Cent Eur J Publ Health 2005; 13 (1): 11–19

CADMIUM EXPOSURE PATHWAYS IN THE CZECH URBAN POPULATION

Puklová V., Batáriová A., Černá M., Kotlík B., Kratzer K., Melicherčík J., Ruprich J., Řehůřková I., Spěváčková V.
National Institute of Public Health, Prague, Czech Republic

Devoted to the 80th anniversary of the National Institute of Public Health foundation.

SUMMARY

The article describes the exposure pathways of cadmium in the Czech urban population. The data on Cd concentrations originated from the Environmental Health Monitoring System, which has been realized in 30 cities since 1994. The data on cadmium content in particular exposure pathways – diet, drinking water, ambient air and soil – were processed for the period 1994–2003. The estimate of the daily dietary intake for an average adult population amounted to 11–19 µg/d, i.e. 0.17–0.30 µg/kg bw/d, which represents 17%–30% of the PTWI (provisional tolerable weekly intake). The contribution from drinking water to the oral exposure is low; on average 0.5 µg/d. Potential exposure to airborne Cd was estimated at about 0.02 µg/d. The additional Cd intake from urban soil ingestion probable in small children was found to be insignificant based on Cd concentrations in the soil of kindergarten playgrounds.

Biomonitoring outputs characterize the recent and life-long cadmium burden of the Czech population from general environment. In 1994–2003, the median blood Cd levels ranged in the interval 0.9–0.4 µg/l blood, in smokers being more than double that in non-smokers. Blood Cd levels detected indicate slightly decreasing trend as well as urine Cd levels (range of median values 0.44–0.28 µg/g creatinine). Since 1996 the levels in children have been found in more than 50% cases below the detection limit of the methods used.

The estimated total cadmium intake in the Czech urban population does not signalize any increased risk of health impairment considering non-carcinogenic effects.

Key words: cadmium, pathways of exposure, exposure estimate, biomonitoring

Address for correspondence: V. Puklová, National Institute of Public Health, Centre of Environmental Health, Šrobárova 48, 100 42, Prague 10, Czech Republic.
E-mail: puklova@szu.cz

INTRODUCTION

Average Background Intake

Humans are exposed to various doses of cadmium depending on the pathway of exposure, dose amount and the exposure duration. For the general population the dominant pathway is ingestion, excepting the smoking habit. In professional exposure the respiratory tract is the most important way of entry (1). Human dietary exposure has been described in the recent opinion published by EFSA (2). Cadmium exposure intake via food commodities is of public health concern, as long-term exposure to cadmium gives rise to accumulation of cadmium in organism. Daily cadmium intake with food of 0.14–0.26 mg per day for more than 50 years, or a cumulative intake of > 2000 mg cadmium may result in below described adverse effects, such as renal tubular dysfunction (3). Drinking water contains very low concentrations of cadmium in non-polluted areas, usually in the range of 0.01–1 µg/l (4). Therefore, the share of drinking water in the oral intake of Cd is minor in general. An increased intake from drinking water may be caused by release of cadmium from galvanized piping, fittings, faucets or heaters. The cadmium content in drinking water can be higher in regions supplied with soft water of a low pH that is aggressive against the piping materials.

At present, for inhalatory exposure in cities and in the vicinity of traffic lanes the greatest Cd source represents fuel and oil combustion, and secondarily airborne particulate matter. In the ambient air most of the cadmium is bound to the respirable fraction of particulate matter. In the urban environment the daily inhalatory exposure to cadmium should not exceed 0.2 µg (5). Deposition of Cd in the lungs, which varies between 10 and 50%, depends on the size distribution of airborne particulate matter. A significant factor influencing the cadmium intake is the smoking habit. Depending on the origin of the tobacco, cigarettes produced in Europe and North America contain 0.5 to 2 µg Cd per g (dry weight). Bláha et al. (6) investigated the Cd content in the cigarettes sold in 1980s in the former Czechoslovakia; it amounted to 0.7–1.97 µg per cigarette. According to (6), 30–70% of the Cd content was released by smoking; that represents the theoretical Cd amount that could be inhaled. Dermal exposure is generally not regarded to be of significance (7, cited in 8).

Toxicity and Adverse Effects

Cadmium has an exceedingly long biological half-life (15–30 years) resulting in its great capacity to accumulate in the organism. Critical target organs in long-term exposure to low concentrations of cadmium are the liver and namely the kidneys (kidney cortex) where 30–60% of ingested Cd is deposited. The higher exposure to Cd may result in renal tubular dysfunction with defective re-absorption, e.g. of proteins and amino acids manifested by proteinuria (3). Chronic renal effects have been observed not only in certain professions but also in the general population (3). Another effect of cadmium accumulation in the organism is a defect in calcium metabolism and the appearance of kidney calculi, which in combination with e.g. nutritional deficiency leads to the development of osteomalacia and osteoporosis. Experimental data as well as data from the surveys (9, cited in 8) point to a possible relation between exposure to cadmium and hypertension, a risk factor of cardiovascular diseases. From the point of view of carcinogenic properties, the IARC classifies cadmium and its compounds as a class 1 human carcinogen, US EPA considers it to be a probable human carcinogen in group B1, as based on the limited evidence of increased lung cancer in humans and on the sufficient evidence in experimental animals. Quantitative estimate of carcinogenic risk from oral exposure was not made due to lack of evidentiary data.

Aim of the Study

The aim of the presented study was to make an estimate of the exposure to cadmium in the Czech urban population using relevant data on cadmium concentrations in various components of the environment such as foodstuffs, drinking water and airborne particulate matter. The data come from an integrated Environmental Health Monitoring System that includes the systematic collection of data on environmental pollutants, population exposure estimates as well as health outcomes and risks assessments. Within the framework of the study the estimates of possible additional cadmium intake from unintentional soil ingestion in preschool children has also been included. An integral part of the cadmium burden estimate in the Czech Republic is the information on Cd levels in human body fluids.

MATERIAL AND METHODS

For the estimation of cadmium population exposure the generally used approach was applied assessing the possible pathways of exposure and their contribution to the total intake. More sophisticated methods, like a probabilistic exposure estimate, would admittedly provide more precise risk assessment, nevertheless such principle is out of the scope of presented study. Cadmium concentrations in various environmental component parts have been followed up in the framework of Environmental Health (EH) Monitoring System, set by a respective governmental resolution (10). It has been realized within eight projects in 30 participant cities and in 2 associated ones since 1994. For the purpose of this study, the data on airborne cadmium from another 12 cities were included. Data come from the period 1994–2003.

Besides a certain number of drinking water samplings, no systematic data are available on levels of cadmium in the rural environment with all its specific traits (individual sources of drinking water, modes of heating, partial home production of foodstuffs, etc.). Therefore, the estimate of cadmium burden does not implicate the rural population.

Sampling

The estimate of the cadmium population intake from food is based on the hypothesis that all food is provided from the community distribution network. The cadmium concentrations in foodstuffs were monitored in 12 cities within the EH Monitoring System. In the first period of the program (1994–1998), the total of 160 most frequently consumed foodstuffs had been sampled and mixed resulting in 46 composite samples from each of 12 cities. The food consumption was derived from the consumption survey performed in 1991 (11). In the second period of monitoring (1999–2003), the sampling mode was changed based on knowledge of statistical insignificance of Cd content in the commercially available foodstuffs from particular cities.

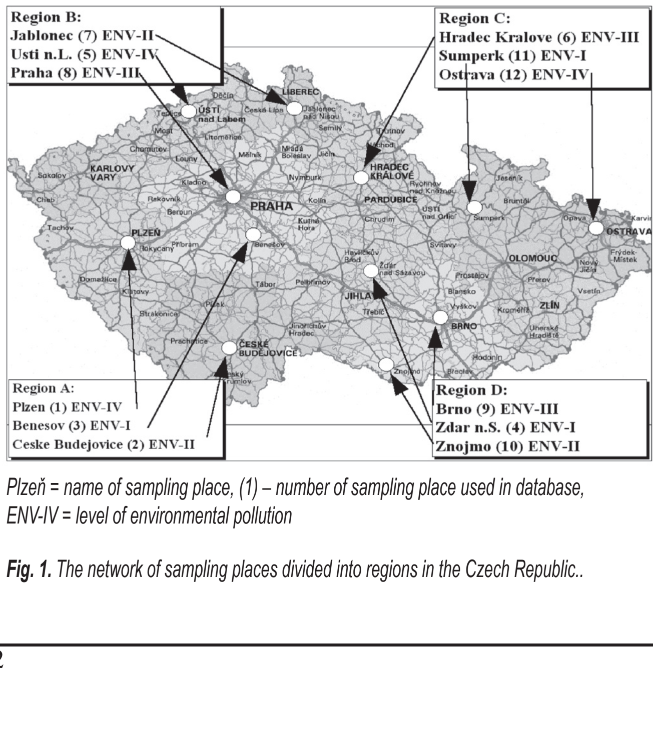
The number of analyzed food commodities increased up to 195. They were combined to 108 composite samples. The samples were taken in identical 12 cities, but for analyses they were mixed to 4 regional samples A–D (Fig. 1), thereby 432 composite samples were made. The average food consumption for the second period was estimated from the survey performed in 1994 (12). In both periods, samplings were carried out in five sampling time intervals over the year taking into consideration the seasonal character of the sale regarding certain foodstuffs.

Data on the cadmium content in drinking water in the public water mains of cities under monitoring come from the period 1994 through 2003. The selection of sampling points was made to meet the conditions of randomized selection and of stable sites characterizing critical points in the water supply network. The methodology of sampling was based on the respective ISO standards.

The scope of cadmium concentrations monitoring in the ambient air gradually dropped off from 120 sampling points in 44 cities at the beginning of the 1990s to 69 points in 38 cities in 2003. The number of sampling sites in a city ranged from 1 up to 10. Samples were taken in the form of 14-day summation samples of airborne particulate matter. There are no systematic data available on cadmium concentrations in the indoor environment so far. The inhalatory exposure scenario is therefore "conservative", i.e. it is assumed that the indoor concentrations (non-smokers) are equal to those in the outdoor environment.

For the purpose of estimate the potential additional exposure in children, the data on Cd soil concentrations obtained on playgrounds (out of sandpits) in a total of 117 kindergartens in 5 cities differing in size and pollution level were used. Soil samples were taken to the depth of 5–10 cm from five sampling points. Chemical analyses were carried out after homogenizing to a mixed sample of each playground.

The exposure factors applied for exposure estimation are presented in Table 1.



Plzeň = name of sampling place, (1) – number of sampling place used in database, ENV-IV = level of environmental pollution

***Fig. 1.** The network of sampling places divided into regions in the Czech Republic..*

Table 1. Exposure factors

Exposure factor	Value used	Ref.
Body weight (integral of lifetime weight)	64 kg	11
Ingested drinking water	1 l/d	14
Inhaled air	20 m^3/d	5
Ingested soil by children	200 mg/d	15
Body weight – children	15 kg	16

Table 2. Limits of quantification/detection

Medium	Limit of quantification/detection
Foodstuffs	0.1–2.0 µg/kg
Drinking water	≤1 µg/l *
Airborne particulate matter	0.0001–0.003 µg/m^3
Soil (dry weight)	0.3 mg/kg
Blood	0.3 µg/l *
Urine	0.2 µg/l *
Hair	2.5 µg/kg (0.5 g analyzed) *

** In human biomonitoring and drinking water monitoring the detection limit is used due to the majority of analyses being under the limit of quantification*

The blood and urine cadmium levels are the most often used biomarkers for assessment the total cadmium burden of humans regardless of the exposure pathway. While the blood cadmium level foremost expresses the current overall exposure, the urine Cd level reflects the life-long load of the organism with this element with its accumulation in the kidney cortex as its target organ. The biomonitoring data from Environmental Health Monitoring System were embraced for a comprehensive view of the Czech population burden with cadmium. Since 1994, a regular follow-up of blood and urine Cd levels in adult blood donors and school children has been running in 4 cities. The adults are 20 to 55 years of age numbering 100 subjects per city annually; school children are 8–10 years of age numbering 100 subjects per city at one- to two-year intervals. For the blood sampling, commercially available polypropylene heparinized monovettes for trace element analysis (Sarstedt) were used.

ANALYSES, QA/QC

Analyses of food samples were preceded by culinary treatment the procedure being established for each commodity on the basis of a questionnaire survey of current ways of cooking preparation. In exposure calculations a correction factor for the culinary processing of foodstuffs is included, which expresses the change in mass of the samples by culinary processing (13).

Cadmium was analyzed after microwave mineralization of samples (except for water samples which were only stabilized with 1% HNO_3), with the atomic absorption spectrometric techniques (FAAS, ETAAS, HGAAS) or by optical emission spectrometry with induction coupled plasma (OES ICP). Soil samples were analyzed by X-ray spectrometry.

Limits of quantification of the methods used are presented in Table 2. In every case there are applied chemicals of high purity (Suprapur, Analpur) and demineralized water (Millipore).

The accuracy of results has been verified with the aid of certified and/or control materials (RM, CRM). All laboratories participate in interlaboratory comparison tests on a national as well as international scale. Most laboratories are accredited at the Czech Institute for Accreditation.

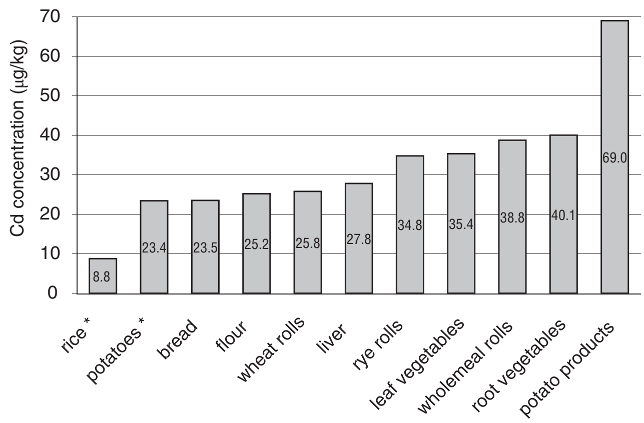
RESULTS AND DISCUSSION

Cadmium Concentration Levels in Particular Exposure Sources

Concentration in Foodstuffs

Within the whole country, the concentrations of cadmium in commercially sold foodstuffs did not differ statistically among 12 cities that were originally selected for sampling according to the different quality of the environment (17). All the commodities were handled according to the habits of Czech customers and underwent a common cooking treatment (peeling, stewing, boiling, roasting, etc.) based on questionnaire surveys (11–13). The data presented come from the monitoring period 1999–2003 due to methodology changes in the course of monitoring described in "Material and Methods".

Cd concentrations in meat ranged in the interval 0.3–2 µg/kg with a few higher levels in hen and rabbit meat (3–5 µg/kg). Fish meat contained 1–3 µg/kg, even less in freshwater fish. However, smoked fish contained much more Cd (30–70 µg/kg). The representative Cd content in fruit is 3 µg/kg with about twice higher levels in berry fruit. Plant-based foodstuffs contain higher Cd concentrations. Both root and leaf vegetables contain similar Cd concentrations, 20–60 µg/kg. Values of flour Cd ranged in interval 20–30 µg/kg, similar concentrations were found in bread. This concentration range is representative also for potatoes. Rye and wholemeal rolls had Cd content in the range of 30–40 µg/kg, wheat rolls containing about two thirds of those levels. Liver cadmium levels were found not to be anyhow excessive, amounting to 30 µg/kg. The average cadmium concentrations in selected food commodities that represent important exposure sources are presented in Fig. 2.



** average Cd concentrations in rice and potatoes from the period 1994–2003*

***Fig. 2.** Average cadmium concentrations in selected composite food samples in the period 1999–2003.*

Table 3. Cadmium concentrations (μg/l) in drinking water from water supply networks in the total of 32 cities, 1994–2003

	n	Min–Max	Arithmetic mean	Geometric mean	Median	90th percentile
Water supply networks in the monitored cities	4,173	<1.0–11.0	0.07–1.70	0.04–0.59	0.05–1.00	0.10–5.00

Table 4. Airborne cadmium concentrations (μg/m³) in the total of 40 cities, 1994–2003

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Arithmetic mean	2.1E-03	2.2E-03	2.4E-03	1.6E-03	1.7E-03	1.4E-03	1.2E-03	1.2E-03	1.1E-03	1.5E-03
Geometric mean	5.6E-04	4.0E-04	6.8E-04	7.7E-04	6.7E-04	6.6E-04	5.8E-04	6.0E-04	5.9E-04	6.0E-04
Median	6.7E-04	3.7E-04	6.5E-04	7.2E-04	5.9E-04	6.5E-04	5.2E-04	5.2E-04	5.5E-04	5.0E-04
Max. annual mean	7.1E-03	4.8E-03	4.9E-03	4.4E-03	4.6E-03	4.7E-03	4.6E-03	4.5E-03	4.7E-03	4.7E-03

Concentration in Drinking Water

Drinking water from the urban public supply network contains very small amounts of cadmium. Cadmium concentrations in water supply networks in the monitored cities (3.3 mil. inhabitants) ranged between the values below 1 μg/l to 5 μg/l in the years 1994 through 2003 (n = 4,173), with five isolated findings up to 11 μg/l. Since no samples taken at waterworks outlets (n = 539) exceeded the limit value, the source of cadmium and the reason for the excess findings at consumer probably consists in a combination of inappropriate material at the end distribution point and longer stagnation of the water in the piping.

The median values of Cd concentration over the period 1994–2003 in water from the individual urban water supply networks were in the range of 0.05 to 0.5 μg/l. In cases of determinations falling below the limit of quantification, one-half of these limits were assumed for calculations. In each city under monitoring the proportion of findings below the limit of quantification (i.e. below 1 μg/l) was at least 50%. From the total number of drinking water samples from all of the cities, 75% fell below the value of the limit of quantification in the period 1994–2003. Only in five water samplings (0.1%) did the Cd content exceed the maximum limit value (5 μg/l) set in Decree on Drinking Water Quality No. 376/2000 Dig. The range of Cd concentrations in drinking water from the water supply networks of 32 cities is presented in Table 3.

The findings of drinking water cadmium concentrations in the period 1994–2003 are in agreement with those from the 1980s when out of 2,628 results of Cd determinations only 2 isolated findings exceeded 10 μg/l, 1,945 findings (i.e. 74%) being below the 1 μg/l limit.

As regards the cadmium content in drinking water from wells which supply about 14% of the population in the Czech Republic, more consistent information is available about the public and commercial ones. From the cadmium content survey performed in the 1990s (n = 985) resulted that 90% of cases were below the limit of quantification. A half of the findings over the limit of quantification did not exceed the value of 1 μg/l. The limit value of 5 μg/l was exceeded in 1% of the samplings. Based on recent information it is not possible to rule out a singular cadmium contamination of a well of the order of micrograms per liter. However, a lasting general exceeding of the limit value is not probable.

Concentration in Urban Air

In the first half of the 1990s, high annual mean concentrations of cadmium in particulate matter up to tens of ng/m³ have been detected. In the period 1994–2003, the mean annual concentrations ranged from values below the detection limit (in Hodonín, 2002) up to 0.02 μg/m³ (AVG) and 0.007 μg/m³ (GEOM) (in Ostrava, 1994). In most urban localities the annual Cd concentrations were found to be below 0.003 μg/m³. Long-term mean concentrations of airborne cadmium air are close to lower end of the 0.003–0.05 μg/m³ interval usually found in urban ambient air (3).

Higher polluted city is Ostrava (steel industry, coking plants) and Příbram (smelting plants) where the mean annual values lie close to the limit. The concentration time trends can be considered as stable at most cities, concentrations varying around relatively low values or decreasing moderately. The inter-annual course of the mean airborne cadmium concentrations in selected cities, and the weighted mean of Cd concentration (potential exposure) in a total of 40 monitored cities (over 3.5 mil. inhabitants total) are presented in Fig. 3. In Table 4, the concentration characteristics of Cd in urban air are described.

Concentration in Soil

Results of Cd concentration samplings in the top layer of soil in kindergartens (n = 117) in five cities were in the range of 0.3 mg/kg to 1.32 mg/kg. Statistical characteristics of Cd concentrations in the soil of kindergartens are presented in Table 5. The draft limit for Cd content in uncontaminated soil included in the amendment of the Decree of the Czech Ministry of Health amounting to 0.3 mg/kg was exceeded in the large majority of kindergartens. There have not been found any significant differences between

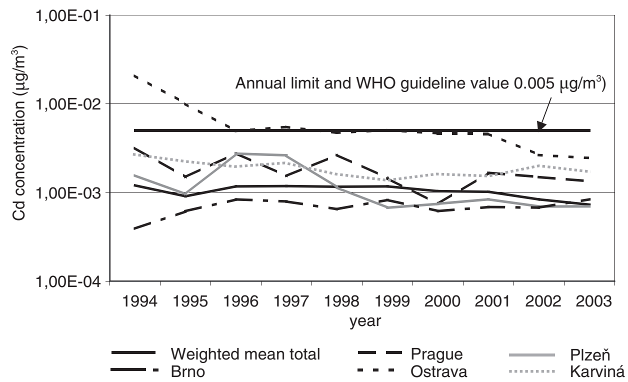


Fig. 3. Trend in airborne cadmium mean concentrations in selected cities, the weighted mean of Cd concentration (potential exposure) in a total of 40 monitored cities.

Table 5. Cadmium concentrations (mg/kg) in the soil of kindergartens in 5 cities, 2001-2002

	Number of kindergartens	Min	Max	Median	Aritmetic mean	Standard deviation
Hradec Králové	27	0.15	0.61	0.40	0.38	0.11
Kroměříž	10	0.41	1.18	0.50	0.53	0.24
Klatovy	10	0.40	0.71	0.48	0.51	0.10
Olomouc	45	< 0.30	0.66	0.41	0.39	0.12
Karviná	25	0.40	1.32	0.61	0.68	0.24

the group of kindergartens situated in industrial areas and the group in areas of the usual "background" urban environment. Likewise, there was found no relation between the magnitude of Cd pollution and detailed localization (downtown or suburbs, vicinity of a heavy-traffic lane).

Estimate of the Total Intake

Oral Intake

At its fifty-fifth meeting, the JECFA evaluated the dietary intake of cadmium using data from a number of countries. Estimates of the mean national intake of cadmium ranged from 0.7–6.3 µg/kg bw/week. Mean dietary intakes, derived from GEMS/Food regional diets (average per capita food consumption based on food balance sheets) and average concentrations of cadmium in these regions, range from 2.8–4.2 µg/kg bw/week. For some individuals, the estimated total intake of cadmium might exceed the PTWI of 7 µg/kg bw because total food consumption for high consumers is estimated to be about twice the mean.

Regarding the major dietary sources of cadmium, the following foods contributed 10% or more to the PTWI in at least one of the GEMS/Food regions: rice, wheat, starchy roots/tubers, and mollusks. Vegetables (excluding leafy vegetables) contribute > 5% to the PTWI in two regions. In a recent SCOOP report (18), thirteen Member States of the EU submitted data based on some of the 16 food categories, relevant for the estimation of cadmium intake. The resulting mean intake was around 100 µg/week (range 2.7–176 µg/week) or 1.6 µg/kg bw for a 60 kg adult. It was noted that none of the Member States reported intake data for all food categories (range 2/16–13/16). Since children have a lower body mass, their body burden per kg body weight will generally be larger than that for adults, but remained below the PTWI.

The estimate of the daily dietary intake in the Czech Republic is based on food consumption data derived from the household budget surveys and the Cd content in particular components of the food basket containing commercially available foods. This estimate for an average person (64 kg) ranged in 1994–2003 in the interval 11–19 µg/d, i.e. 0.17–0.30 µg/kg bw/d, that represents 17–30% of the PTWI value WHO 7 µg/kg bw/w, or RfD US EPA 1 µg/kg bw/d. The US EPA exposure limit value (19) relates to the cadmium intake from foodstuffs with an expected 2.5% biological availability, and is based on the highest level of Cd in the human renal cortex not associated with significant proteinuria, with NOAEL being 10 µg/kg bw/d (with uncertainty factor 10 for interindividual variability). The intake estimated for the Czech population can be also compared with a stricter criterion, which has been determined by the Agency for Toxic Substances and Disease Registry (ATSDR) in Atlanta. The minimum risk level (MRL) of chronic oral exposure according to that source is 0.2 µg/kg bw/d (20, cited in 8) on the basis of the NOAEL 2.1 kg/bw/d for renal damage as the critical effect with the same uncertainty factor as used US EPA.

A similar estimate of the daily intake is given by Vermeire *et al.* (21, cited in 8) for the Dutch population 0.28 µg/kg bw/d. Another estimate for the Dutch population (1988–1989) was 0.22 µg/kg bw/d for males and 0.17 µg/kg bw/d for females (8). Järup et al. (9, cited in 8) estimates the average daily intake for Swedish population at 0.22 µg/kg bw/d.

Exposure data obtained within monitoring the consumer food basket represents an estimated exposure for the average individual. The values of foodstuff availability found by the method of representative structured survey of household budgets were used for calculations reflecting the social distribution of the population in the years 1991 and 1994. Data on individual consumption are not available yet. Important Cd exposure sources for the Czech population are potatoes, pastry and other cereal products and flour, somewhat less vegetables. The share of foodstuffs of animal origin on exposure to Cd is low in comparison with that of plant one.

The trend in dietary exposure doses (Fig. 4) has been calculated with the aid of the model of standardized foodstuff consumption for 5 type-population groups – children 4–6 years old; adult males over 18 years of age; adult females over 18; pregnant and breast-feeding females; and the elderly over 60 years of age (22). For calculations of exposure doses the recommended doses of foodstuffs for those specified population groups according to (23–26) have been implemented. The recommended dose has a standard value for the whole monitoring period unlike the

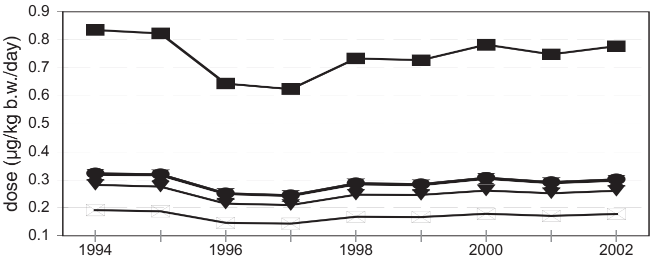


Fig. 4. *Trend in dietary exposure to cadmium based on consumption model of recommended foodstuffs doses .*

Table 6. *Daily cadmium intake (µg/person/d) by the Mean Adult Population from various foods in European countries*

Food group	BE*	DK*	FI*	FR*	DE*	HE*	IR*	IT*	NL*	NO*	PT*	SE*	UK*	Mean	CZ*
Milk, milk products	0.10	0.35	0.42	0.05		0.11		0.26	0.42			0.17	0.06	0.22	0.09
Condensed, powder milk, cheese, youghurt	0.03	0.00			0.12			1.47				0.055	0.07	0.29	0.06
Fats and oils		0.10			0.12			0.01			0.11		0.07	0.08	0.04
Fruit and vegetables	7.91	4.21	1.80	5.73	8.77	1.17		15.00	9.49	3.09	14.1	1.8	5.32	6.54	4.10
Confectionary		0.30	0.03		0.42				0.17	0.18				0.22	0.30
Cereals & bakery wares	4.57	8.25	6.36	1.69	5.45	1.34		3.41	4.34	7.45	0.39	3.9	5.00	4.35	6.24
Meat	3.30	0.29	0.09	0.66	2.07	0.27			7.14	0.75		0.35	0.53	1.54	0.33
Offal	0.03		0.10	0.24	0.20	0.43					0.03		0.08	0.16	0.04
Fish meat		0.29	0.32	0.20	0.18	13.9	0.07	0.11	0.10	3.56	0.20	0.10	0.18	1.62	0.12
Bivalve, crustaceans and cephalopods	0.34		0.15	0.68	0.09	2.14	0.32				1.05			0.68	
Eggs	0.00	0.01	0.00	0.02	0.10					0.085		0.005	0.01	0.03	0.015
Sweeteners			0.00	0.05	0.06					0.01	0.47	0.001	0.45	0.13	0.006
Salts and spice				0.43	0.08				1.17					0.56	0.29
Beverages		1.85	0.01	0.85	1.59+				0.97	0.47	0.11		0.19	0.74	0.06
Ready to eat									0.33	0.18			0.11	0.21	0.25
Composite food									0.99					0.99	
Sum	16.30	16	9.30	10.60	19.20	19.30	0.39	20.20	25.10	15.80	16.50	6.40	12.10	14.40	11.92

+Including drinking water. *The acronymes of states: BE = Belgium, DK = Denmark, FI = Finland, FR = France, DE = Germany, HE = Switzerland, IR = Ireland, IT = Italy, NL = The Netherlands, NO = Norway, PT = Portugal, SE = Sweden, UK = United Kingdom, CZ = Czech Republic. Source: European Commission, 2004(2)

actual food consumption. The result in fact reflects the trend in the concentration of Cd in the whole consumer food basket. The estimate of the development of the population burden according to this method has a tendency to vary without any marked trend. The exposure in children is greater in view of the relatively greater food intake per unit of body mass.

Information on the daily Cd intake from various food by the mean adult population in several European countries in comparison with the Czech data is presented in Table 6.

The estimate of the contribution to the total oral intake from drinking water is based on the median Cd concentration in all monitored public water networks weighted by the number of the inhabitants supplied from the respective water network. With the common consumption of about 1 liter drinking water per day, as found in the Health, Life Style and Environment survey (HELEN) in the Czech urban population (14), the mean value of Cd intake from drinking water amounted to 0.5 µg/d. This value represents 1.5% of the reference dose set by IRIS US EPA (0.5 µg/kg bw/d) considering the supposed Cd absorption from drinking water to be 5% (19). The share of drinking water in the oral intake 2–3% is in compliance with the WHO guideline value for this proportion to be at most 10% of the total oral intake (4).

Inhalatory Exposure

For the Cd exposure assessment from inhalation, there has been applied the value of 1.04E–3 µg/m^3 over the period under study at 40 cities. That potential exposure – "supply" – was calculated as the mean value of annual concentrations in all monitored cities over the period 1994–2003, weighted by the number of potentially exposed inhabitants in the respective city. Assumed a contemplated daily consumption of air amounting to 20 m^3, the estimated inhalatory intake of cadmium amounted to 3.25E–4 µg/kg bw/d, i.e. 2.08E-02 µg per person and day. Considering the retention in the lungs to be 25% (5), the deposition could amount 5.2E-3 µg/d.

The smoking habit represents a significant but avoidable source of exposure to cadmium. In smokers one cigarette represents a substantial additional intake of about 0.1–0.2 µg of cadmium (5). It has been estimated that with each cigarette smoked the blood Cd level increases by 1.6% (27). According to a recent survey on the smoking habit (28), 25% of the Czech population were regular smokers in 2002. About 50% of the Czech smokers consume more than 10 cigarettes daily, it means further contribution of at least 1–2 µg Cd per day.

Additional Cadmium Intake from the Topsoil in Preschool Children

In consequence of the environmental pollution the soil in urban agglomerations can take a share in an increased exposure to toxic substances by ingestion of soil and dust namely in small children. Results of surveys have confirmed a correlation between the soil contamination with toxic metals and the increased exposure of urban children (e.g. 29). For the potential additional exposure estimate in the child population, the soil Cd concentrations in the playgrounds in 117 kindergartens in five cities have been used. For this rough estimate the ordinary ingestion of soil (contrary either to a pica episode or to geophagy) was contemplated. The conservative value of the mean soil ingestion according to US EPA (15), 200 mg/d has been used.

The mean daily exposure to cadmium through unintentional soil ingestion was obtained by the mathematical model calculating the mean daily dose for non-carcinogenic substances according to (30). Calculations were based on the median value of soil Cd concentration and the exposure factors presented in Table 1, with use of the probable exposure duration of 210 days/year for the central European conditions. The estimated exposure dose amounted at most to about 0.5% of the oral intake limit. Expressed by the Hazard Index of 0.004, no importance for the urban child population is resulting as for non-carcinogenic effect. However, the bioavailability of Cd bound in the soil was not considered. The results obtained have to be rated as little representative owing also to limited number of investigated localities.

Human Cd Levels in Body Fluids and Tissues

In the period 1996–2003, the median blood cadmium levels in adults ranged from 0.4 μg/l to 0.9 μg/l blood with a decreasing tendency in time. Part of the results has been published already (31, 32). Since the blood cadmium level is markedly influenced by the smoking habit and there were 36% of smokers in the surveys, the summary results (Fig. 5) are presented separately for smokers and for non-smokers. The median values in non-smokers are not influenced by gender or locality. The Cd level in smokers, in comparison with non-smokers, is more than twice as high. The insignificant difference between males and females corresponds with less cigarettes smoked by females.

The presented results correspond with values obtained in the 1990s within the framework of project MONICA. In a group of 406 non-smokers the values (mean and SD) of 0.40 ± 0.47 μg/l have been measured, while in smokers (n = 205) the mean values ranged from 1.32 to 2.55 depending on the number of cigarettes smoked (33). Cadmium blood levels monitored within the framework of a WHO project in three urban localities of the Czech Republic in 1984 revealed in non-smokers GM values in the range of 0.81–l.54 μg/l, depending on the locality monitored (34). The burden of the Czech population in the past decades and the decreasing trend over time reflect results of a retrospective study of the Cd content in deep-frozen sera from the period of 1970–1999 (35).

Results of monitoring the blood cadmium concentration in the Czech population correspond with the usual values given for non-smokers in the range of 0.2–0.8 μg/l (36). Comparing the results in the Czech Republic with similar data in European countries, the largest data series represents the German Environmental Survey (GerES III). The median blood Cd levels in the German adult population in 1998, including a total of 4,646 participants, were 0.28 μg/l in non-smokers and 1.17 μg/l in smokers (37). Similar values with those in the Czech Republic were found in the nonsmoking population in Umbria (central Italy) (38) and in Spain (39).

For the evaluation of temporal trends and reference values computing the results obtained in non-smokers have been applied. The blood cadmium levels in non-smokers in particular monitoring years presented in Fig. 6 (males) and Fig. 7 (females) show a decreasing tendency in both genders.

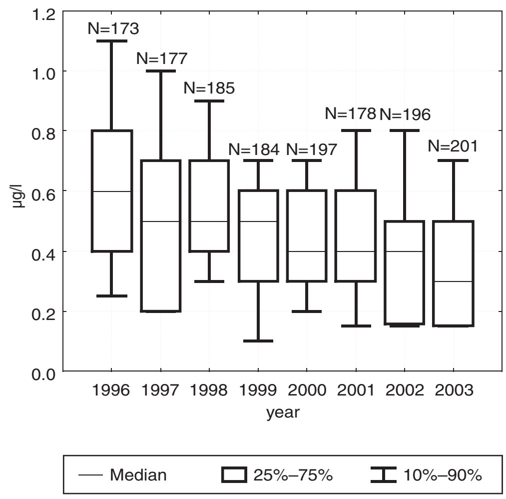


Fig. 6. *Blood cadmium levels in non-smoking men.*

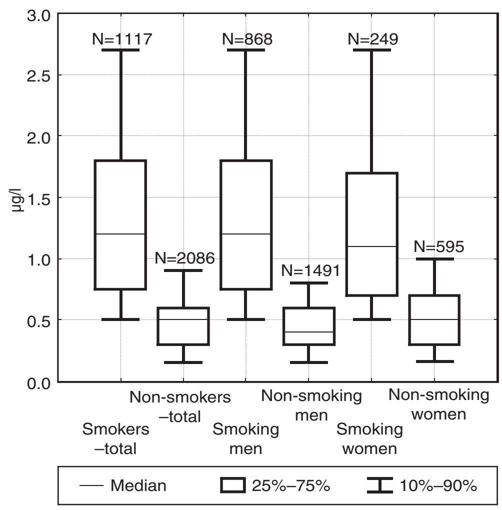


Fig. 5. *Blood cadmium levels in adults in 1996–2003 (smokers vs. non-smokers).*

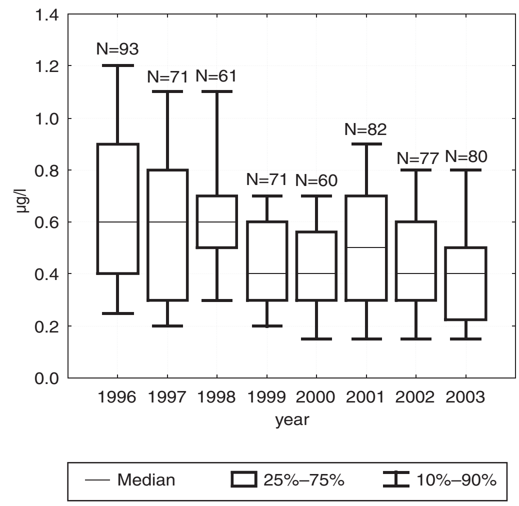


Fig. 7. *Blood cadmium levels in non-smoking women.*

Urine cadmium levels in adults were monitored at two-year intervals. The values (median, µg/g creatinine) are presented in Fig. 8. Part of the results was already published in the form of descriptive statistics (40). Contrary to blood Cd levels, no significant differences have been demonstrated in the urine of smokers and non-smokers. The urine levels reflect cumulative exposure, and the effect of smoking does not have to be evident. Similar results have already been presented in a study (34). In the group of non-smokers insignificantly higher values have been observed in females (Fig. 9). That is probably related to the higher resorption rate of Cd in females (41). Median urine Cd levels ranged 0.28–0.44 µg/g creatinine in the period 1996–2003, indicating a decreasing trend. Somewhat lower values found in the German population (42) in the GerES III study (median 0.18 µg/g creatinine) can be partly explained by a lower detection limit, partly by a higher exposure of the Czech population in the past. The latter reason has been also evidenced by results from the mid 1980s (34) when the mean cadmium levels in the urine were in the range of 0.45 to 1.33 µg/g creatinine in non-smokers.

Blood cadmium levels in the child population monitored since 1996 were in more than 50% of cases below the detection limit of the method used (< 0.3 µg/l blood). Urine cadmium levels in children reached the median value of 0.24 µg/g creatinine in 1996, in 1997 and 1998 that was 0.1 µg/g creatinine. In the following years of monitoring the values have been found below the detection limit in more than 50% of samples.

Cadmium concentrations were also measured in children's hair. Results from the period 1994–2001 were published in the form of descriptive statistics (43). The cadmium values in children's hair, 0.14 µg/g (median) and 0.47 µg/g (90th percentile), do not signalize any marked exposure in children. Senft et al. (44) consider normal levels in the child population to be in the range of 0.3–1.5 µg/g. Nevertheless, the Cd level in hair is not considered to be an entirely reliable indicator of exposure from the general environment (45).

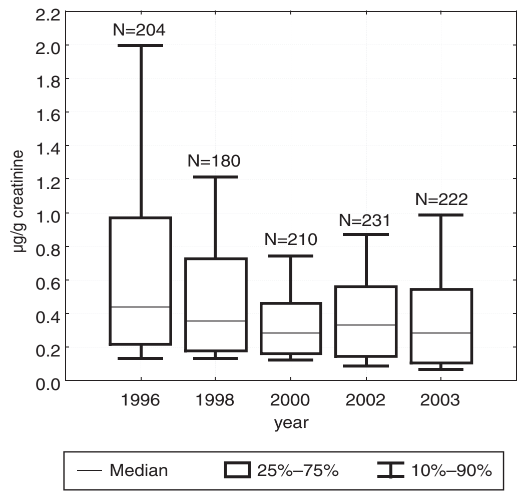


Fig. 8. Urine cadmium levels in adults (non-smokers).

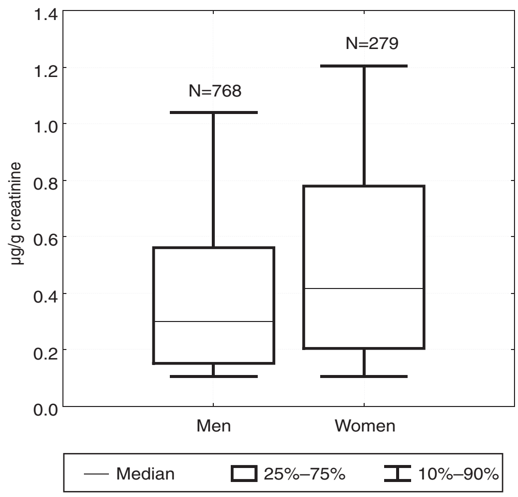


Fig. 9. Urine cadmium levels in men and women (non-smokers).

CONCLUSIONS

On the basis of systematic monitoring of cadmium concentrations in foodstuffs, drinking water and the ambient air an estimate of the overall cadmium intake in an average urban adult population in the Czech Republic has been made. This estimation was performed within the framework of the integrated Environmental Health Monitoring System (46) in the period 1994–2003. The oral Cd intake from food and drinking water was estimated to range in an interval of 0.18 µg/kg bw/d – 0.30 µg/kg bw/d, which represents 18%–30% of the PTWI WHO. This oral Cd intake does not differ from the range of the most frequently reported intakes in other European countries. The estimated exposure dose 12.7 µg/d found in 2003 is in agreement with WHO conclusions that exposure to cadmium in the European population ranges mostly close to the lower end of the interval 10–25 µg/d.

Higher dietary Cd intake is naturally expected in children due to the relatively greater food consumption per unit of body mass. Additional exposure of preschool children from unintentional ingestion of soil on children's playgrounds in the ordinary urban environment was assessed to be marginal, and does not represent any significant health risk (for non-carcinogenic effects).

Exposure to cadmium from the ambient air of 0.021 µg/d cannot be by current knowledge considered to be significant.

Results of biological monitoring in the period 1996–2003 characterize the recent and long-term cadmium burden of the Czech population from the general environment. The data obtained indicate a moderate decreasing trend in the exposure to cadmium and confirm the importance of smoking in relation to higher cadmium levels in the blood. Low values in the blood, urine and hair of children compared to the adult population reflect the functionality of the placental barrier for cadmium.

The estimated cadmium intake in the urban population of the Czech Republic at the present time does not signalize any increased risk of health impairment considering non-carcinogenic effects. Differences in human susceptibility given by physiological conditions make it otherwise difficult to speak of any unambiguous link between Cd intake and health effects. Nevertheless, also human cadmium bio-levels do not signalize any serious public health problem in general. However, population groups under risk and residents in spot-contaminated localities need to be investigated further.

REFERENCES

1. Bencko V, Cikrt M, Lener J: Toxic metals in environment and occupational environment (in Czech): Grada Publishing, Prague, 1995.
2. Opinion of the Scientific Panel on Contaminants in the Food Chain on a request from the Commission related to cadmium as undesirable substance in animal feed (Question N° EFSA-Q-2003-033), The EFSA Journal (2004) 72, 1–24
3. Integrated Programme on Chemical Safety. Environmental Health Criteria 134, Cadmium. WHO Geneva 1992.
4. Guidelines for Drinking Water Quality, Second edition: WHO Geneva, 1997.
5. Air Quality Guidelines, Second Edition: WHO Regional Office for Europe, Copenhagen, Denmark, 2000.
6. Bláha K jr, Kašparová L, Čábelková Z, Cikrt M: Smoking as a source of Cd, Ni, Hg, and Mn intake. Čs Hyg 1989; 34(2):103–110.
7. Wester RC, Maibach HI, Sedik L, Melendres J, DiZio S, Wade M: In vitro percutaneous absorption of cadmium from water and soil into human skin. Fund Appl Toxicol 1992; 19: 1–5.
8. Baars AJ , Theelen RMC , Janssen PJCM, Hesse JM, Apeldoorn ME van, Meijerink MCM, Verdam L, Zeilmaker MJ: Re-evaluation of human-toxicological maximum permissible risk levels. RIVM Report 711 701 025 2001: 297.
9. Järup L et al.: Health effects of cadmium exposure – a review of the literature and a risk estimate. Scand J Work Environm Health 1998; 24, suppl 1:1–52.
10. The Resolution of the Czech Government No. 369/1991 to the Proposal of the System of Environmental Impact on Population Health of the Czech Republic (in Czech).
11. Ruprich J, Dofková M, Kleinwachterová H, Kopřiva V, Resová D, Řehůřková I: Food basket for the Czech Republic, Exposure factors – CZ 1991. Prague: National Institute of Public Health; 1993 (in Czech).
12. Ruprich J, Dofková M, Kleinwachterová H, Kopřiva V, Resová D, Řehůřková I: Food basket for the Czech Republic, Exposure factors – CZ 1994. Prague: National Institute of Public Health; 1997 (in Czech).
13. Ruprich J, Dofková M, Kopřiva V, Resová D, Řehůřková I: Food basket for the Czech Republic, Exposure factors – CZ 1997. Prague: National Institute of Public Health; 2000 (in Czech).
14. Žejglicová K, Malý M, Krýslová S, Švandová E: Evaluation of health status – project HELEN. Technical Report from Environmental Health Monitoring System. Prague: National Institute of Public Health; 2003 (In Czech).
15. Exposure Factors Handbook. US EPA 600/8–89/043; 1990.
16. Soil Screening Guidance: Technical Background Document, Second Edition. EPA/540/R95/128; May 1996.
17. Řehůřková I: Monitoring of the dietary exposure of the population to chemical substances in the Czech Republic: Design and history. Cent Eur J Publ Health 2002;10 (4):174–179.
18. European Commission SCOOP 2004, task 3.2.11. Assessment of the dietary exposure to arsenic, cadmium, lead and mercury of the population of the EU Member States. European Commission, Directorate-General Health and Consumer Protection, Reports on tasks for scientific co-operation March. http://europa.eu.int/comm/food/food/chemicalsafety/contaminants/scoop_3-2-11_heavy_metals_ report_en.pdf
19. Integrated Risk Information System: Substance file – Cadmium, CASNR 7440-439 (update May 1999), US EPA, DC Washington, USA.
20. Toxicological profile for cadmium, draft for public comment (update). US Depth of Health & Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta (GA), USA, 1997.
21. Vermeire TG, Apeldoorn ME van, Fouw JC de, Janssen PJ: Voortel voor de humaan-toxicologische onderbouwing van C-(toetsings)waarden. RIVM Report no. 725201005, Bilthoven: National Institute of Public Health and the Environment;1991.
22. Ruprich J et al.: Health effects from burden by chemicals in food chains. Technical Report from Environmental Health Monitoring System. Brno: National Institute of Public Health; 2003 (in Czech).
23. Brázdová Z: Nutrition recommendations for the Czech Republic. Rega Brno 1995; 5–22 (in Czech).
24. Brázdová Z, Ruprich J, Hrubá D, Petráková A: Dietary Guidelines in the Czech Republic III: Challege for the 3rd Millenium. Cent Eur J Publ Health 2001;9(1): 30–34.
25. Ralph J: Appendix 2: Dietary reference values. In: Garrow JS, James WPT: Human Nutrition and Dietetics. Churchil Livingstone, 9th edition. Edinburgh 1993; 792.
26. Ralph J: Appendix 2 : Dietary reference values. In: Garrow JS, James WPT.: Human Nutrition and Dietetics. Churchil Livingstone, 9th edition. Edinburgh 1993; 793.
27. Herber RFM, Christensen JM, Sabbioni E: Critical evaluation and review of cadmium concentrations in blood for use in occupational health according to the TRACY protocol. Int Arch Occup Environ Health 1997;69:373–378.
28. Sovinová H, Sadílek P, Czémy L: Trend in smoking habit prevalence in Czech adult population and attitudes to tobacco products and their use in 1997–2002. Prague: National Institute of Public Health;2003.
29. Mielke HW, Gonzales CR, Smith MK, Mielke PW: The urban environment and children´s health: soil as an integrator of lead, zinc and cadmium in New Orleans, Louisiana, USA. Environ res (US) 1999; 81 (2):117–129.
30. Risk Assessment Information System RAIS, http://risk.lsd.ornl.gov/homepage/tm/for_res_so.shtml).
31. Beneš B, Spěváčková V, Šmíd J, Čejchanová M, Černá M, Šubrt P, Mareček J: The concentration levels of Cd, Pb, Hg, Cu, Zn and Se in blood of the population in the Czech Republic. Cent Eur J Publ Health 2000; 8:117–119.
32. Černá M, Spěváčková V, Čejchanová M, Beneš B, Rössner P, Bavorová H, Očadlíková D, Šmíd J, Kubínová R: Population-based biomonitoring in the Czech Republic – the system and selected results. Sci Total Environ 1996; 204:263–270.
33. Korečková-Sysalová J: Determination of cadmium and lead levels in human blood of a general Czech population by GFAAS. Biol Trace Element Res 1997;56:321–329.
34. Cikrt M, Tichý M, Bláha K, Bittnerová D, Havrdová J, Lepší P, Šperlingová I, Němeček R, Roth Z, Vít M, Herber RFM: The study of exposure to cadmium in the general population. II Morbidity studies. Pol J Occupat Med Environ Health 1992; 5 (4): 345–356.
35. Beneš B, Spěváčková V, Čejchanová M, Šmíd J, Švandová E: Retrospective study of concentration levels of Pb, Cd, Cu and Se in serum of the Czech population in time period 1970–1999. Cent Eur J Publ Health 2001; 9 (4): 190–195.
36. Elinder CG, Friberg L, Kjellström T, Nordberg G, Oberdoerster G: Biological monitoring of metals. IPCS, WHO, Geneva;1994.
37. Becker K, Kaus S, Krause C, Lepom P, Schulz C, Seiwert M, Seifert B: German Environmental Survey 1998 (GerES III): environmental pollutants in blood of the German population. Int. J Environ Health 2002; 205: 297–308.
38. dell'Omo M, Muzi G, Piccinini R, Gambelunghe A, Morucci P, Fiordi T, Ambrogi M, Abbritii G: Blood cadmium concentrations in the general population of Umbria, Central Italy. Sci Total Environ 1999; 226:57–64.
39. Moreno MA, Marin C, Vinagre F, Ostapczuk P: Trace element levels in whole blood samples from residents of the city Bajadoz, Spain. Sci Total Environ 1999; 229:209–215.
40. Beneš B, Spěváčková V, Šmíd J, Čejchanová M, Kaplanová E, Černá M, Gajewská V, Blatný J: Determination of normal concentration levels of Cd, Pb, Hg, Cu, Zn and Se in urine of the population in the Czech Republic. Cent Eur J Publ Health 2002;10(1–2):3–5.
41. Buchet JP, Lauwerys R, Roels H, Bernard A, Bruaux P, Clayes F, Ducoffre G, DePlaen P, Staessen J, Amery A, Lijnen P, Thijs L, Rondia D, Sartor F, Saint Remy A, Nick L: Renal effects of cadmium body burden of the general population. The Lancet 336 1990; 699–702.
42. Becker K, Schulz C, Kaus S, Seiwert M, Seifert B: German Environmental Survey 1998 (GerES III): environmental pollutants in the urine of the German population. Int J Hyg Environ Health 2003; 206:15–24.
43. Beneš B, Sladká J, Spěváčková V, Šmíd J: Determination of normal concentration levels of Cd, Cr, Cu, Hg, Pb, Se and Zn in hair of the child population in the Czech Republic. Cent Eur J Publ Health 2003; 11(4): 184–186.
44. Senft V, Soukupová H, Čechová M, Bílek M, Kohout J, Tuček M: Monitoring of the influence of a chemical plant on the environment by an assessment of nickel and cadmium content in childrens' hair. Čs Hyg 1992; 37 (6): 337–347 (in Czech).
45. Wilhelm M, Idel H: Hair analysis in environmental medicine. Zbl Hyg 1996; 198:485–501.
46. Environmental Health Monitoring System in the Czech Republic. Summary Report 2003. Prague: National Institute of Public Health; 2004. www.szu.cz/chzpa/sumrep.htm.

Received July 26, 2004

Received in revised form and accepted October 4, 2004