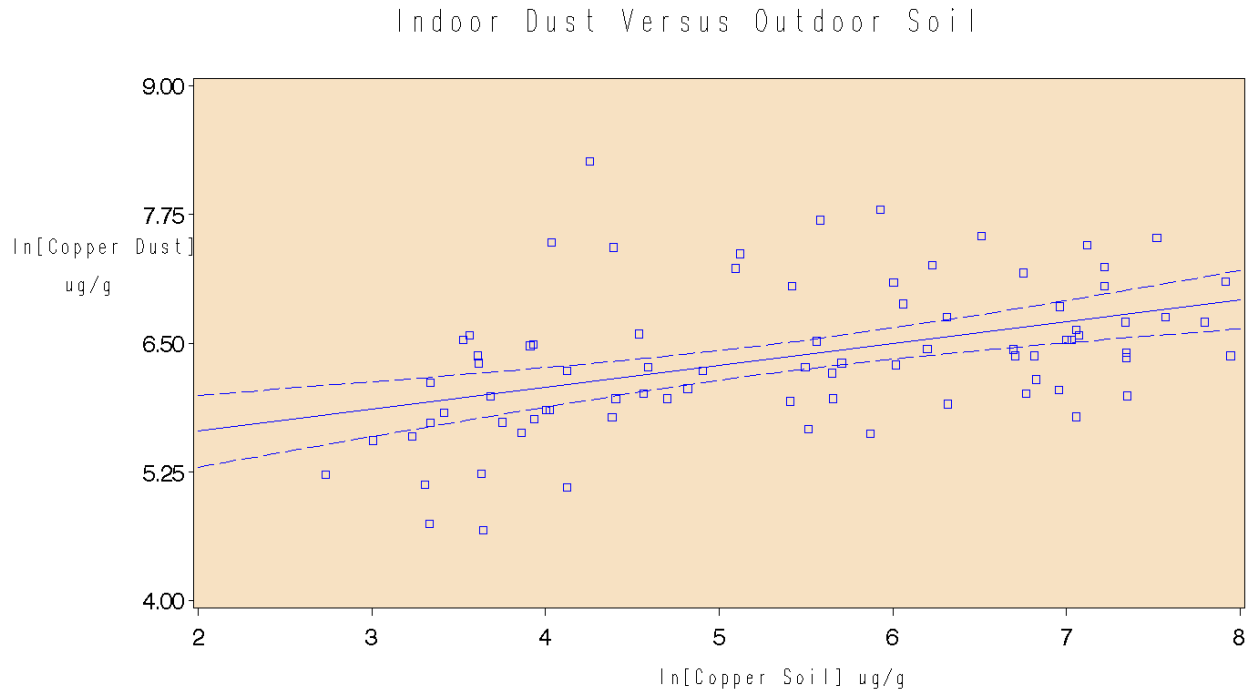
Figure 3-3   Prediction Plot – ln [copper dust] *vs*. ln [copper soil]

Indoor Dust Versus Outdoor Soil
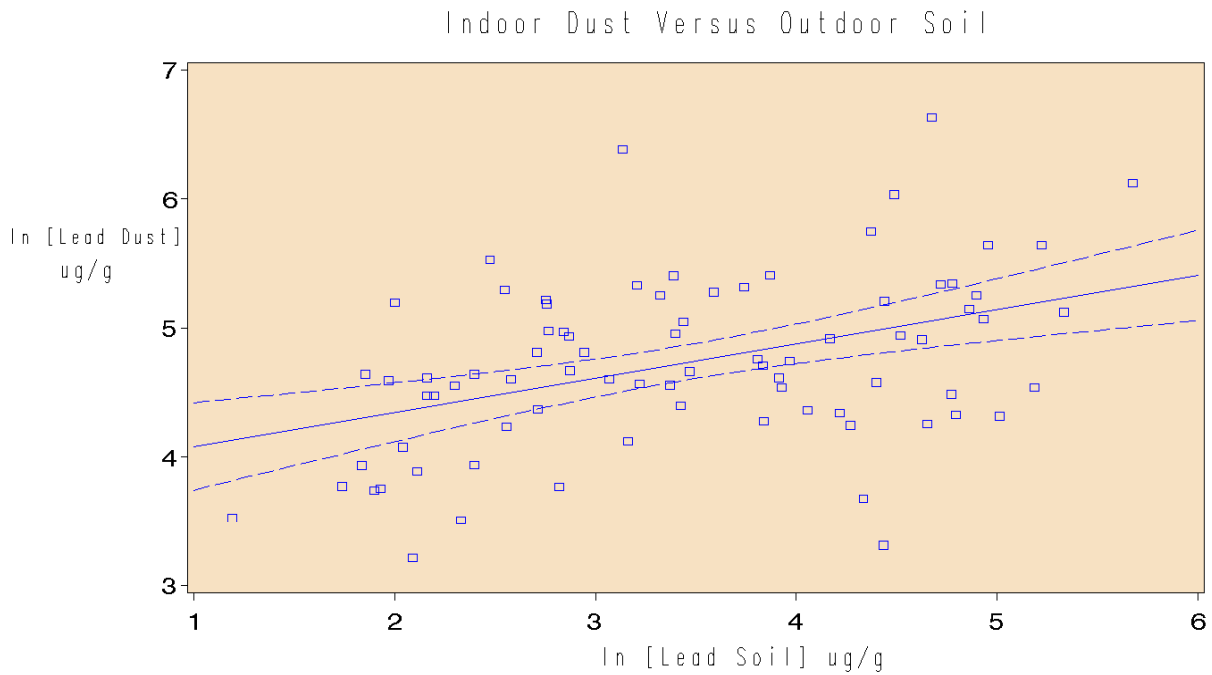
Figure 3-4   Prediction Plot – ln [lead dust] *vs*. ln [lead soil]
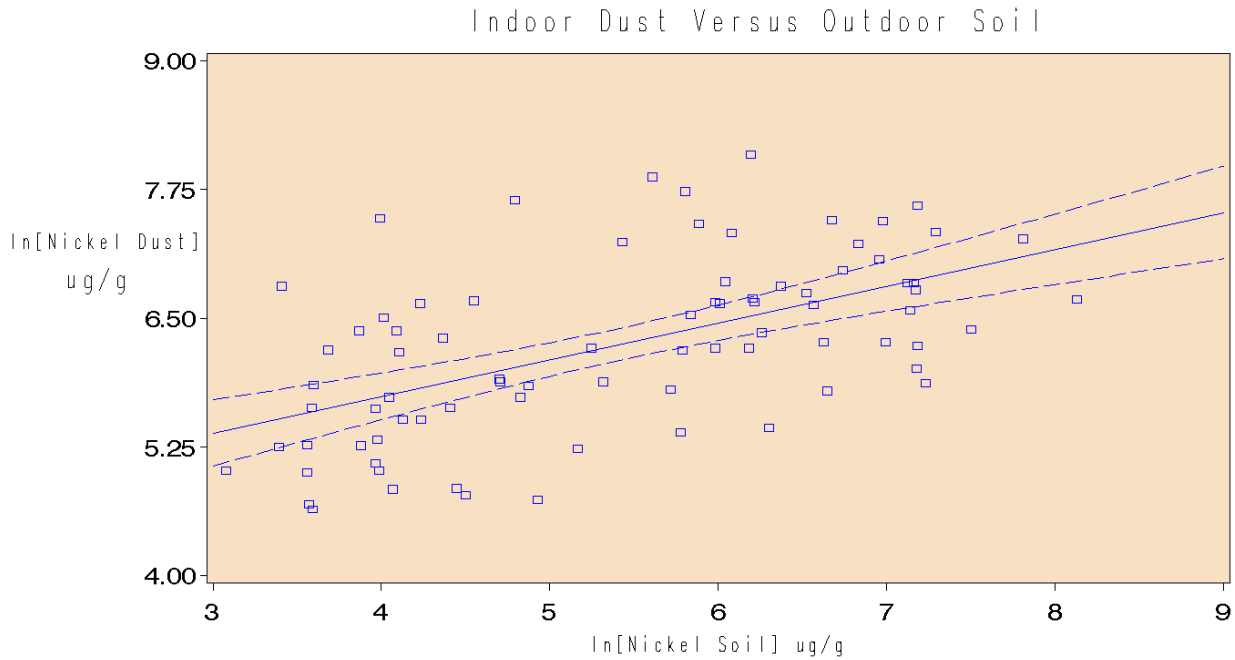
Indoor Dust Versus Outdoor Soil

Figure 3-5 **Prediction Plot – ln [nickel dust] *vs*. ln [nickel soil]**

3.8 Additional Analysis – Age of the House as a Second Explanatory Variable

In an attempt to explain additional variation in the observed indoor dust concentration, the age of each house sampled was entered into the model as a second explanatory variable. In some instances, only the approximate age of the structure was entered into the model since only the decade in which the structure was built was known. For eight (8) of the residential houses sampled, age was not recorded. It was thought that the age of the home might help to explain additional variance observed in the indoor dust concentrations. Prior to placing house age into the model, Pearson correlation coefficients (r) were generated between metal-specific indoor dust concentrations and the age of each home. Table 3.6 provides the Pearson correlation coefficient matrix.

Table 3.6   Pearson Correlation Coefficient (r) Matrix

	Age	Arsenic	Cobalt	Copper	Lead	Nickel
Age	1.00	0.07 (0.51)[a] 74	0.27 (0.02) 74	0.12 (0.30) 74	0.26 (0.03) 74	0.19 (0.10) 74
Arsenic	0.07 (0.51) 74	1.00	0.61 (<0.001) 82	0.48 (<0.001) 82	-0.003 (0.97) 82	0.59 (<0.001) 82
Cobalt	0.27 (0.02) 74	0.61 (<0.001) 82	1.00	0.48 (<0.001) 82	0.09 (0.43) 82	0.66 (<0.001) 82
Copper	0.12 (0.31) 74	0.48 (<0.001) 82	0.48 (<0.001) 82	1.00	0.22 (0.04) 82	0.83 (<0.001) 82
Lead	0.26 (0.03) 74	-0.003 (0.97) 82	0.09 (0.43) 82	0.22 (0.04) 82	1.00	0.17 (0.13) 82
Nickel	0.19 (0.10) 74	0.59 (<0.001) 82	0.66 (<0.001) 82	0.83 (<0.001) 82	0.17 (0.13) 82	1.00

[1] value in brackets represents the p value

Significant correlations ($p<0.05$) between indoor dust levels and age of the residential structure were observed for lead and cobalt; however, these correlations were very weak with r values of 0.26 and 0.27, respectively. The multiple regression analysis for lead and cobalt (*i.e.* the addition of a second explanatory variable, house age) did not explain any additional variance in the dependant variable (*i.e.* the indoor house dust concentration). In both cases, the age coefficient was not significantly different from zero ($p>0.1$) and was removed from the model during the backward elimination process. Based on this preliminary examination, age was not considered a significant explanatory variable.

3.9   Additional Analysis – Indoor Dust to Outdoor Soil Concentration Ratios

Concentration ratio (CR) values can be defined as the concentration of a specific metal observed in indoor dust (µg/g) divided by the concentration observed in co-located yard soil. CR values were calculated for each site, the results of which have been summarized in Table 3.7.

Table 3.7   Summary Statistics of Residential Concentration Ratio Values[a]

Variable	Mean	Std Dev	Std. Error	N	Minimum	Maximum	Median	Skewness
Arsenic	2.89	3.31	0.370	80	0.055	17.33	1.61	2.29
Cobalt	3.27	2.50	0.279	80	0.318	10.61	2.56	1.30
Copper	0.28	0.27	0.030	80	0.021	1.18	0.186	1.43
Lead	5.95	6.40	0.713	80	0.326	42.76	4.68	3.10
Nickel	4.26	5.60	0.626	80	1.50	32.41	2.22	3.18

[a] CR value defined as [indoor dust μg/g] / [yard soil μg/g]

With the exception of copper, all median CR values (n =80) were greater than 1.0. This indicates that indoor dust levels were 2.8 to 5.9 times higher than corresponding soil levels.

A scatter plot of copper CR values ([indoor dust - μg/g] / [yard soil - μg/g]) *versus* corresponding copper concentrations in yard soil is provided in Figure 3-6. The scatter plot indicates that CR values (describing the relationship between copper in indoor dust and yard soil) vary with increasing yard soil concentrations. As yard soil concentrations increase, CR values tend to decrease. Figure 3-7 represents a scatter plot of the transformed data set (ln transformed).
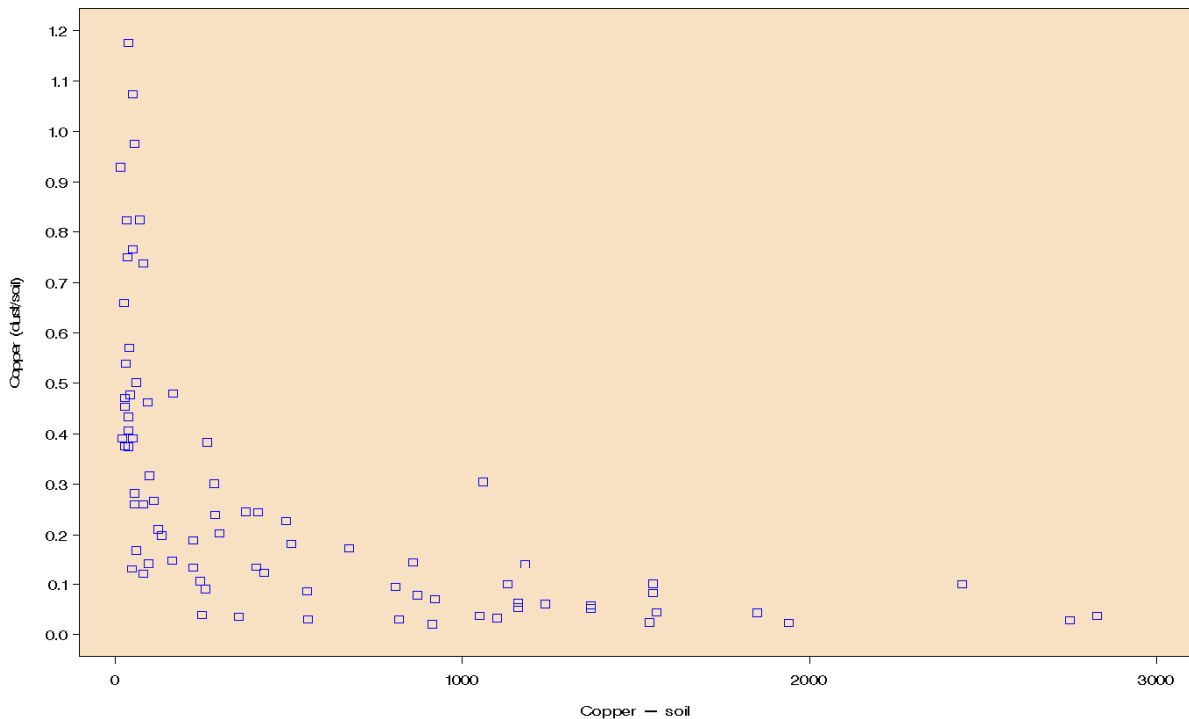

Figure 3-6   Scatter Plot of Copper CR values ([indoor dust] / [yard soil]) *vs*. Copper Concentrations in Outdoor Yard Soil (μg/g)
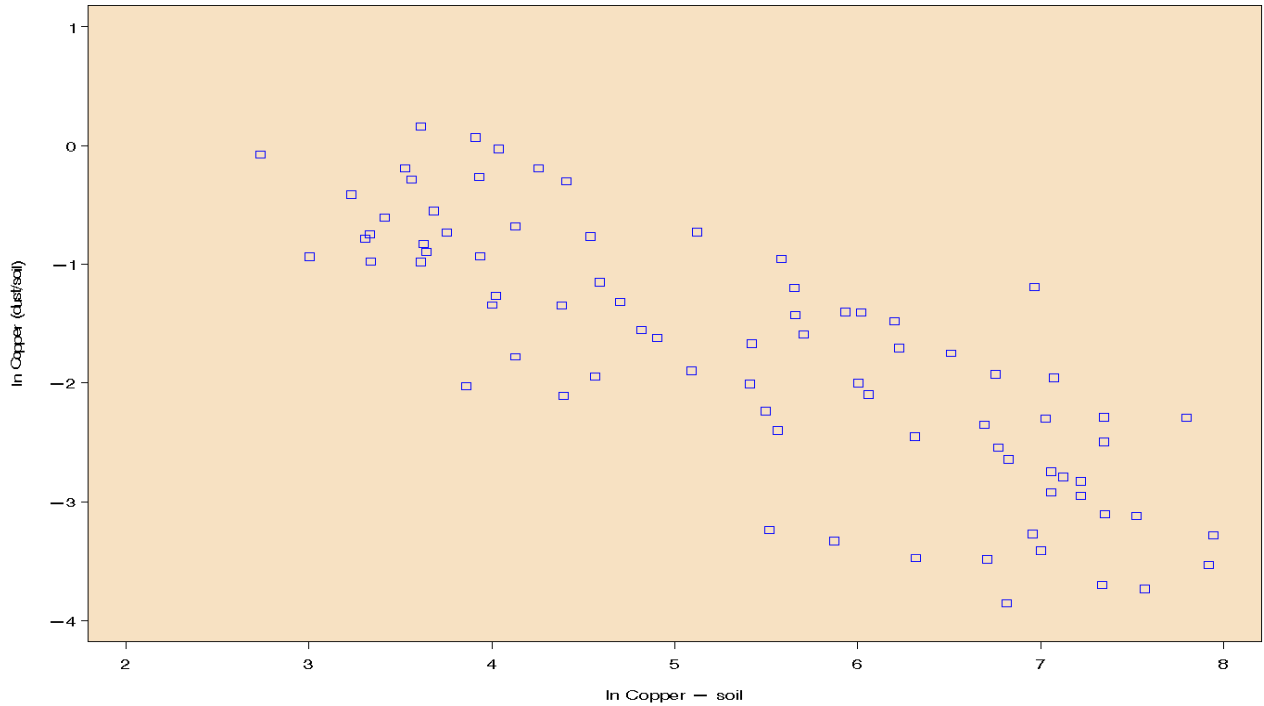
Figure 3-7   Scatter Plot of ln transformed Data – Copper CR values *vs*. Copper Concentrations in Outdoor Yard Soil (µg/g)

Significant negative correlations (p<0.01) between estimated CR values and yard soil concentrations were determined for all COCs. Pearson correlation coefficient (r) values fell between -0.55 to -0.33 for copper and arsenic, respectively. Table 3.8 provides the correlation matrix and significant levels. CR values for all COCs were significantly correlated in the negative direction (p<0.01) with outdoor yard soils. In general, CR values for all COC were observed to decrease with increasing soil concentration; however, this observation was found over a relatively large soil concentration range.

Table 3.8   Partial Pearson Correlation Coefficient (r) Matrix[a]

	Arsenic CR value	Cobalt CR value	Copper CR value	Lead CR value	Nickel CR value
Arsenic – soil (µg/g)	-0.335 (0.0024)	NA	NA	NA	NA
Cobalt – soil (µg/g)	NA	-0.42 (0.001)	NA	NA	NA
Copper – soil (µg/g)	NA	NA	-0.558 (<0.001)	NA	NA
Lead – soil (µg/g)	NA	NA	NA	-0.37 (0.006)	NA
Nickel – soil (µg/g)	NA	NA	NA	NA	-0.37 (0.0007)

[1] value in brackets represents the p value

4.0 DISCUSSION

4.1 Comparison Between Predicted Indoor Dust Levels Using A CR Value *versus* Linear Regression

The slope of the best fit linear regression line (as reported in Section 3.7) and the mean concentration ratio (CR) value for any COC is not equivalent. The slope of the regression line was determined by the method of least squares and represents the rate of change (over a specific concentration range) in the indoor dust level as a function of yard soil concentration. CR values are defined as the concentration of metal in indoor dust (μg/g) divided by the concentration observed in co-located yard soil (μg/g). As previously demonstrated, the CR values do not remain constant over a large range of yard soil concentrations. As the concentration in outdoor yard soil increases, CR values decrease, suggesting that indoor dust concentrations do not simply increase (in a linear fashion) with increasing soil concentration. A comparison between predicted Ni indoor dust concentrations using the CR approach *versus* the linear regression equation provided in Table 3.5 has been provided in Figure 4-1.
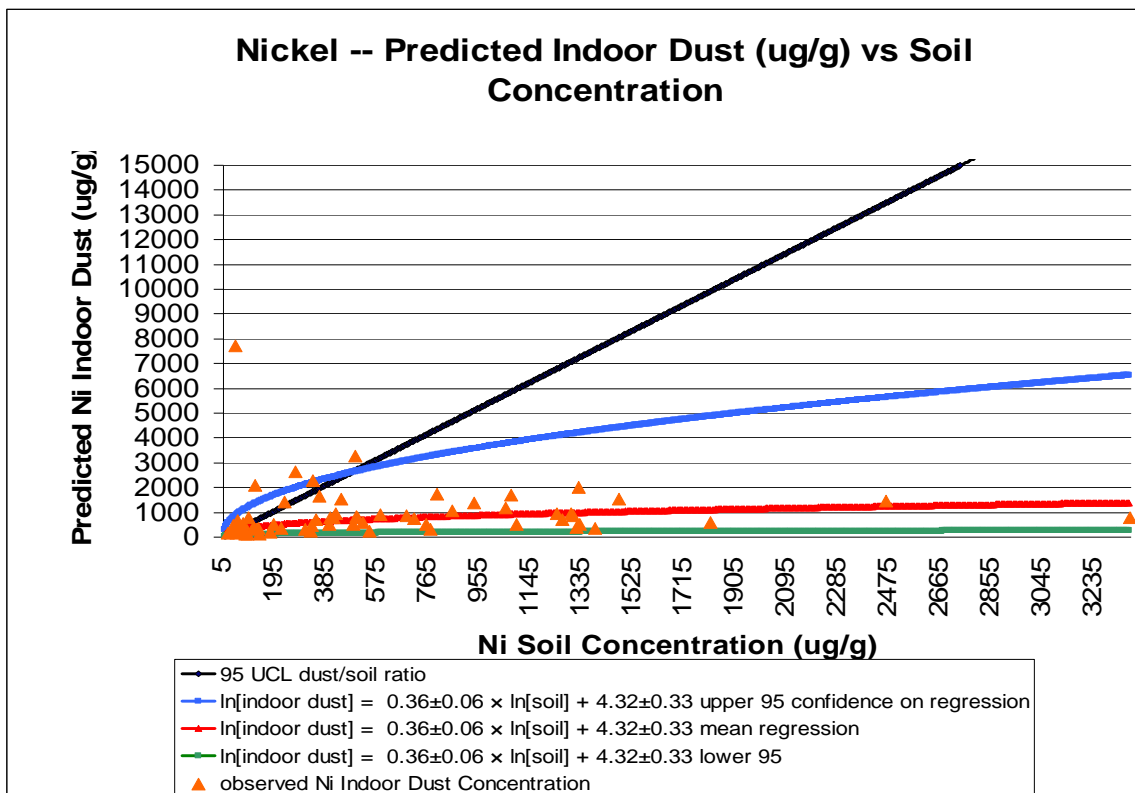

Figure 4-1 **Predicted Ni Concentrations in Indoor Dust using the 95 UCL CR value and the Linear Regression Equation**

The 95% Upper Confidence Limit (95 UCL) Ni CR value (or dust/soil ratio) of 5.45 (μg/g indoor dust/μg/g yard soil) was used to predict indoor dust levels over a range of yard soil concentrations observed in the Sudbury area. Similarly, the linear regression equation for Ni presented in Table 3.5 was also used to derive indoor dust concentrations using the same yard soil data. The use of the 95 UCL Ni CR value overestimates Ni indoor dust concentrations as Ni levels in yard soil increase. Relative to the mean regression line, use of the CR value over predicts indoor dust levels at yard concentrations greater than 400 μg/g. At 1 000 μg/g Ni in outdoor yard soil, the use of the 95 UCL CR value would predict an indoor Ni dust concentration of approximately 5 700 μg/g. The mean and 95 upper confidence limit of the linear regression line would predict indoor Ni dust concentrations of 920 μg/g and 3 800 μg/g, respectively. A concentration of 1 180 μg/g Ni was observed in indoor dust at a co-located yard soil concentration of 1,050 μg/g.

In conclusion, CR values tend to be an adequate predictor of indoor dust concentrations when they are applied to relatively low concentrations of nickel in soil. As concentrations in yard soil increase, however, CR values tend to over estimate corresponding indoor dust levels relative to those predicted using linear regression methods. It is apparent from Figure 4-1 that the indoor dust-to-soil ratio does not remain constant over a wide range of metal concentrations in soil. Based on the discussion above, the use of regression equations to estimate indoor dust concentrations from outdoor soil concentrations is preferred to the use of CR values.

4.2 Review of Other Indoor Dust Studies

Several studies have been conducted to define the relationship between levels of contaminants in household or indoor dust *versus* outdoor soil. Based on a review of the literature, there seems to be adequate evidence to suggest a relationship exists between levels of contaminants measured in indoor dust and the levels observed in nearby outdoor soil. However, there are varying degrees of certainty and strength to this relationship.

4.2.1 Literature Review of Relationships between Metal Concentrations in Outdoor Soil versus Indoor Dust

A recent study by Rasmussen (2004) collected indoor dust and outdoor soil and dust from 48 homes across the city of Ottawa, Ontario. Dust samples were collected into new vacuum cleaner bags by the homeowner. Outdoor soil samples consisted of a composite of the top 5 cm of soil from five locations in the yard surrounding the home being sampled. The results of the study

indicated that the multi-element composition of indoor dust differed significantly from that of garden soil or street dust. For most elements, levels in household dust exceeded natural background concentrations for the region whereas most concentrations in garden soil and street dust were low in comparison with local background concentrations. The authors found no significant correlations for element concentrations in household dust *versus* street dust or household dust *versus* garden soil. Mean concentration ratios (CRs) for indoor dust *versus* garden soils were greater than 1 for most elements (see Table 4.1). Rasmussen (2004) developed mean CR values for lead and nickel of 5.5 and 3.4 respectively. These were similar to the mean CR values developed using the current dataset of 6.0 and 4.3 for lead and nickel, respectively.

A study by Harrison (1979) found similar indoor/outdoor dust concentration ratios in a study of household and street dust in Lancaster area of the United Kingdom. The mean levels of total metals in household dust were found to be higher than in dust collected from rural roads, and to a lesser degree, urban roads. Mean concentration ratios for household dust *versus* urban road dust and for household dust *versus* rural road dust were greater than 1 for most elements (Table 4.1). Lancaster area is not considered to be impacted by significant industrial emissions.

A population-based exposure survey conducted by Hwang *et al*. (1997) in Anaconda, Montana, examined the relationship between exterior soil and indoor dust in homes near a historic copper smelter operation. Geometric mean arsenic concentrations in five types of soil collected around the exterior of the homes ranged from 121 to 236 µg/g, with a total average soil concentration of 192 µg/g. An average arsenic level of 75.14 µg/g was reported for indoor dust. Significant correlations reported between arsenic concentrations in indoor dust and each of the five soil types collected ranged from r = 0.42 to r = 0.52 (p < 0.0005) (log-transformed data), with an average arsenic concentration ratio for indoor dust to outdoor soil of 0.391.

Calabrese (unpublished, as reported in Walker and Griffin, 1998) reported a similar indoor dust/outdoor soil concentration ratio of 0.387 for average arsenic concentrations in samples collected from a smaller sub-set of the same homes in Anaconda, Montana. Calabrese used different sampling methods and reported significantly different arsenic concentrations in soil (average = 74.67 µg/g) and indoor dust (average = 29.03 µg/g); however, the average indoor/outdoor concentration ratio was similar to the ratio observed by Hwang *et al*. (1997).

The Ontario Ministry of the Environment (MOE) recently conducted a review of available literature discussing the relationship between concentrations of metals in outdoor soil and indoor

dust for the Rodney Street Community Human Health Risk Assessment in Port Colborne, Ontario (MOE, 2002). The review included an evaluation of a study conducted by PTI Environmental Services (PTI, 1994) at a contaminated site in Bartlesville, Oklahoma, in which levels of various metals were measured in outdoor soil and indoor dust. The study reported concentration ratios of indoor dust to outdoor soil for arsenic, cadmium, lead, and zinc, of 0.20, 0.35, 0.50, and 0.36, respectively (MOE, 2002). The MOE selected a CR value of 0.39, derived from the Hwang and Calabrese studies, to define the relationship between indoor dust and outdoor soil concentrations of nickel in Port Colborne.

Studies conducted in areas that have historically, or continue to be, impacted by neighbouring industrial activities, such as mining or smelting operations, provide evidence that a significant relationship exists between metal concentrations in outdoor soil and levels found in household dust. Regions or cities with less industrial activity have not shown evidence to support this relationship; however, in most studies, higher levels of contaminants are reported in household dust than in surrounding outdoor soil, which tends to be similar to natural background levels.

Table 4.1 provides a summary of the ratios between metal levels in indoor dust and outdoor soil reported in various studies.

Table 4.1   Concentration Ratios for Indoor Dust *versus* Outdoor Soil and Dust Reported in Various Studies

Relationship	Mean concentration ratios								Study Ref.
	As	**Pb**	**Ni**	**Se**	**Cu**	**Co**	**Cd**	**Zn**	
Indoor dust/ outdoor soil	1.69	5.50	3.37	1.67	13.90	1.03	16.37	6.18	1
	0.391	-	-	-	-	-	-	-	2
	0.387	-	-	-	-	-	-	-	3
	0.20	0.50	-	-	-	-	0.35	0.36	4
Indoor dust/ street dust	4.9	6.95	3.62	2.5	4.48	1.05	13.39	6.20	1
Indoor dust/ urban road dust	-	0.381	1.229	-	1.545	0.934	2.326	2.191	5
Indoor dust/ rural road dust	-	1.302	2.324	-	2.797	1.197	5.095	3.939	5

[1] Rasmussen *et al*. 2004
[2] Hwang *et al*. 1997
[3] Calabrese (unpublished)
[4] PTI, 1994
[5] Harrison, 1979

Regression analysis is an approach often used to examine the relationship between metal concentrations in indoor dust and outdoor soil. The slope of a regression equation (dust concentration/soil concentration) for a data set can be used to define the changes in dust concentration over a range of soil concentrations. However, it should be noted that the slope of a regression equation for the plot of indoor dust concentrations over outdoor soil concentrations and mean concentration ratios for the same data set are not analogous and should not be used for comparison of different data.

Regression analysis conducted by Murgueytio *et al*. (1998) on indoor dust and outdoor soil data collected during an exposure study in the Big River Mine Tailings site, south of St. Louis, Missouri, found a significant correlation between indoor dust lead concentrations and outdoor soil lead levels ($r^2 = 0.36$; $p < 0.000$ [sic]).

The relationship between contaminants in indoor dust and outdoor soil in residential homes has also been examined by the U.S. Environmental Protection Agency (U.S. EPA) at several Superfund sites across the United States. Residential dust sampling at one Superfund site near Denver, Colorado, found only a weak correlation between the levels of arsenic and lead in soil and dust ($r^2 = 0.14$ and 0.18, respectively; $p < 0.01$). However, regression analysis of the paired soil and dust data revealed statistically significant regression line slopes, for both arsenic and lead (U.S. EPA Region VIII, 2001). A comparison of soil-dust relationships for arsenic and lead at other U.S. EPA Region VIII Superfund sites is presented in Table 4.2.

Table 4.2   Soil-Dust Relationships at Other U.S. EPA Superfund Sites[1]

Site	Slope of Regression Line (ppm dust/ppm soil)	
	Arsenic	Lead
Anaconda, MT	0.31	
Bingham Creek, UT		0.43
Butte, MT		0.24
Deer Lodge, MT	0.001	-0.01
East Helena, MT		0.88
Flagstaff/Davenport, UT		0.06
Midvale OU1, UT	0.03	0.04
Leadville, CO	0.10	0.33
Murray Smelter, UT	0.17	0.19
Sandy City, UT		0.13
Sharon Steel, UT		0.76
Vasquez Blvd. & I-70, CO	0.06	0.34

[1] U.S. EPA Region VIII, 2001

The slope of the regression lines for indoor dust and outdoor soil concentrations of arsenic (0.22) and lead (0.26) in the GSA (Table 3.4) fall within the range of slope values observed at Superfund sites across the United States.

4.2.2   *Indoor Dust Study for HHRA conducted in Port Colborne, Ontario*

As part of a Community Based Risk Assessment conducted in 2002, indoor dust and co-located outdoor soil concentrations were collected from 31 residential homes and properties in Port Colborne, Ontario (JWEL, 2004). The study involved the collection of four types of indoor dust samples including indoor air samples, fabric surface samples, hard surface samples and attic samples. Various collection methods were used to collect each dust sample type, including air flow pumps and filters to collect indoor air samples of total suspended solids (TSP) and PM_{10} particles, personal air sampling pumps with nozzles to collect dust from carpets and upholstery, moistened wipes to collect dust from hard surfaces and wipe and grab samples for the collection of attic dust. Soil cores were collected concurrently from the yards of the same residences.

Analysis of the indoor dust and outdoor soil concentrations for cobalt, copper and nickel showed significant correlations between four dust sample types and concentrations in yard soil. Nickel in TSP ($r=0.36$, $p<0.049$), cobalt and nickel in fabric samples ($r=0.50$, $p<0.005$ and $r=0.61$, $p<0.0004$, respectively) and nickel in hard surface samples ($r=0.50$, $p<0.005$) were significantly correlated to soil concentrations. However, regression analysis indicated the strength the significant correlations was low; $r^2=0.13$ for nickel in TSP, $r^2=0.25$ and $r^2=0.37$ for cobalt and nickel in fabric samples, respectively, and $r^2=0.25$ for nickel in hard surface dust.

The results of the study were used to calculate reasonable maximum long-term average concentrations of metals in indoor dust (95% upper confidence limits on the mean). These values were then used to estimate human exposure as part of a human health risk assessment.

5.0 CONCLUSIONS

Detailed information on the concentrations of the six COCs was obtained in indoor household dust and co-located outdoor soil samples for the GSA.

The data indicate that concentrations of the COCs in indoor dust are generally higher than concentrations in outdoor soil.

Concentrations of the COCs in dust and soil differed between the five Communities of Interest, which is consistent with the 2001 Sudbury soils survey.

The use of the linear regression equations (presented in Table 3.5) to predict indoor dust concentrations (as a function of outdoor soil concentrations) was considered appropriate. Although the explanatory power (*e.g.*, R^2 values) of some regression models were poor, these relationships were considered more appropriate than the use of mean CR values, which were shown to vary over a wide range of yard soil concentrations. The Sudbury-specific dust; soil relationships developed from this survey will be used to generate dust exposure values for the Sudbury HHRA.

6.0   REFERENCES

ASTM. 2004. ASTM Standard Practice for Collection of Floor Dust for Chemical Analysis (Designation: D 5438-00). ASTM International, West Conshohocken, PA.

Colt, J.S., Zihm, S.H., Camann, D.E., and Hart, J.A. 1998. Comparison of pesticides and other components in carpet dust samples collected from used vacuum cleaner bags and from a high volume surface sampler. Environ Health Perspect, 106:721-724.

Harrison, R.M. 1979. Toxic metals in street and household dusts. Sci Total Environ, 11: 89-97.

Hinwood, A.L., Sim, M.R., Jolley, D,. de Klerk, N., Bastone, E.B., Gerostamoulos, J., and Drummer, O.H. 2004. Exposure to inorganic arsenic in soil increases urinary inorganic arsenic concentrations of residents living in old mining areas. Env Geochem Health, 26:27-36.

HUD. 1995. HUD Technical Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing. U.S. Department of Housing and Urban Development (HUD). Washington, DC. Online: http://www.hud.gov/offices/lead/guidelines/hudguidelines/index.cfm.

Hwang, Y.H., Bornschein, R.L., Grote, J., Menrath, W., and Roda, S. 1997. Environmental arsenic exposure of children around a former copper smelter site. Environ Res, 72: 72-81.

Hysong, T.A., Burgess, J.L., Cebrian Garcia, M.E., and O'Rourke, M.K. 2003. House dust and inorganic urinary arsenic in two Arizona mining towns. J Expo Anal Env Epid, 13:211-218.

JWEL. 2004. Port Colborne Community Based Risk Assessment - Draft. Human Health Risk Assessment, Appendix 11: Indoor Dust Study. Jacques Whitford Environmental Limited, May 2004.

Lanphear, B.P., Matte, T.D., Rogers, J., Clickner, R. P., Dietz, B., Bornschein, R. L., Succop, P., Mahaffey, K. R., Dixon, S., Galke, W., Rabinowitz, M., Farfel, M., Rohde, C., Schwartz, J., Ashley, P., and Jacobs, D. E. 1998. The contribution of lead-contaminated house dust and residential soil to children's blood lead levels – a pooled analysis of 12 epidemiological studies. Environ Res, 79(1): 528-532.

Lioy, P.J., Freeman, N.C., Wainman, T., Stern, A.H., Boesch, R., Howell, T., and Shupack, S.I. 1992. Microenvironmental analysis of residential exposure to chromium-laden wastes in and around New Jersey homes. Risk Anal, 2(2):287-99.

Lioy, P.J., Freeman, N.C.G., and Millette, J.R. 2002. Dust: a metric for use in residential and building exposure assessment and source characterization. Environ Health Perspect, 110(10):969-983.

MOE. 1997. Guideline for Use at Contaminated Sites. Ontario Ministry of the Environment.

MOE. 2002. Soil Investigation and Human Health Risk Assessment for the Rodney Street Community, Port Colborne: Part B, Appendix 6. March, 2002.

Morawska, L. and Salthammer, T. 2004. Introduction to sampling and measurement techniques. In: Indoor Environment – Airborne Particles and Settled Dust. Morawska, L. and Salthammer, T. (eds). Wiley-VCH GmbH & Co. KGaA.

Murgueytio, A.M., Evans, R.G., Sterling, D.A., Shadel, B.N., and Clements, B.W. 1998. Relationship between lead mining and blood lead levels in children. Arch Environ Health, 53(6): 414-423.

PTI. 1994. Remedial Investigation Report. National Zinc Site. PTI Environmental Services. September 1994. Cited In: MOE, 2002.

Rasmussen, P.E., 2004. Can Metal Concentrations in Indoor Dust be Predicted from Soil Geochemistry? Canadian Journal of Analytical Sciences and Spectroscopy. Volume 49, No. 3, 2004.

Rutz, E., Valentine, J., Eckart, R., and Yu, A. 1997. Pilot study to determine levels of contamination in indoor dust resulting from contamination of soils. J Soil Contam, 6(5):525-536. Cited In: MOE, 2002.

U.S. EPA. 2001. Identifying Lead Hazards in Residential Properties. EPA Fact Sheet. U.S. Environmental Protection Agency. Online: http://www.epa.gov/lead.

U.S. EPA Region VIII. 2001. Baseline Human Health Risk Assessment Vasquez Boulevard and I-70 Superfund Site, Denver, Co. U.S. Environmental Protection Agency, Region VIII. August 2001. Online: www.epa.gov/region8/superfund/sites/VB-I70-Risk.pdf.

U.S. EPA. 2005. SW-846 Test Methods Manual [Online]. U. S. Environmental Protection Agency, Office of Solid Waste. May, 2005. Online: http://www.epa.gov/epaoswer/hazwaste/test/main.htm#chap.

Walker, S. and Griffin, S. 1998. Site-specific data confirm arsenic exposure predicted by the U.S. Environmental Protection Agency. Environ Health Perspect, 106(3): 133-139.

Zhipeng, B., Lih-Ming, Y., Rich D.Q., Adgate, J.L., Ashleyu, P.J., Lioy, P.J., Rhoads, G.G., and Junfeng, Z. 2003. Field evaluation and comparison of five methods of sampling lead dust on carpets. AIHA J, 64:528-532.