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Health Risk Assessment of Heavy Metals Adsorbed in Particulates

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***Abstract*—**The progress of concentrations of particular heavy metals was assessed in chosen localities in region Moravia, the Czech Republic, from 2007 to 2009. Particular metals were observed in localities with various types and characterization of zone. Pb, Ni, As and Cd were emphasized as a result of their toxicity and potential adverse health effect to the exposed population. The progress of metal concentrations and their health effects in the most polluted localities were examined. According to the results, the air pollution limit values were not exceeded. Based on the health risk assessment, the probability of developing tumorous diseases is acceptable, except for the increased probability of cancer risk from long-term exposure to As.

***Keywords*—**Air pollution, heavy metals, health risk assessment, individual lifetime cancer risk

I. Introduction

PARTICULATE MATTER (PM) is considered as one of the air pollutants with many undesirable health effects on population. The physical and chemical properties are responsible for adverse health effects of PM. Especially, the composition of PM and content of other harmful chemical substances contribute to damage to the health of exposed people. The significant role of specific heavy metals in the toxicity of PM is currently supported by many recent studies. These studies provide evidence that particle-associated metals contribute to health effects of PM [1].

The research work emphasizes lead, cadmium, nickel and arsenic in consequence of their toxicity and potential adverse health effect to the exposed population. Although, the situation of air pollution by heavy metals is no longer alarming, the exposure to such metals has been linked with substantial health risk in terms of their carcinogenic effects. Resulting from chronic metal exposure, assessing the chance of developing cancer belongs to one of the most serious and relevant issues in air pollution health risk assessment.[1]

II. The Analysis of current state

A. Particulate Matter

Please PM is recognized as one of the pollutants with adverse health effects as a result of its capability of binding a number of organic and inorganic substances to particles surface [2]. Heavy metals are considered toxic components of PM and they are responsible for a variety of pathological changes in living organism [3]. Concentrations of heavy metals are observed and contrasted with limit values.

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Table I presents limit values of particular heavy metals. Content of various metallic components in PM is considered the factor most directly responsible for the adverse health effects connected with PM mass concentration. It is distinguished between natural (e.g. volcanic activities, emission from fires) and anthropogenic (e.g. incomplete combustion, transport, industrial processes, worker exposure etc.) sources of metals found in PM. Generally, the content of particular metals is observed in PM_{10} (particulate matter up to 10 micrometers in size). Stations in the Czech Republic observe several heavy metals. Accented metals found in PM_{10} are lead (Pb), arsenic (As), nickel (Ni) and cadmium (Cd) for reason of the data availability.

B. Heavy metals

Lead has been used in wide range of purposes for thousands of years because of its unique properties. But its widespread usage has resulted in increased Pb concentrations in environment. Common sources of lead exposure are connected with numerous occupations encountered lead (e.g. lead mining and manufacturing, plumbing etc.). Lead exposure occurs through inhalation. Most of inhaled lead is absorbed into the body and can be deposited for a long period of time in some tissues. The substantial threat consists in potential releasing of accumulated lead into the bloodstream and it can be distributed within the body. Damages to the health derived from lead exposure affect nervous system, kidneys and blood. Lead exposure is the possible source of tumors. US EPA has considered lead to be Group B2 (probable human carcinogen) [4].Cadmium is recognized as one of the most noxious pollutants in the environment. The major source of airborne cadmium results from exposure in occupational settings. Other sources are related to burning fossil fuels, mining and metallurgical processes. The toxicity of Cd consists in accumulation in soft tissues (liver and kidneys) and in mineralizing tissues (bones). Key health endpoints include kidney and bone damage and cancer. Chronic exposure from inhalation can cause chronic pulmonary effects. Cadmium exposure has been examined in several studies by reason of its potential carcinogenic risks. The International Agency for Research on Cancer (IARC) has classified cadmium and cadmium compounds as Group I (human carcinogens) and US EPA as Group B1 (probable human carcinogen).

Nickel is one of the metals usually found in PM_{10} resulted from fossil fuel combustion. The most toxic form of Ni is nickel carbonyl gas. Immediate symptoms of exposure to nickel carbonyl gas contain headache, nausea, weakness, vomiting and, in some cases, death [5]. Inhalation of nickel may lead to nasal and pulmonary tumors. IARC has classified nickel and nickel compounds as Group 1 (human carcinogens) and metallic nickel as Group 2B (possibly carcinogenic to humans). US EPA has classified nickel refinery dust and nickel subsulfide as Group A (human carcinogen) and nickel carbonyl as Group B2 (probable human carcinogen).

Arsenic occurs as a natural element and is found in the environment. Volcanic eruptions, combustion of fossil fuels and industrial processes rank among general sources. Exposure from occupational settings plays also important role as one of the key sources. The exposure to As can result in serious health effects to skin, gastrointestinal track and nervous system. Furthermore, it was examined that exposure to inorganic arsenic is associated with lung cancer. US EPA has classified inorganic arsenic as Group A (human carcinogen). Other form of As, gaseous arsine, is extremely toxic to humans. Acute inhalation exposure can result in death.

C. The method of health risk assessment

The method of health risk assessment was generated by well-known institutions such as US EPA and WHO on the international level and by Ministry of Health and Ministry of Environment in the Czech Republic. According to those institutions, the risk assessment process consists of four crucial steps: hazard identification, exposure assessment, dose-response assessment, and risk characterization (US EPA, 1987).

TABLE I
AIR POLLUTION LIMIT VALUES ACCORDING TO THE GOVERNMENT ORDER NO. 597/2006 COLL.

Pollutant	Averaging Interval	Limit Value [$\mu g \cdot m^{-3}$]
Pb	Calendar Year	$5x10^{-1}$
Cd	Calendar Year	$5x10^{-3}$
Ni	Calendar Year	$2x10^{-2}$
As	Calendar Year	$6x10^{-3}$

The first step is described as a review of the key research and studies to identify any potential health problems that a chemical can cause. In the second step, exposure assessment, scientists determine the amount, duration and pattern of exposure to the chemical. The next step, dose-response assessment, focuses on the estimate of the amount of a chemical that is likely to result in a particular adverse health effect in humans. In this step the cancer and noncancer effects have to be distinguished. The last step, risk characterization, assesses the risk for the chemical to cause cancer or other illnesses in the general population. It brings information from the previous steps together. Moreover, this step includes description of uncertainties and weaknesses, which result from failings accumulated in preceding steps.

III. PROBLEM SOLUTION

A. The method of health risk assessment

The theoretical part of the research work was compiled with the method of literature search. The risk assessment method was used in accordance with the legal system of the Czech Republic [6] and the US EPA method [7]. The data of concentrations, which were used in the research work, proceed from the database of Czech Hydrometeorological Institute (CHMI) [8].

The following formula (1) was used for the health risk assessment to assess how many people are likely to be taken ill with cancer:

$$ILCR = LADD \times ICPF \qquad (1).$$

Equation (1) includes ILCR, which represents non-dimensional individual lifetime cancer risk, which signifies the increased probability that the number of tumor diseases exceeds the general average. LADD [$mg \cdot kg^{-1} \cdot day^{-1}$] represents the lifetime average daily dose and ICPF [$mg \cdot kg^{-1} \cdot day^{-1}$] represents inhalation cancer potency factor, which signifies the carcinogenic potential of the distinct pollutant. LADD was calculated on the basis of following formula (2):

$$LADD = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT} \qquad (2).$$

Formula (2) contains exposure factors and CA [$mg \cdot m^{-3}$], which represents the average concentration of particular metal, calculated as an arithmetic average of measured concentrations. IR [$m^3 \cdot h^{-1}$] represents the intake rate, ET [$h \cdot day^{-1}$] represents exposure time, EF [$day \cdot year^{-1}$] symbolizes exposure frequency, ED [year] symbolizes exposure duration, BW [kg] symbolizes body weight and AT [day] is the average time. Values of exposure factors and ICPF values, which enter the risk assessment, proceed from materials of the legal system of the Czech Republic and the database of Californian Environmental Protection Agency (CAL EPA), the department Office of Environmental Health Hazard Assessment (OEHHA) [9].

B. Outcomes and discussion

The air pollution assessment and cancer risk assessment were implemented to determine the level of air pollution by particular metals in selected localities and the cancer potential as adverse effects to humans of monitored metals during observed period of time. Brno and Ostrava belong to the most polluted areas in Moravia. Table 2 contents annual average concentrations of observed metals in particular stations in Brno and Ostrava from 2007 to 2009. The missing values in Brno-Lisen and Brno-Kroftova signify that concentrations were not observed in certain year.

TABLE II
ANNUAL AVERAGE CONCENTRATIONES OF PARTICULAR HEAVY METALS (ng m^{-3})

Name of Station	Pb 2007	Pb 2008	Pb 2009	Cd 2007	Cd 2008	Cd 2009	Ni 2007	Ni 2008	Ni 2009	As 2007	As 2008	As 2009
Brno-Masna	**17.4**	**15.6**	**12.6**	**0.4**	**0.6**	**0.4**	**4.2**	**3.5**	**4.1**	**1.0**	**0.8**	**0.7**
Brno-Dobrovskeho	10.8	10.0	7.7	0.3	0.2	0.3	2.5	1.8	3.3	0.6	0.4	0.6
Brno-Lisen	-	-	8.4	-	-	0.3	-	-	0.8	-	-	0.8
Brno-Kroftova	13.7	12.0	-	0.3	0.3	-	1.3	1.4	-	1.1	0.9	-
Ostrava-Privoz	**38.7**	**36.1**	**34.0**	**0.9**	**1.0**	**0.9**	**6.1**	**5.0**	**3.9**	**4.4**	**3.1**	**2.9**
Ostrava-Poruba IV.	8.8	10.8	12.1	1.8	0.4	0.4	2.4	1.3	1.6	1.8	0.7	1.1
Ostrava-Poruba/CHMU	19.0	19.9	18.8	0.6	0.6	0.6	1.1	0.9	1.0	2.1	1.5	1.7

According to Table 2, the uppermost annual average concentrations are in Ostrava-Privoz and Brno-Masna (highlighted values). Therefore, the cancer risk assessment was carried out in those two localities. Annual average concentrations were compared to the air pollution limit values (listed in Table 1). By comparing actual concentrations and limit values, the air pollution limit values for all metals were not exceeded during the monitored period of time. The most burdened locality is Ostrava-Privoz.

Minimal metal concentrations appear predominantly from the fifth to the seventh month. Maximal metal concentrations appear predominantly in the eleventh and twelfth month. Maximal concentrations in wintertime could result from temperature inversion.

The health risk assessment was carried out on the grounds of the four step procedure described in chapter 1.5. Two most polluted localities, Ostrava-Privoz and Brno-Masna, were chosen to realize the health risk assessment for both, adults and children, during the monitored period of time. The health risk assessment was implemented on the basis of calculation of specific values for all selected heavy metals. Specific risk values, which were assessed, were compared in two selected localities.

Cancer potential of selected metals was emphasized as a consequence of the long-term exposure to those metals. The inhalation exposure scenario was used.

The amounts of metals that are likely to result in a particular adverse health effect were estimated. The exposure to metals was quantified on basis of formula (2). LADD was calculated for both, adults ($LADD_A$) and children ($LADD_C$), with the help of concentrations listed in Table 2 and values of exposure factors for the inhalation exposure scenarios. Adopted values are the following: the intake rate $IR_A = 0.83\ m^3 \cdot h^{-1}$ for adults and $IR_C = 0.6\ m^3 \cdot h^{-1}$ for children; the exposure time ET = 16.43 $h \cdot day^{-1}$; the exposure frequency EF = 350 $day \cdot year^{-1}$; the exposure duration ED_A = 70 years for adults and ED_C = 6 years for children; the body weight BW_A = 70 kg for adults and BW_C = 15 kg for children; the average time AT_A = 25 500 days for adults and AT_C = 2 190 for children.

Values of $ILCR_A$ and $ILCR_C$ were calculated with the help of formula (1), calculated values of LADD and ICPF values. ICPF values for the monitored metals were adopted from the database of CAL EPA and they are the following: ICPF = 0.042 $mg \cdot kg^{-1} \cdot day^{-1}$ for Pb, ICPF = 15 $mg \cdot kg^{-1} \cdot day^{-1}$ for Cd; ICPF = 0.91 $mg \cdot kg^{-1} \cdot day^{-1}$ for Ni; ICPF = 12 $mg \cdot kg^{-1} \cdot day^{-1}$ for As.

The acceptable level of cancer risk is recognized as $1x10^{-6}$, which signifies the increase of individual lifetime cancer risk by 1 case of 1 million exposed populations. Children are considered as more susceptible to the impact of pollutants than adults.

The probability of developing cancer from long-term Pb exposure could be regard as insignificant among adults and acceptable among children (about 1 child of 1 million exposed people) in both stations, Ostrava-Privoz and Brno-Masna, during the assessed period of time. The probability of developing tumorous diseases from long-term Cd exposure could be indicated as acceptable among adults (almost 3 adults in the group of million people in Ostrava-Privoz and about 1 adult in Brno-Masna). Nevertheless, the probability of developing cancer among children is on the level of acceptability (almost 10 children of 1 million exposed people in Ostrava-Privoz and almost 6 children in Brno-Masna). Although the probability of developing cancer among children ranges between limits of acceptability, the cancer risk is slightly increased.The probability of developing cancer from long-term Ni exposure could be considered as acceptable for both adults and children (about 1 adult and 2 to 4 children of 1 million exposed people) in both localities during the assessed period of time.According to results, the cancer risk of As was increased among children during the assessed period of time. The probability of developing cancer among children from long-term exposure to As could not be regarded as acceptable, because it ranges above the level of acceptability (about 3 children of 100 thousand exposed people in Ostrava-Privoz). Assessed values of ILCR among adults show that the cancer risk of As was slightly increased (about 6 to almost 10 adults of 1 million people in Ostrava-Privoz). It can be confirmed that exposure to As is quite a serious problem in respect of child population in Ostrava-Privoz.

TABLE III
CALCULATED VALUES OF $ILCR_A$ AND $ILCR_C$ FOR ASSESSED PERIOD OF TIME IN OSTRAVA-PRIVOZ

	$ILCR_A$			$ILCR_C$		
Metal	**2007**	**2008**	**2009**	**2007**	**2008**	**2009**
Pb	$3.036x10^{-7}$	$2.832x10^{-7}$	$2.667x10^{-7}$	$1.024x10^{-6}$	$9.555x10^{-7}$	$8.996x10^{-7}$
Cd	$2.522x10^{-6}$	$2.802x10^{-6}$	$2.522x10^{-6}$	$8.508x10^{-6}$	$9.453x10^{-6}$	$8.508x10^{-6}$
Ni	$1.037x10^{-6}$	$8.499x10^{-7}$	$6.629x10^{-7}$	$3.498x10^{-6}$	$2.867x10^{-6}$	$2.237x10^{-6}$
As	$9.864x10^{-6}$	$6.949x10^{-6}$	$6.500x10^{-6}$	$3.328x10^{-5}$	$2.345x10^{-5}$	$2.194x10^{-5}$

TABLE IV
CALCULATED VALUES OF $ILCR_A$ AND $ILCR_C$ FOR ASSESSED PERIOD OF TIME IN BRNO-MASNA

	$ILCR_A$			$ILCR_C$		
Metal	**2007**	**2008**	**2009**	**2007**	**2008**	**2009**
Pb	$1.365x10^{-7}$	$1.224x10^{-7}$	$9.887x10^{-8}$	$4.607x10^{-7}$	$4.129x10^{-7}$	$3.335x10^{-7}$
Cd	$1.121x10^{-6}$	$1.682x10^{-6}$	$1.121x10^{-6}$	$3.782x10^{-6}$	$5.672x10^{-6}$	$3.782x10^{-6}$
Ni	$7.120x10^{-7}$	$5.950x10^{-7}$	$6.970x10^{-7}$	$2.409x10^{-6}$	$2.007x10^{-6}$	$2.351x10^{-6}$
As	$2.242x10^{-6}$	$1.793x10^{-6}$	$1.570x10^{-6}$	$7.562x10^{-6}$	$6.050x10^{-6}$	$5.293x10^{-6}$

ILCR values for both groups in Ostrava-Privoz were moderately higher than those values in Brno-Masna. Nevertheless, ILCR values are comparable in both stations, except those ILCR values of As among children in Ostrava-Privoz, which are higher than those in Brno-Masna about one rank and bring higher probability of cancer among children. Ostrava-Privoz is industrial locality. Therefore, it can be expected that metal concentrations and ILCR values will be higher than those in other localities, which are not industrial.

Calculated values of ILCR can be expected as a little inaccurate in consequence of specific uncertainties. Some of uncertainties of health risk assessment are the following:

1) The input data are results of some models and approximations.
2) The impossibility to connect effects of observed pollutants and other undetected pollutants.
3) Some specific factors are not considered, only general features are reflected on.
4) The concrete number of population of specific locality is not known.
5) The exposure scenario assumes that the population is exposed to effects of pollutants almost two thirds of the day and almost the whole year.
6) The exposure scenario also assumes the average weight (70 kg). It can be supposed that the weight is probably higher than the average weight.

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