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Arsenic Exposure in Children Living Near a Former Copper Smelter

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About 10,000 people live in communities surrounding the former copper smelter at Anaconda, Montana. Most of these people live in the town of Anaconda, which is generally upwind of the smelter. The community of Opportunity is approximately 6 kilometers from the smelter stack. Mill Creek is a small community downwind of and adjacent to the smelter.

The smelter ceased operations in 1980, after almost a century of ore processing. Soil and dust on the smelter site and in the vicinity remain contaminated with arsenic, although at this time air and drinking water arsenic levels are not elevated. Results of soil and dust sampling for arsenic in the communities around the smelter are summarized in Table 1. In the town of Anaconda, surface soil arsenic levels from residential sites have averaged around 100 ppm or greater. The mean level in Mill Creek was 398 ppm in a study of 5 yards and 715 ppm in a study of 37 yards.

Young children are generally believed to be the population with the most nonoccupational exposure to soil. (Kimbrough et al. 1984; Day et al. 1975) Several models of exposure to environmental arsenic in the Anaconda area have predicted that children living in all communities surrounding the smelter would be having significant and measurable exposure to arsenic (United States Environmental Protection Agency, unpublished data). Two exposure surveys, conducted while the smelter was operative, demonstrated that excess exposure to arsenic was occurring in young children. (Baker et al. 1977; Hartwell et al. 1984). Until our surveys, no exposure data had been collected since the smelter was closed.

It has been estimated that the average child ingests between 100 mg and 10 g of soil a day. (Lepow et al. 1974; Walter et al. 1980). In the town of Anaconda, this could result in an average intake per child of 13-1,300 ug of arsenic per day. Because arsenic is readily absorbed from the gastrointestinal tract, exposure to environmental arsenic was expected to be easily demonstrable in children living in Anaconda. We, therefore, conducted arsenic exposure surveys in March 1985 and in July 1985

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to determine if excess arsenic exposure was continuing. The March survey was completed at the end of the Montana winter, when the ground was still frozen and children were spending most of their time indoors. In the July survey, we investigated exposure in the summer, when children were having greater contact with outside soils.

About 70% of a daily dose of arsenic, which has a half-life of 10-30 hours, is eliminated in the urine in a biphasic manner. (Crecelius, 1977) Urinary arsenic levels, therefore, correlate with exposure over the few days preceding testing. When the intake of seafood and arsenic-containing wine is minimal, increased levels of arsenic in urine correlate with environmental exposure.

Table 1. Results of environmental sampling after smelter closure by community, Montana, 1985.

Community	Sample	Number of samples	Mean (ppm)	Range (ppm)
Mill Creek	Soil[1]	37	715	150-1950
	Soil[2]	10	398	203- 693
	Housedust[2]	5	264	104- 386
Anaconda	Soil[3]	7	94	28- 270
	Soil[2]	14	144	27- 345
	Housedust[2]	10	58	12- 102
Opportunity	Soil[3]	5	80	16- 126
	Soil[2]	7	136	47- 302
	Housedust[2]	5	62	49- 88
Livingston	Soil[2]	6	44	19- 146
	Housedust[2]	5	4	4- 5

[1]Data from Tetra Tech, Incorporated, 1985. Surface soil samples obtained from all yards in Mill Creek.
[2]Data from Ecology & Environment, 1985. Surface soil samples obtained from yards of 5 homes each in Mill Creek, Opportunity, and Livingston and 10 homes in Anaconda. Dust samples obtained from standardized locations from 5 homes each in Mill Creek, Opportunity, and Livingston and 10 homes in Anaconda.
[3]Data from Tetra Tech, Incorporated, 1985. Surface soils collected from yards and fields in Mill Creek, Anaconda, and Opportunity.

MATERIALS AND METHODS

During the weeks of March 17-April 2, 1985, children 2 to 6 years of age were found by going from door to door in the towns of Anaconda and Livingston and the communities of Mill Creek and Opportunity. We selected Livingston as the control community, because it is demographically similar to the town of Anaconda but has no history of mining or smelting industries. In March, we randomly selected blocks to be surveyed, with probabilities of selection being in proportion to population density, until approximately a 30% sampling of eligible children was achieved in each community. We tested all eligible children in the Mill Creek community, because of the high levels of environmental contamination and the small size of the population. In July, all March survey participants from Mill Creek, Opportunity, and the eastern half of Anaconda were requested to participate in a second survey. A sample of March participants was randomly chosen from Livingston and the western half of Anaconda to be retested. Each Mill Creek participant had at least two urinary arsenic levels measured in July.

We obtained signed parental consent for all participants. In March, we interviewed parents by questionnaire about their childrens' habits and household information. In July, parents were questioned only about recent fish consumption by their children.

Instructions for collection of first-morning urine samples of participating children and sterile containers were left with the parents, and samples were collected the next morning. Shortly after the samples were collected, nitric acid was added, and they were frozen.

Urine samples were analyzed by the Division of Environmental Health Laboratory Sciences, Center for Environmental Health, Centers for Disease Control. Atomic absorption was used to determine total arsenic concentrations, with a lower limit of detection of 8 micrograms per liter (ug/l). In addition, creatinine concentrations on all samples were measured with an ACA (DuPont) automated analyzer.

Data were analyzed by comparing results from each community with those from Livingston and by comparing each child's July urinary arsenic level with his or her March level. In July, at least two first-morning urine samples were obtained from each child in Mill Creek, and the reported levels for these children are the mean values. Because urinary arsenic levels were neither normally nor log-normally distributed, nonparametric statistical tests were used for comparisons.

RESULTS AND DISCUSSIONS

Of the 232 urine samples obtained in March, 92 were from Anaconda, 25 from Opportunity, 10 from Mill Creek, and 105 from Livingston. Of the 123 urine samples obtained from children in July, 61 were from Anaconda, 21 from Opportunity, 8 from Mill Creek, and 33 from Livingston. The children who did not participate in July were similar in demographic characteristics and March urinary arsenic levels to those who did participate.

Fifty-three percent of March participants and 57% of July participants were male. The mean age of March participants was 4.06 years. Age distributions in all communities were similar. Seaford consumption in the days prior to sampling were similar in all communities.

Mean urinary arsenic levels and arsenic levels adjusted for urinary creatinine concentration are shown by community in Table 2 for all participants, with nondetectable urinary arsenic levels assigned a value of half the detection limit, 4 ug/l. Mill Creek children had significantly higher urinary arsenic levels than did Livingston children in both the March and July surveys (Mann-Whitney U test, $p<.00001$). Urinary arsenic levels in other communities tested did not differ significantly from those of Livingston children.

Table 2. Comparison between March and July 1985 urinary arsenic levels, by community, Montana.

	Mean arsenic level (ug/l)		Mean arsenic level adjusted for creatinine (ug/g)	
Community	March	July	March	July
Mill Creek	66.1	54.0	48.7	53.8
Anaconda	14.4	17.7	21.2	21.7
Opportunity	10.6	15.3	16.4	16.1
Livingston	10.6	16.6	19.1	17.1

ug/l=micrograms per liter
ug/g=micrograms per gram
Nondetectable urinary arsenic levels were assigned a value of 4 ug/l (half the detection limit).

Because distributions of urinary arsenic levels in all communities except Mill Creek were so similar, data from these communities were combined for the following statistical analyses. Forty-six percent of the March participants and 30% of the July participants living outside of Mill Creek had

nondetectable urinary arsenic levels. In addition to the mean, Table 3, therefore, includes measures of the distribution that are not affected by the value assigned to nondetectable urinary arsenic levels. Creatinine-adjusted urinary arsenic levels were calculated in two ways: (1) by assigning a value of 4 ug/l to nondetectable urinary arsenic levels and (2) by excluding these samples from analysis. Urinary arsenic levels in all communities except Mill Creek increased in the summer ($p<.05$ for all communities except east Anaconda, Wilcoxon signed rank test). This difference disappeared after adjustment for urinary creatinine concentration. Unadjusted urinary arsenic levels in Mill Creek decreased in the summer (Table 2).

There are three basic approaches to assessing the probable magnitude of a population's exposure to contaminated soil: (1) to estimate or model the amount of exposure that may be occurring, (2) to extrapolate from previously studied communities with similar environmental characteristics, and (3) to conduct a population-based exposure survey. These approaches are not mutually exclusive, and each has inherent uncertainties and difficulties.

We believed that the third method, the population-based survey, was appropriate for Anaconda, because models predicted that significant exposures were occurring in all of the communities surrounding the smelter and because no exposure studies appropriate for extrapolation were available. Our data, particluarly the demonstration that urinary arsenic levels in the town of Anaconda were not significantly different from those in Livingston, contradicted the predictions of some of the exposure models. Although the mean urinary arsenic levels in the town of Anaconda were very slightly greater than those of Livingston, the differences were not significant. Furthermore, the urinary arsenic levels in the town of Opportunity, where soil levels are similar to those in Anaconda, were less than those in Livingston. These results may indicate the importance of factors other than soil arsenic level, like behavior, in determining exposure.

These data do not rule out the possibility that excess arsenic exposure is occurring at soil levels of around 100 ppm. The 95^{th} percentile confidence limits on the biologic measurements are such that statistically it is impossible to say that exposure was not occurring. Numbers of soil samples are limited, and the representativeness of soil sampling cannot be assessed. In addition, urine sampling was performed on only 2 days in all of the communities studied, except Mill Creek. Excess arsenic exposure could have occurred on days we did not sample. Conclusions drawn from our epidemiologic data, however, involve less guessing and extrapolation than do conclusions drawn from

Table 3. Summary statistics for urinary arsenic levels in survey participants (excluding residents of Mill Creek)

Urinary arsenic concentration	Number of participants	Number (%) of non-detects.	Urinary arsenic level at different percentiles 50th	75th	95th
March (ug/l)	222	102 (46)	8.2	16.2	34.7
July (ug/l)	115	34 (30)	15.3	22.9	44.3
With nondetectable urinary arsenic levels assigned a value of 4 ug/l					
March, adjusted for creatinine (ug/g)	222	102 (46)	11.6	22.4	64.2
July, adjusted for creatinine (ug/g)	115	34 (30)	10.8	22.3	68.8
With nondetectable urinary arsenic levels excluded from analysis					
March, adjusted for creatinine (ug/g)	120	---	19.2	33.6	75.2
July, adjusted for creatinine (ug/g)	81	---	21.4	31.8	55.0

ug/l=micrograms per liter
ug/g=micrograms per gram

modeling and extrapolation from other studies. This should be considered when decisions about appropriate remedial actions are made.

Many factors probably contributed to the relatively high urinary arsenic levels in the Mill Creek children. Environmental levels of arsenic are highest in Mill Creek. A larger proportion of the families studied in Mill Creek have dogs and cats coming in and out of their homes than in other communities. These animals may track dust and dirt into the homes, and children could be exposed to additional dirt and dust by playing with their pets. Responses to questions about children's behaviors did not explain our findings.

We hypothesized that childhood exposure to arsenic-contaminated soil would increase in Montana as the weather warmed and children spent more time outdoors. During the July survey, urinary arsenic levels increased above those of March in Anaconda, Opportunity, and Livingston. Contrary to our expectations, the mean urinary arsenic level of the Mill Creek children was higher in March than in July, possibly because of greater exposure to arsenic-contaminated housedust in winter.

Our findings have relevance for other residential sites where remedial actions to eliminate exposure to arsenic in residential soils are being considered. Childhood exposure to soil probably varies with region, socioeconomic status, and other factors, but the lack of demonstrable exposure in children in the town of Anaconda suggests that mean soil arsenic levels of about 100 ppm are not associated with excess exposure in young children. The demonstrated exposure in Mill Creek, however, indicates that higher levels are. Although there are uncertainties involved in using epidemiologic data to assess exposure, in Anaconda these uncertainties are less than those associated with modeling or extrapolation from previously studied populations. Action levels for remedial activities designed to minimize risk from exposure to arsenic-contaminated soil should be based on available epidemiologic data as well as on models.

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REFERENCES

Baker EL, Hayes CG, Landrigan PJ, Handke JL, Leger RT, Housworth WJ, and Harrington JM (1977) A nationwide survey of heavy metal absorption in children living near primary copper, lead, and zinc smelters. Am J Epidemiol 106:261-273

Crecelius EA (1977) Changes in chemical speciation of arsenic after ingestion. Environ Health Perspec 19:147-150

Day JP, Hart M, and Robinson MS (1975) Lead in urban street dust. Nature 253:343-345

Hartwell T, Handy R, Harris B, and Williams S (1984) Heavy metal exposure in populations living around zinc and copper smelters. Report to U.S. Environmental Protection Agency, Contract 8-02-2442.

Kimbrough RD, Falk H, and Stehr P (1984) Health implications of 2,3,7,8-tetrachlorodibenzodioxin (TCDD) contamination of residential soil. J Toxicol Environ Health 14:37-93

Lepow ML, Bruckman L, Rubino RA, Markowitz S, Gillette M, and Kapish J (1974) Role of airborne lead in increased body burden of lead in Hartford children. Environ Health Perspec 7:99-102

Walter SD, Yankel AJ, and von Lindern IH (1980) Age-specific risk factors for lead absorption in children. Arch Environ Health 35:53-57

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