Proceedings of the 23rd Annual British Columbia Mine Reclamation Symposium in Kamloops, BC, 1999.
The Technical and Research Committee on Reclamation

ASSESSMENT OF ARSENIC EXPOSURD IN A RESIDENTIAL AREA LOCATED ON MINE TAILING: A CASE STUDY

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ABSTRACT

During the 1950s to the early 1960s tailing from the Campbell Mine were deposited into an area that would eventually become the 6th/7th Street section of the Balmertown townsite. Investigation of the area in the early 1990s revealed that tailing containing arsenic minerals were underlying eleven homes. Many of the tailing samples collected contained total arsenic levels greater than 1000 mg/kg.

In 1993 an arsenic exposure assessment was undertaken to determine the affect of the arsenic contained in the tailing on the health of residents in the study area. As an alternative to adopting default values for an EPA exposure model a comprehensive background database was developed. The data was used to undertake EPA exposure calculations and to perform a Monte Carlo analysis to estimate the potential range of exposures in the area. A separate urinalysis study was performed to validate the results of the exposure assessment.

The results of the assessment indicated that the total lifetime exposure of arsenic to residents in the study area did not significantly increase due to the arsenic minerals in the tailing. The limited exposure was partially due to the low levels of arsenic in the identified exposure pathways for residents and the limited bioavailability of the arsenic in the mineral sulphide form. It was concluded that the arsenic minerals did not significantly increase the risk to human health and therefore the removal of the tailing and overlying soil was not required.

INTRODUCTION

The Placer Dome North America (PDNA) Campbell Mine is located in Balmertown in northwestern Ontario. Gold was first discovered on the property in 1945 with the establishment of the mine and milling facilities in 1949. Gold ore at the Campbell Mine is mined from quartz carbonate veins which contain varying amounts of sulphide minerals including arsenopyrite (FeAsS). The presence of arsenopyrite has resulted in elevated levels of arsenic in the ore and mill effluent (tailing) material. During the 1950s to the early 1960s overflow tailing from the Detta Lake tailing impoundment were deposited onto the future area of the 6th/7th Street section of the Balmertown townsite. Upon the expansion of the townsite onto the eastern edge of the deposited tailing, the area was covered with a thin layer of borrow material, arid twenty-three homes were subsequently built during the period of 1965 to 1985. In 1990 rehabilitation of the deposited material was undertaken and identified tailing was removed and replaced with clean material. Subsequent investigation revealed that tailing still remained under eleven homes on the east side of 7th Street and the adjoining backyards of the homes on 6th Street.

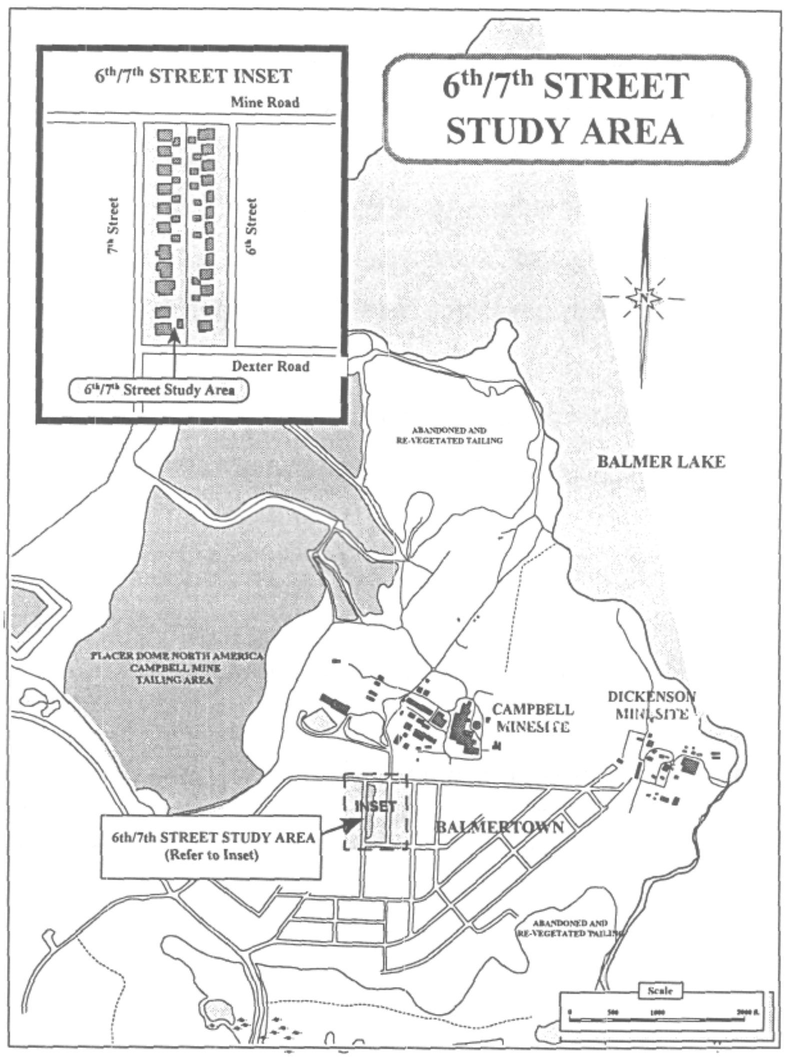
Preliminary health and environmental data collected from the study area indicated a minimum arsenic exposure potential. However, uncertainties regarding the impact of the arsenic on the overall health of the residents in the study area still remained. Thus, in 1993 an arsenic exposure assessment was initiated to resolve this key issue. The following sections outline the programs and results of the assessment conducted over a two year period.

STUDY AREA

The study area is located in the 6th/7th Street section of Balmertown, Ontario adjacent to the PDNA Campbell Mine (refer to Figure 1). Eleven homes in the study area were built upon old tailing material resulting from historic operations at the mine. An extensive drilling program undertaken to investigate the area revealed that the tailing material covered a total area of approximately one acre. Organic topsoil was encountered in all boreholes ranging from 0.1 m to 1.1 m thick. Below the topsoil, the lithology consisted of borrow material (0.3 m to 1.60 m thick), overlying tailing (O m to 1.60 m thick) and lacustrine soils. Samples collected from the drilling program indicated that total arsenic levels were elevated in both the borrow and tailing material. A significant number of the tailing samples contained arsenic levels in excess of 1000 mg/kg. A preliminary pétrographie examination of the samples indicated that there was a potential for the mobilization of inorganic arsenic from the tailing material. The extent of the potential mobilization was unknown.

A background urinalysis screening program was conducted to determine if elevated levels of speciated arsenic (inorganic arsenic and its metabolites) were present in the residents of the study area. Urinary arsenic was selected as an indicator for arsenic exposure because the presence of arsenic in urine reflects arsenic exposure within the last few days. It may also be useful in identifying specific sources of arsenic exposure. Urine was analyzed for total arsenic, which included the non-toxic organic forms as well as the potentially toxic inorganic forms, and for speciated arsenic, which reflected the inorganic arsenic and its

Figure 1: Study Area - 6th/7th Street Area of Balmertown



metabolites. Speciated arsenic is more relevant to assessing health risks of arsenic than total arsenic, because with speciated arsenic, only the toxic inorganic form and its metabolites are measured. However, total arsenic data was also collected in order to compare the results of this program with other programs that only measured total arsenic. The results of the program indicated that levels of speciated arsenic were well below the health based limit of 50 μg/L. In addition, a survey of total arsenic levels in garden vegetables, drinking water, and surface water from the study area indicated levels were also below the respective Ontario Provincial guidelines. Based upon the available information it was believed that the arsenic exposure potential for the residents in the study area was minimal. However, due to the elevated levels and potential for mobilization of inorganic arsenic in the tailing, and uncertainties regarding arsenic bioavailability and the cumulative exposure of arsenic sources in the study area on the health of the residents, the decision was made to proceed with a comprehensive exposure assessment.

METHODS

Approach to Exposure Assessment and Preliminary Screening Calculations

An exposure assessment investigates the potential for exposure to one or more contaminants in any of several media (ie., water, air, soil). It is a procedure used to estimate the likelihood that individuals will be exposed to one or more contaminants under a specific set of conditions. In this exposure assessment preliminary screening calculations using background data were performed for several exposure pathways. The pathways were assessed for the study population and two control populations as follows:

- the Balmertown study area;
- the Balmertown control area (residential areas of Balmertown not built on tailing); and
- the Red Lake Control area which consisted of the town of Red Lake (a nearby community located southwest of Balmertown).

Based upon the results of the calculations it was determined that four pathways contributed the majority of the arsenic exposure to adults and children in the study area (refer to Table 1).

Table 1. Percent Contribution of Total Uptake of Inorganic Arsenic by Exposure Pathway

Exposure Pathway	Adult[1]	Child[1]
Food Ingestion	59 - 74%	81 - 97%
Ingestion of Drinking Water	22 - 26%	1.9 –2.2%
Incidental Ingestion of Soil	0 – 7%	0 – 5%
Incidental Ingestion of Dust	0.5 – 15%	0.4 – 13%
Dermal Contact with Soil	0 – 1.3%	0 –1.2%
Dermal Contact with Dust	0.3 – 2.9%	0.3 – 3%
Dermal Contact with Drinking Water	0.1 – 0.6%	0%
Inhalation of Particulate	0 – 0.2%	0 – 0.1%

Note:

1. Percent Contribution of Total Uptake of Inorganic Arsenic by Exposure Pathway.

As a result, the following pathways were selected for inclusion in the exposure assessment:

- ingestion of food;
- ingestion of drinking water;
- incidental ingestion of soil; and
- incidental ingestion of dust.

Point Exposure Estimates

Point exposure estimates for the four pathways were developed for residents in each household in the study and control populations. The estimates were based upon extensive background soil, dust, drinking water, and food data collected as part of the exposure assessment. Key variables such as bioavailability and ingestion rates of arsenic were determined based on in vitro testing of background samples and comparison to similar studies or through the use of published regulatory guidelines. The total daily arsenic exposure for residents in each household was then calculated by summing the daily exposure estimates from the four identified pathways. The total exposure over a 70-year lifetime was then determined by adding the exposure for adults and children together.

Soil and Dust Calculation

Arsenic exposure estimates related to the ingestion of soil and dust were developed by coupling estimates of intake based upon variable values that were the same for all households (ie., amount of soil ingested daily, duration of exposure, body weight) with the background environmental soil and dust data collected at each house (ie., concentration of arsenic in soil and house dust). The daily intake of arsenic as a result of incidental ingestion of soil and dust was calculated as follows:

$$\text{Intake (mg/kg-day)} = \frac{CS \times IR \times CF \times BIO \times FR \times EF \times ED}{BW \times AT}$$

Given:

CS	=	arsenic concentration in soil (mg/kg)
IR	=	ingestion rate (80 mg soil and dust/day for children ages 1-6; 20 mg soil and dust/day for older children and adults)
CF	=	conversion factor (lO^kg/mg)
BIO	=	bioavailability of arsenic in soil (unitless)
FR	=	fraction of soil or dust
EF	=	exposure frequency (150 days/year for soil and 350 days/year for dust)
ED	=	exposure duration (6 years for children ages 1-6; 64 years for individuals over 6 years)
BW	=	body weight (16 kg for children ages 1-6; 70 kg for individuals over 6 years)

AT = averaging time for carcinogenic effects (70 years times 365 days/year for a total of 25,550 days for children and adults)

Drinking Water Calculation

Arsenic exposure estimates related to the ingestion of drinking water were developed using an identical approach to the soil/dust estimates with the exception that since drinking water measurements were not available for each house an average arsenic concentration value was used. The daily intake of arsenic from ingesting drinking water was calculated as follows:

$$\text{Intake (mg/kg-day)} = \frac{CW \times IR \times BIO \times EF \times ED}{BW \times AT}$$

Given:

CW = arsenic concentration in water (mg/litre)

IR = water ingestion rate (1.5 litres/day for adults; 0.6 litres/day for children)

BIO = bioavailability of arsenic in water (unitless)

EF = exposure frequency (350 days/year)

ED = exposure duration (64 years for adults; 6 years for children)

BW = body weight (70 kg for adults; 16 kg for children)

AT = averaging time for carcinogenic effects (70 years times 365 days/year for a total of 25,550 days for children and adults)

Food Calculation

Arsenic exposure estimates related to the ingestion of food were developed based upon a review of background data and estimates calculated by the Ontario Ministry of the Environment and Energy (OMOEE). The daily intake of arsenic from ingesting food was calculated as follows:

$$\text{Intake (mg/kg-day)} = \frac{IR \times EF \times ED}{AT}$$

Given:

IR = ingestion rate of arsenic in food (mg/kg-day)

EF = exposure frequency (350 days/year)

ED = exposure duration (64 years for adults; 6 years for children)

AT = averaging time for carcinogenic effects (70 years times 365 days/year for a total of 25,550 days for children and adults)

Monte Carlo Analysis

The Monte Carlo simulation analysis is a technique that can be used to characterize a range of plausible exposures to an environmental contaminant. Like more conventional techniques (ie., the calculation of point estimates) this method starts with an equation that expresses exposure in terms of several input variables. However, the Monte Carlo analysis then uses probability distributions instead of a single input value to develop a range of potential exposures. Since the input distributions represent input quantity frequencies in a population (ie., concentration of arsenic in soil and dust, etc), the resulting collection of calculated output values form a probability distribution that describes the fraction of individuals in a population (ie., study or control area populations) that experience various exposures.

The Monte Carlo analysis was conducted for the four identified pathways. When available site specific data (ie., arsenic concentration in soil, dust, drinking water, food) was used to develop probability distributions for input into the exposure calculation. If site specific data was not available (ie., body weight, exposure duration, soil and dust ingestion rate) literature values were used to develop synthetic input distributions. Often the result of the point estimate calculations was used as the arithmetic mean of the distribution.

Urinalysis Screening Program

A urinalysis screening program was conducted since urinary arsenic is an indicator of arsenic exposure and can be used to identify specific arsenic sources (ie., arsenic exposure from the four identified pathways). In addition, urine arsenic levels can be correlated with potential health effects. The purpose of the urinalysis screening program was to determine if residents in the study area had significant exposure to arsenic and to validate the predictive results of the point estimate calculations and Monte Carlo analysis. Subsequent to the initial background study an additional three-phase urinalysis screening program was conducted as part of the exposure assessment. Like the background study the levels of total and speciated urinary arsenic were evaluated in both study and control populations.

RESULTS

Point Exposure Estimates

For the individual house calculations the total exposure to inorganic arsenic for residents living in the study area was almost identical to the total exposure of residents living in the control areas (refer to Table 2). The total lifetime exposure was calculated to be 3.1E-04 mg/kg-day, 3.1E-04 mg/kg-day, and 3.0E-04 mg/kg-day for the residents of the Balmertown study area, the Balmertown control area, and the Red Lake control area, respectively. The exposures were similar since the exposure from food and drinking water was calculated to be identical for both the study and control areas and since food and drinking water constituted the majority of the total lifetime exposure to arsenic (ie., 96% of combined exposure in the study area and in the Balmertown control area and almost 100% in the Red Lake control area). Arsenic exposure from soil and dust was higher for residents of the Balmertown study area and the Balmertown control area than for residents of the Red Lake control area. However, the overall contribution to exposure from soil and dust was minimal when compared to the contribution from food and drinking water. Combined exposures; from soil and dust never accounted for more than 11 percent of the total exposure for any of the residents (ie.s adults or children) in either the study or control areas.

Table 2. Exposure and Percent of Total Exposure by Medium for Individual Houses

	Soil		Dust		Drinking Water		Food		Total Exposure	
	Mean mg/kg-day	Percent[1]	Mean mg/kg-day	Percent[1]	Mean mg/kg-day	Percent[1]	Mean mg/kg-day	Percent[1]	Mean mg/kg-day	Percent[1]
BSA[2]										
Children	2.2E-06	4	4.3E-06	7	1.1E-05	18	4.2E-05	70	6.0E-05	99
Adults	1.3E-06	<1	2.6E-06	1	6.8E-05	27	1.8E-04	72	2.5E-04	100
Lifetime	3.5E-06	1	6.9E-06	2	7.9E-05	25	2.2E-04	71	**3.1E-04**	99
BCA[3]										
Children	7.3E-07	1	6.1E-06	10	1.1E-05	18	4.2E-05	70	6.0E-05	99
Adults	5.0E-07	<1	3.7E-06	1	6.8E-05	27	1.8E-04	72	2.5E-04	100
Lifetime	1.2E-06	<1	9.8E-06	3	7.9E-05	25	2.2E-04	71	**3.1E-04**	99
RLCA[4]										
Children	1.2E-07	<1	1.0E-06	2	1.1E-05	20	4.2E-05	78	5.4E-05	100
Adults	7.1E-08	<1	6.3E-07	<1	6.8E-05	28	1.8E-04	75	2.4E-04	103
Lifetime	1.9E-07	<1	1.7E-06	1	7.9E-05	26	2.2E-04	73	**3.0E-04**	100

Note:

1. Based on the mean value. Totals may not add to 100 percent.
2. BSA = Balmertown Study Area.
3. BCA = Balmertown Control Area.
4. RLCA = Red Lake Control Area.

Monte Carlo Analysis

The results of the Monte Carlo analysis showed that the total exposure to inorganic arsenic was, on average, similar for residents of both the study and control areas (refer to Table 3A). The total mean lifetime exposure was calculated to be 8.62E-05 mg/kg-day, 8.81E-05 mg/kg-day, and 8.19-05 mg/kg-day for the residents of the Balmertown study area, the Balmertown control area, and the Red Lake control area, respectively. The average value for arsenic exposure from soil and dust was higher for the Balmertown study area (6.81E-06 mg/kg-day) when compared to the Balmertown control area (6.62E-06 mg/kg-day) and the Red Lake control area (1.37E-06 mg/kg-day). On average, the soil and dust pathways accounted for a larger fraction of arsenic exposure in both the Balmertown study area (7.9 percent) and the Balmertown control area *(7.5* percent) than for the Red Lake control area (1.3 percent) (refer to Table 3B).

A key aspect of the Monte Carlo analysis is that it provides an estimate of the range of arsenic exposure for the residents of the study and control areas. As a result, the risk to the overall health of the residents can be evaluated for both average and "high end" exposures. For arsenic in soil and dust, the 90th percentile (ie., a "high end" exposure) was approximately six times (ie., Balmertown and Red Lake control areas) to seven times (ie., Balmertown study area) greater than the 50th percentile (ie., typical exposure), reflecting the relatively large range of soil and dust ingestion rates used in the analysis. However for total arsenic exposure (ie., soil, dust, drinking water, food), the 90th percentile was much closer to the 50th percentile (ie., only about 2.5 times greater than the 50th percentile) indicating that high end exposures and typical exposures were not vary different. As a result, the exposure risk to residents with "high end" exposures appears to be relatively similar to the exposure risk to residents with typical exposures.

Table 3A. Monte Carlo Results Total Lifetime Average Exposure to Arsenic

	Exposure Attributable to Soil and Dust mg/kg-day	Exposure Attributable to Soil, Dust, Drinking Water, and Food mg/kg-day
BSA[1]		
Arithmetic Mean	6.81E-06	8.62E-05
50th Percentile	2.36E-06	6.84E-05
90th Percentile	1.62E-05	1.67E-04
BCA[2]		
Arithmetic Mean	6.62E-06	8.81E-05
50th Percentile	2.61E-06	6.93E-05
90th Percentile	1.58E-05	1.74E-04
RLCA[3]		
Arithmetic Mean	1.37E-06	8.19E-05
50th Percentile	5.42E-07	6.42E-05
90th Percentile	3.39E-06	1.62E-04

Note:

1. BSA = Balmertown Study Area.
2. BCA = Balmertown Control Area.
3. RLCA = Red Lake Control Area.

Table 3B. Monte Carlo Results Lifetime Average Exposure to Arsenic

	Balmertown Study Area mg/kg-day		Balmertown Control Area mg/kg-day		Red Lake Control Area mg/kg-day	
Soil and Dust	6.81E-06	7.9%	6.62E-06	7.5%	1.37E-06	1.7%
Water	1.65E-05	19.1%	1.65E-05	18.7%	1.66E-05	20.2%
Food	6.29E-05	73.0%	6.50E-05	73.8%	6.39E-05	78.0%
Total	**8.62E-05**		**8.81E-05**		**8.19E-05**	

Urinalysis Screening Program

The results of the urinalysis screening program indicated that residents in the study area had slightly higher levels of total and speciated arsenic in their urine, but the differences were not statistically significant. The mean values for total and speciated arsenic were never more than 5.8 μg/L and 0.6 μg/L, respectively, higher in the study population than in the control populations. When compared to background total and speciated arsenic levels in unexposed populations of both adults and children, the results of the program for residents in both the study and control areas are well within the levels observed in these populations, and thus do not reflect undue arsenic absorption. Furthermore, all individual speciated urinary arsenic measurements were well below the health-based action level of 50 μg/L. The screening program revealed that arsenic levels in urine collected on Mondays were lower than levels collected during the week. The finding indicates that exposure to arsenic did not increase during the weekend when the residents were at home and potentially more likely to come into contact with arsenic containing soils and dusts. The similarity in values between adults and children for both the study and control populations implies that incidental ingestion of soil and dust containing arsenic was not a significant pathway of arsenic exposure.

DISCUSSION

A comparison of the results of the Monte Carlo analysis to the point exposure estimates for the individual households indicated that, based upon lifetime exposure duration, the exposure estimates represent conservative (ie., 50^{th} to 90^{th} percentile) estimates of exposure. Thus, the exposure estimates tend to be representative of the risk to the overall health of the residents for "high end" exposures. Similarly, a review of the predicted average urinary arsenic levels (ie., based upon the point exposure estimates for the various households) compared to the actual levels determined by the urinalysis screening program indicated that the calculated exposure to arsenic was likely higher than the actual exposures. The predicted levels of arsenic in urine ranged from 17 to 60 percent and 54 to 200 percent higher than the observed levels for adults and children, respectively. As a result, it can be concluded that the point exposure estimates are conservative and represent worst case "high end" exposures.

Based upon the results of the: point exposure estimates and the urinalysis program, exposure to total inorganic arsenic in the Balmertown study area is similar to exposure to total inorganic arsenic in communities unaffected by elevated levels of arsenic in soil and dust. Although exposure to arsenic in soil and dust was greater in both the Balmertown study and control areas than in the Red Lake control area, the overall contribution of arsenic from soil and dust was minor when compared to the total exposure contribution from arsenic in food and water. In addition, if all soil and dust was removed the total lifetime exposure to arsenic in the Balmertown study area would only be reduced by 3 percent. Even if the average soil and dust concentrations in the Balmertown study area was reduced by one-half, total lifetime exposure would only be reduced by 2 percent.

The results of the point exposure estimates, which were determined to be conservative, indicated that the total lifetime exposure to arsenic in the study area did not significantly increase due to the arsenic minerals in the tailing. The results of the exposure estimates were validated by the urinalysis screening program. Based upon this information it was concluded that the risk to human health did not significantly increase and therefore the removal of the tailing and overlying soil was not required. Ongoing monitoring of key indicators is continuing in order to confirm these conclusions. Regular communication of the results with the residents of the study area continues as a further commitment of the mine to the health of the community.

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