

Personal monitoring of lead and cadmium exposure — a Swedish study with special reference to methodological aspects

by Marie Vahter, DrMedSc,¹ Marika Berglund, MSc,¹ Birger Lind,¹ Lars Jorhem,² Stuart Slorach, PhD,² Lars Friberg, MD¹

VAHTER M, BERGLUND M, LIND B, JORHEM L, SLORACH S, FRIBERG L. Personal monitoring of lead and cadmium exposure — a Swedish study with special reference to methodological aspects. *Scand J Work Environ Health* 1991;17:65-74. Methods for determining personal exposure to lead and cadmium were tested in Stockholm in 1988. Lead and cadmium in breathing-zone air, 24-h duplicate diets, and feces of 15 nonsmoking women (27-46 years of age) were studied. Blood was collected at the beginning of and immediately after the test period (seven consecutive days). An extensive quality assurance program was included. Most technical problems were encountered in the 24-h collection of airborne particles. The pumps were noisy, and the batteries had to be recharged every 6-8 h. The lead and cadmium levels in feces were found to be useful indicators of the total ingested amounts of these metals. Because of the large day-to-day variation in the dietary intake of lead and cadmium, the sampling period for duplicate diets and feces should be at least 5-6 d.

Key terms: air, blood, duplicate diets, dust, exposure, feces, methods, quality control.

Lead (Pb) and cadmium (Cd) may be found in work environments, ambient air, dust, drinking water, food, and tobacco smoke. For both metals the difference between the average human exposure levels and the exposure levels at which the first signs of adverse health effects can be seen is very small. Accurate estimates of human exposure to environmental pollutants are of vital importance for the assessment of the risks these pollutants pose and for the design and implementation of efficient control strategies. The World Health Organization (WHO) and the United Nations Environment Programme (UNEP) are coordinating an international exposure assessment effort — the Human Exposure Assessment Location (HEAL) program (1, 2). Initially, methods for monitoring exposure to lead, cadmium, chlorinated hydrocarbons, and nitrogen dioxide, including methods for quality assurance, were developed and tested on small groups of selected individuals. Measurements of personal exposure to lead and cadmium from air, food, and beverages were carried out on small groups of nonsmoking women in Beijing, Stockholm, Yokohama, and Zagreb. A review of the studies has recently been published by WHO and UNEP (3). Our report gives a detailed evaluation

of the methods used in the determination of human exposure to lead and cadmium in Stockholm.

Material and methods

Study design and sampling

Exposure monitoring of lead and cadmium, involving 15 nonsmoking women, 27-46 years of age, and not occupationally exposed to lead or cadmium, was carried out in February and March of 1988. Personal exposure via air, food, and beverages was measured during seven consecutive 24-h periods. Each period started in the afternoon at 1500. The nonsmoking women working in three departments of the Karolinska Institute in Stockholm were asked to join the study. All but one of 18 women agreed to participate. Before the beginning of the measurements the women were informed about the aims of the study, the sampling procedures to be used, and how to avoid contamination of the samples. Questionnaires concerning personal data, life-style factors, health status, home address, occupation, and so forth were completed by each participant. In order to check that all the samples were collected and labeled properly and that the questionnaires were completed, the study supervisor had daily meetings with the subjects, and any problems were discussed.

Lead and cadmium in blood were determined for the evaluation of the total exposure (4-6). Blood samples (10 ml venous blood) were collected at the beginning of and immediately after the test period (days 1 and 8) in evacuated blood collecting tubes (Venoject,

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VT-100H, Terumo Corporation, Tokyo) containing heparin as an anticoagulant. The blood was transferred to 5-ml polyethylene tubes and stored deep-frozen until the analysis.

The total amount of suspended airborne particulates (24-h samples) in the breathing zone of each subject was sampled during the whole test period of seven consecutive days. Low-volume personal air samplers (T 13350 Casella pump AFC 123, equipped with alternating current adapters) with a flow rate of 2 l/min were used. The Casella pump AFC 123 was chosen from six different personal air-monitoring devices on the Swedish market because of the relatively low noise level, low weight (460 g), the built-in low battery shutdown device, a flow rate at 2 l/min kept within $\pm 5\%$, and a fairly low price. The filter holders were equipped with 37-mm membrane filters (Millipore HAWP 03700) with a 0.45- μm pore size. The pump was carried at all times as the subjects moved around outdoors and indoors. During most of the time spent in one and the same room the pump was connected to an electrical outlet to recharge the batteries. In a test of sampling efficiency in relation to the pore size of the filters, airborne particles were simultaneously collected on four occasions (2 d indoors and 2 d outdoors) with 0.45- and 0.8- μm pore size filters.

For the evaluation of the dietary intake of lead and cadmium, duplicate portions of all foods and beverages, including drinking water, but not certain medicines and chewing gum, consumed during the entire study period were collected as 24-h samples. Duplicate portions of everything ingested during each 24-h period, starting in the afternoon at 1500, were collected in one and the same container and stored deep-frozen until the analysis. Food records were kept by each participant so that the relation between high intakes of lead and/or cadmium and the consumption of certain foods could be studied. The consumption of canned foods was recorded, since it is known that foods packed in lead-soldered cans may contain much more lead than the corresponding fresh foods (7). The subjects were not asked to record the weight of each food item consumed, since it was feared that the extra work and inconvenience involved would influence the food consumption pattern. However, they were asked to record the approximate volume of beverages consumed. In the follow-up questionnaires on the recording of foods, information was sought on foods ingested but not collected as a duplicate portion and any changes in food consumption habits due to the sampling procedure.

In adults the gastrointestinal absorption of lead and cadmium is low, about 5–20 % on the average (8–11). Therefore, the fecal content of lead and cadmium may be used as an indicator of the amounts of lead and cadmium ingested. Provided that there are no other sources of ingested lead and cadmium, fecal lead and cadmium may be used for validating the results of the duplicate diet study. All feces corresponding to

the food and beverages ingested during the entire study period were collected. Since the gastrointestinal transit time varies greatly (12), a colored marker (carmine red, checked for metal content) was ingested at the beginning and at the end of the food sampling period in order to indicate the first and last stools to be collected. The first colored stool, but not the second, was collected. The feces were collected in specially designed metal-free plastic bags, weighed, and stored deep-frozen until the analysis.

Analytical procedures

All utensils were washed with 10 % nitric acid and rinsed several times with deionized water before use. Standards were prepared from stock standards (British Drug Houses, United Kingdom) containing 1000 mg/l of the metals as nitrate salts.

Blood samples were analyzed according to Stoeppler et al (13) and Stoeppler & Brandt (14), with certain modifications (15, 16). An 0.3-ml sample was deproteinized by the addition of 0.5 ml of 0.8 M nitric acid. The concentrations of lead and cadmium were determined with the use of graphite furnace atomic absorption spectrophotometry (GFAAS) with background correction and peak area evaluation (Perkin Elmer models 373 and 5000 Zeeman with HGA—500, autosampler AS—40, recorder 056 and computer Epsom Hx20 or Perkin Elmer 7500). Standard graphite tubes were used for the determination of lead and I'Vov's platform in a pyrolytical graphite tube for the determination of cadmium.

Air filters were digested in 2 ml of concentrated nitric acid/perchloric acid (1:1) at 100°C for 20 min in glass beakers. After dilution to 10 ml with deionized water, the solutions were analyzed by GFAAS with background correction after a further 1:1 dilution with deionized water. Quality-control samples of dust were analyzed with the same method, but the concentrations of lead and cadmium were determined by flame atomic absorption spectrometry with background correction.

The diet samples were thawed and each 24-h sample was thoroughly homogenized in a food blender equipped with a titanium knife. Subsamples were weighed in duplicate into platinum crucibles and, after drying, ashed at 450°C in a time/temperature programmable furnace (Carbolite, Food Ashing, United Kingdom). When free from visible carbon particles, the ash was dissolved in 20 ml of 0.1 M nitric acid (17). Lead and cadmium were determined by GFAAS in a Perkin-Elmer 3030/HGA—500 with a deuterium background correction system, autosampler AS—40 and printer PR—100. All of the determinations were made by the standard addition technique. The energy content of each duplicate diet was determined by standard methods (18).

The frozen feces samples were thawed, dried at 105°C to constant weight, homogenized by grinding in liquid nitrogen with a ring mill (Shatterbox, model

8500, Spex Ind, United States) and freeze-dried (Edwards Modulyo EF4, United States). Duplicates of 2.4 g of the dried sample (corresponding to about 10 g of wet weight) were dry-ashed at 470°C overnight in a time/temperature programmable muffle furnace (Carbolite, Food Ashing). The ash was dissolved in 15 ml of 1 M nitric acid. Empty crucibles treated as those with samples were used as blanks. Standards were made in 1 M nitric acid. Flame atomic absorption spectrophotometry with deuterium background correction was used for the determination of lead and cadmium (19, 20).

The analytical quality control was based on the program developed in the UNEP/WHO biological monitoring project for lead and cadmium (21–23). The analytical performance evaluation involved the analysis of sets of quality-control samples and an evaluation of the results with linear regression analysis (24). In general, 8–12 external quality-control samples, the metal concentrations of which were not known to the analyst, were analyzed together with the monitoring samples. The quality-control samples consisted of spiked bovine blood, spiked air filters, house dust, freeze-dried simulated human diets, and freeze-dried human feces. The preparation of the quality-control samples has been described by Lind et al (25) and Jorhem & Slorach (26). The range of concentrations of lead and cadmium in the quality-control samples was chosen to cover the whole range of concentrations expected to be found in the monitoring samples collected at the four HEAL sites.

Results

As shown in figures 1 and 2, the results of the quality-control analyses (blood, air filters, dust, diets, and feces), carried out together with the analyses of the monitoring samples, were in good agreement with the quality-control reference values. Many of the monitoring samples contained less lead and cadmium than expected, and sometimes less than the quality-control samples. Four quality-control blood samples for lead and cadmium were within the concentration range of the monitoring samples. Two of the quality-control samples were internal quality-control samples, containing 28 µg Pb/l and 0.3 µg Cd/l (not shown in the figures); the analysis gave 29 and 27 µg Pb/l and 0.3 and 0.4 µg Cd/l, respectively.

The quality-control air filters contained 1.0–28 µg Pb/filter, while the air monitoring samples contained 0.04–0.49 µg Pb/filter. Blank filters analyzed together with the monitoring samples showed less than 0.03 µg Pb/filter (detection limit), and the analysis of internal quality-control filters containing 1.6 (SD 0.04) µg Pb/filter gave 1.6 (SD 0.11) µg Pb/filter, indicating an $y = x$ equation also in the low concentration range. The quality-control air filters for cadmium contained 6–110 ng Cd/filter, and only one quality-control sample was within the concentration range of the monitor-

ing samples (1–7 ng Cd/filter), most of which were close to the detection limit of 1 ng Cd/filter.

All eight quality-control diet samples for lead and four quality-control diet samples for cadmium were within the concentration ranges of the collected duplicate diets when the latter were calculated on a dry weight (dw) basis [21–469 µg Pb/kg (dw) and 4.8–118 µg Cd/kg (dw)]. Three quality-control feces samples for lead, and four for cadmium, were within the concentration ranges of the monitoring samples [0.2–3.3 µg Pb/g (dw) and 0.2–0.8 µg Cd/g (dw)].

The concentrations of lead and cadmium in the blood collected from the 15 women are given in table 1. There was no difference in the blood concentrations of lead and cadmium between days 1 and 8.

We calculated the concentrations of lead and cadmium in the breathing-zone air by dividing the amounts of lead and cadmium on the filters used in the personal air samplers by the volume (in cubic meters) of air filtered during the 24-h sampling periods. The data are given in table 2. On the assumption of a daily respiration volume of 13 m³ (moderate physical activity), it can be estimated that, on the average, 838 (SD 186) ng of lead and 10 (SD 2.2) ng of cadmium were inhaled per day.

The test for sampling efficiency in relation to the pore size of the membrane filter showed 46 and 66 ng Pb/m³ with a 0.45-µm pore size and 50 and 66 ng Pb/m³ with a 0.8-µm pore size for the two outdoor test sites. Corresponding results for the two indoor test sites were 30 and 58 ng Pb/m³ with the 0.45-µm pore size and 38 and 52 ng Pb/m³ with the 0.8-µm pore size.

A total of 105 daily duplicate diets was collected, seven by each woman. The average daily amount of food and beverages collected, as well as the content of lead and cadmium in the 24-h diets, are given in table 3. The average energy content of the daily duplicate diets was 7.8 (SD 1.3, range 5.8–9.7) MJ. Figures 3 and 4 show the distribution of the lead and cadmium content for the 105 duplicate diets. Figure 5 shows a typical example of the day-to-day variation in the dietary intake of lead and cadmium. In order to evaluate the number of test days required for making reliable estimates of the daily intake, we calculated the average daily dietary contents of lead and cadmium also for assumed test periods of 2–6 d (table 4).

All of the women reported complete feces collection. A total of 123 stools was collected and analyzed for lead and cadmium. For four of the subjects, the first red feces appeared during the first day after the ingestion of the carmine red, for eight subjects during the second day, for two subjects during the third day, and for one subject during the fifth day. The number of stools between the colored markers varied between 5 and 12. The dry weight to wet weight ratio for the feces was 0.28 on the average (SD 0.04, range 0.19–0.34). The total amounts of lead and cadmium eliminated during the whole sampling period were calcu-

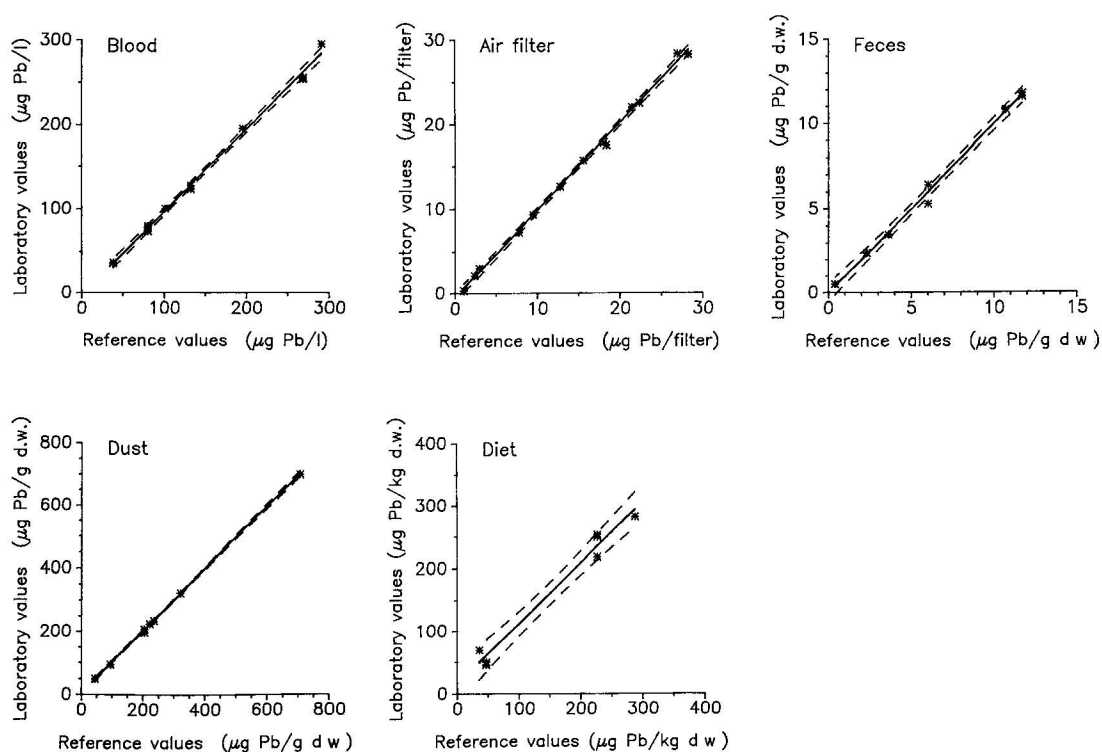


Figure 1. Lead in the quality-control samples (blood, air filter, feces, dust, and diet) analyzed together with the monitoring samples. The 95 % confidence interval is indicated by the broken lines. (dw = dry weight)

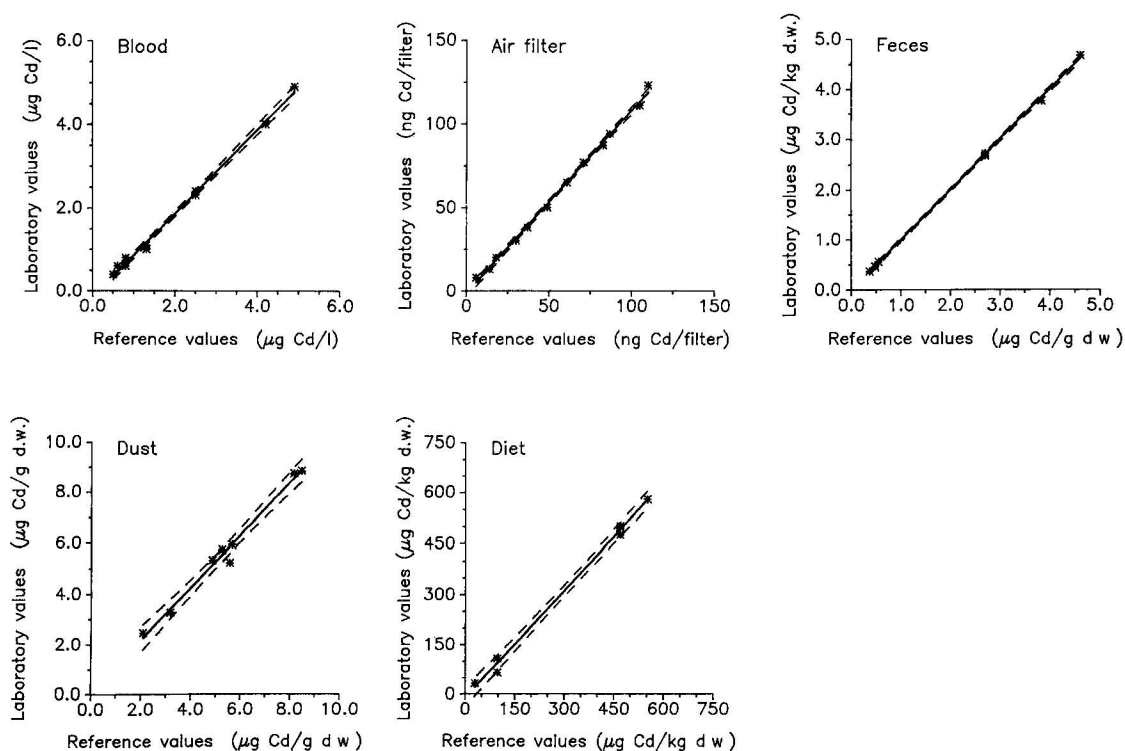


Figure 2. Cadmium in the quality-control samples (blood, air filter, feces, dust, and diet) analyzed together with the monitoring samples. The 95 % confidence interval is indicated by the broken lines. (dw = dry weight)

Table 1. Concentrations of lead (Pb) and cadmium (Cd) in the blood of 15 nonsmoking women.

	Mean	SD	Median	Range
$\mu\text{g Pb/l}$				
Day 1	30	8.1	27	21–44
Day 8	29	8.6	29	15–43
$\mu\text{g Cd/l}$				
Day 1	0.32	0.16	0.33	0.11–0.79
Day 8	0.32	0.17	0.30	0.13–0.86

Table 2. One-week average air concentrations of lead (Pb) and cadmium (Cd) in the breathing zone (personal monitoring) of 15 nonsmoking women.

	Mean	SD	Median	Range	Range ^a
ng Pb/m^3	64	14	66	42–94	15–169
ng Cd/m^3	0.8	0.16	0.8	0.5–1.1	0.4–2.6

^a Range of all 24-h samples.

lated and compared with the metal contents of the duplicate diets collected during the 7 d. The average fecal elimination as a percentage of the dietary intake was 104 (range 72–158) % for lead and about 113 (range 74–148) % for cadmium.

We calculated the average daily stool mass and the daily fecal elimination of lead and cadmium for each woman by dividing the total amounts of feces and fecal

Table 3. One-week average daily intake of food and beverages and dietary intake of lead (Pb) and cadmium (Cd) (duplicate diet contents) for the 15 nonsmoking women.

	Mean	SD	Median	Range
g diet/d				
Wet weight	2342	341	2270	1563–3033
Dry weight	393	52	391	307–477
$\mu\text{g Pb/d}$	26	7.9	26	13–40
$\mu\text{g Cd/d}$	8.5	2.1	8.1	5.7–14

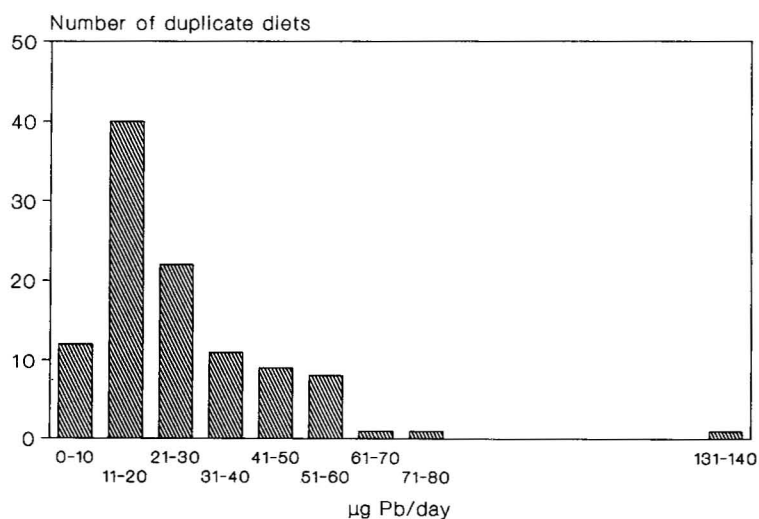


Figure 3. The content of lead in the 105 daily duplicate diets.

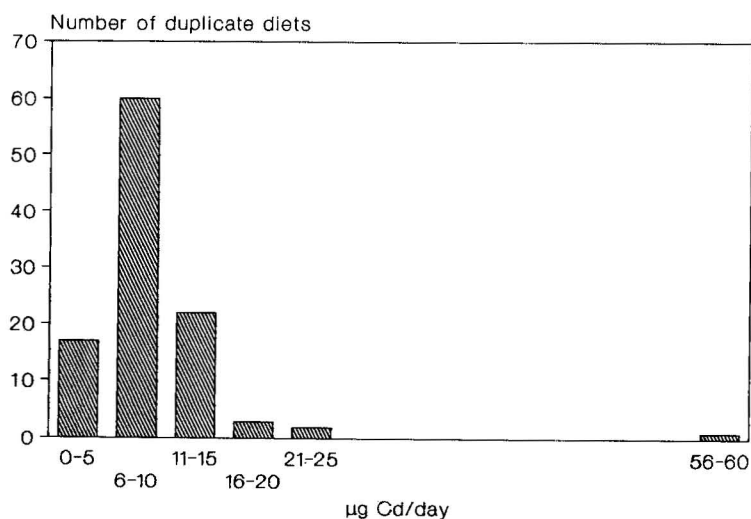


Figure 4. The content of cadmium in the 105 daily duplicate diets.

Table 4. Average daily dietary intake of lead and cadmium in relation to the number of days studied.

Number of days	% of 7-d average					
	Lead			Cadmium		
	Mean	SD	Range	Mean	SD	Range
2	77	27	28–133	81	19	52–118
3	92	31	28–149	88	16	48–112
4	100	23	58–150	103	19	46–129
5	98	19	54–131	99	18	44–121
6	104	8	84–115	102	6	89–112
7	100	.	.	100	.	.

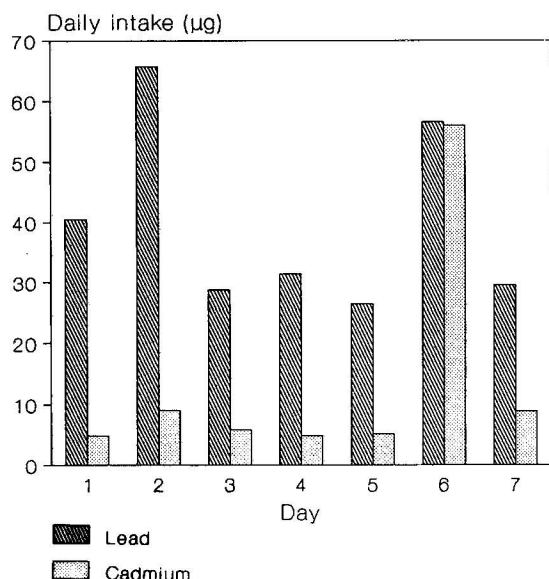


Figure 5. Examples of the day-to-day variation in the dietary intake of lead and cadmium by one subject.

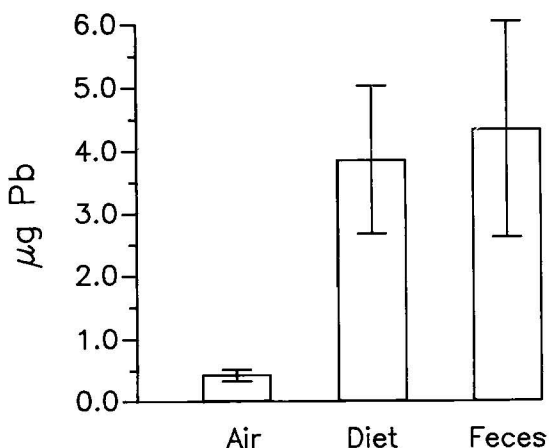


Figure 6. Mean daily absorption of lead estimated from the breathing-zone air levels (on the assumption of 50 % absorption in the respiratory tract), duplicate diets, and feces (on the assumption of a gastrointestinal absorption of 15 %) of all the subjects. The standard deviations are indicated by the vertical bars.

metal contents during days 3 to 8 of the test period (for one subject days 5 to 10) by 6 (table 5). In order to evaluate the number of study days required for making reliable estimates of the fecal elimination, we calculated the average daily stool mass and average daily fecal elimination of lead in relation to the number of days studied (table 6). Five days were required for obtaining good estimates of both daily stool mass and daily fecal elimination of lead on an individual level.

Table 5. One-week average daily stool mass and fecal elimination of lead (Pb) and cadmium (Cd) from 15 nonsmoking women.

	Mean	SD	Median	Range
g feces/d				
Wet weight	88	45	78	51–232
Dry weight	24	7.5	22	15–44
µg Pb/d	24	9.7	23	10–41
µg Cd/d	8.9	2.0	8.8	5.5–12

Table 6. Average daily stool mass of 15 nonsmoking women and average daily fecal elimination of lead in relation to the number of days studied, starting from day 3 after the ingestion of the marker (for one subject day 5). Figures represent the percentage of average daily fecal elimination of lead during 6 d of feces collection.

Number of days studied	Stool mass (% of 6-d mean)			Fecal lead elimination (% of 6-d mean)		
	Mean	SD	Range	Mean	SD	Range
2 (days 3–4)	80	46	0–141	76	51	0–175
3 (days 3–5)	83	33	7–139	80	38	8–149
4 (days 3–6)	88	31	22–132	86	34	23–130
5 (days 3–7)	94	12	70–107	90	13	71–115
6 (days 3–8)	100	.	.	100	.	.

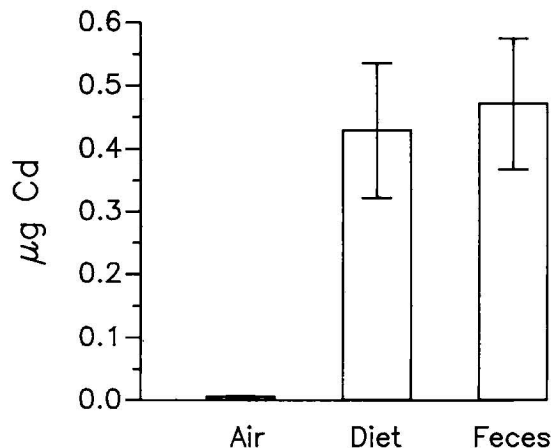


Figure 7. Mean daily absorption of cadmium estimated from the breathing-zone air levels (assuming 50 % absorption in the respiratory tract), duplicate diets, and feces (on the assumption of a gastrointestinal absorption of 5 %) of all the subjects. The standard deviations are indicated by the vertical bars.

The data for the fecal elimination of cadmium were very similar to those for lead.

The estimated average daily absorption of lead and cadmium, based on the amounts in air, duplicate diets, and feces, is shown in figures 6 and 7.

Discussion

The main objective of the present study was to test exposure monitoring methodologies, and several different sampling techniques were used. The fact that all the women worked at the same place facilitated our evaluation of the problems encountered in the sampling, handling, and storage of the different samples collected. The importance of continuous encouragement throughout the study was emphasized by the subjects. The main sampling problems were associated with the 24-h monitoring of airborne lead and cadmium. The commercially available personal air monitors are designed for occupational exposure monitoring studies with 8-h exposure periods, and it was necessary to recharge the batteries every 6–8 h. Therefore, the pumps had to be connected to an electrical outlet most of the time when the subjects were at home or sitting in their offices. In addition the noise of the operating pumps gave rise to some complaints. Equipment suitable for 24-h personal sampling of the general population needs to be developed. With filters of a larger pore size, giving rise to lower air resistance, the pumps were found to be less noisy. The determination of lead in simultaneously collected samples, with 0.45- and 0.8- μ m pore size filters, showed no significant difference in collection efficiency over a 24-h period.

The large day-to-day variation observed in the dietary intakes of lead and cadmium indicates that certain occasionally consumed foodstuffs were responsible for a large part of the total dietary intake of these metals. This fact has to be considered when the method and the number of days and persons to be studied are chosen. The duplicate diet method gives a more precise estimate of the dietary intake than estimates based on the analysis of individual foodstuffs combined with food consumption data. However, it has been reported that the collection of duplicate diets may decrease the food intake and change the food consumption pattern (27). In our study, there was no indication of markedly decreased food consumption due to the sampling. The women indicated only a minor decrease in the amount of food consumed due to the sampling (eg, half a fruit or cake instead of a whole one). One woman had her lunch less frequently at a restaurant. In addition, the amounts of food and beverages ingested, 393 g(dw)/d, on the average, did not indicate a low food intake. Schütz (28) reported an average daily food intake of 313 g(dw) in a study of 33 duplicate diets from 16 Swedish women 68–69 years of age.

According to the follow-up questionnaires on the food records, the women had collected duplicate portions of essentially everything ingested, except chewing gum and certain medicines. Several of the women had more lead and/or cadmium in their feces than in the corresponding duplicate diets, and this result may indicate an error in the duplicate diet collection. However, there may be other explanations for the high fecal elimination of lead and cadmium. Part of these metals in feces originates from the fecal excretion of endogenous lead and cadmium. Chamberlain (8) has estimated the daily clearance of lead in feces to correspond to the amount of lead in 0.05 kg of blood. Thus, in our study, the average fecal excretion of endogenous lead would be about 1.4 μ g Pb/d (ie, about 6 % of the average daily fecal elimination). The fecal excretion of endogenous cadmium is about the same as the urinary excretion (29) [ie, about 0.2–0.3 μ g/d for nonsmoking Swedish women 30–50 years of age (30)].

A possible reason for the high fecal recoveries after adjustment for the excretion of endogenous lead and cadmium may be that the feces collected did not correspond exactly to the food collected during the study period. Some of the first feces samples collected (with the red marker) contained amounts of lead and/or cadmium greatly exceeding those in the corresponding first day's duplicate diets. Since the duplicate diet collection started at 1500 in the afternoon, at which time the carmine marker was ingested, a high dietary lead and/or cadmium intake earlier that day may have influenced the first colored feces samples. If the first feces samples with metal contents greatly exceeding (2–9 times) those of the corresponding first duplicate diets were excluded, the average fecal elimination adjusted for endogenous excretion, as a percentage of the dietary content, would be 85 (range 59–121) % for lead and 97 (range 66–144) % for cadmium. These figures are consistent with the reported 10–20 % average gastrointestinal absorption of lead in adults (8, 9, 11) and 5 % average gastrointestinal absorption of cadmium (10).

Another possible reason for the high fecal content of the metals in relation to the dietary content may be sources of peroral lead and cadmium other than the diet. It can be estimated that inhaled particles cleared from the lungs and swallowed contributed very little to the fecal lead and cadmium. Even if as much as 90 % of the inhaled lead and cadmium were cleared from the lungs and swallowed, the amount would not contribute more than 0.7 μ g of lead and 0.009 μ g of cadmium per day to the feces. We did not investigate other sources of peroral lead and cadmium.

As has already been mentioned, fecal lead and cadmium may be used as an indicator of the total ingested amounts of these metals. Feces collection is considerably cheaper than the duplicate diet technique, and in many cases less inconvenient for the subjects involved. Furthermore, feces collection does not influence food

intake and the food consumption pattern. Because of the large day-to-day variations in the dietary intakes of lead and cadmium and variations in the gastrointestinal transit time, the feces sampling period should be as long as possible. In our study, 5 d were required for a reasonably good estimate of the daily fecal elimination. In order that the seasonal variations in metal exposure can be determined, the feces collection must be repeated.

The main problem with fecal lead and cadmium as indicators of exposure is the variation in gastrointestinal absorption between individuals, and possibly also over time for one and the same individual. The gastrointestinal absorption of lead and cadmium is influenced by the nutritional status of the subject, the presence of food in the stomach, and the presence of other metals in the diet (8, 10, 11). Iron deficiency, which is common among fertile women (31), may increase the gastrointestinal absorption of lead and cadmium (32, 33).

The small number of selected subjects studied does not allow an extrapolation of the results to the general population. However, according to the information given in the questionnaires, there is no reason to believe that the selected women differed to any significant extent from nonsmoking women in the general population with regard to their exposure to lead and cadmium. Furthermore, the average blood cadmium level (0.3 $\mu\text{g/l}$) is similar to that reported for nonsmoking women in a previous study (21), and the average blood lead level (30 $\mu\text{g Pb/l}$) is consistent with that (33 $\mu\text{g Pb/l}$) recently reported for children and teenagers in southern Sweden (34, 35). However, the average blood lead level was lower than that (64 $\mu\text{g Pb/l}$, $N=45$) found for nonsmoking women in 1980 (21) and in 1984 (42 $\mu\text{g Pb/l}$, $N=18$) (36). In all these studies blood lead was analyzed with the same procedure with adequate quality control. The decreasing blood lead levels probably reflect a true decrease in the general population's exposure to lead. Legislative measures taken in Sweden in 1981 lowered the maximum permitted level of lead in gasoline from 0.4 to 0.15 g/l, and in 1987 unleaded gasoline was introduced. In 1988 about 30 % of the gasoline used was unleaded. A similar trend of decreasing blood lead levels in parallel to the decreasing lead levels in gasoline has been reported for children in southern Sweden (35, 37). The gradual replacement of food cans with lead-soldered side seams by welded cans or other types of packages (38) may also have contributed to lower blood lead levels.

The levels of lead and cadmium in the breathing-zone air (personal monitoring) were very low, 64 ng Pb/m^3 and 0.8 ng Cd/m^3 . Considerably higher air metal concentrations have been reported for Stockholm in studies using stationary air monitors. In 1987–1988 monthly average air lead levels of 0.4 and 0.7 $\mu\text{g/m}^3$ were found in areas of Stockholm with heavy traffic (39). As to cadmium in air, an annual

mean concentration of 0.9 ng/ m^3 has been reported for rural areas in Sweden and weekly mean concentrations of about 5 ng/ m^3 for Stockholm (40). The most likely explanation for the low air metal levels in our study is that the women under study spent about 90 % of their time indoors. This possibility shows the necessity of personal sampling for the estimation of human exposure to airborne pollutants. On the average, airborne cadmium contributed only about 1 % to the total uptake (absorbed amounts) of cadmium. For lead, the contribution from air was about 10–15 %. In the summer, when people normally spend more of their time outdoors, the contribution from air may be higher.

The diet was found to be the major source of exposure to both lead (average 26 $\mu\text{g Pb/d}$) and cadmium (average 8.5 $\mu\text{g Cd/d}$). Similar daily dietary intakes of lead (27 $\mu\text{g Pb/d}$) and cadmium (10 $\mu\text{g/d}$) were reported in 1983 by Slorach et al (41) on the basis of the analysis of seven prepared daily diets typical for a Swedish adult male. However, the prepared diets did not include canned food or wine, which often contains relatively high levels of lead. In our study a high daily intake of lead was, in many cases, associated with the consumption of these foods. The prepared diets did not include shellfish. In our study the consumption of hand-peeled shrimp, which contain remnants of the hepatopancreas, was associated with a high daily intake of cadmium (18). Further studies are needed to evaluate possible changes in the exposure to lead and cadmium via the diet.

This pilot study made it possible to identify the main problems in the collection and analysis of different types of exposure monitoring samples and to identify major routes of exposure. In a full-scale study, on a representative sample of the general population, it would probably not be essential to carry out personal air monitoring of cadmium. Personal monitoring of exposure to airborne lead might be useful, especially in areas with heavy traffic during seasons when people spend more time outdoors. For many of the women there were large day-to-day variations in the dietary intakes of lead and cadmium. Therefore the sampling periods should be as long as possible and preferably repeated. Identification of the food items responsible for the high peaks in the intake would make it possible to decrease the exposure considerably.

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