

SUPPORTING INFORMATION

to the paper:

Comparative Health Risks of Domestic Waste Combustion in Urban and Rural Slovakia

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The study presented in the article was a complex research involving many issues, the detailed treatment of which could only be mentioned briefly or omitted in the printed version of the article. The information listed in following pages intend to put more light into the technical details of the work and on the sources of data used in different stages of the risk assessment procedure. Detailed tables and graphics presenting the results are also involved.

CONTENTS OF THE SUPPORTING INFORMATION DOCUMENT

- ◆ Design of prototype villages
- ◆ Municipal waste combustor – emission source and receptor specifications
- ◆ Chemicals of potential concern involved in the study
- ◆ Sources of the dose response data used in the study
- ◆ Modeling tools used for the exposure assessment
 - CALPUFF air dispersion model
 - EMERAM environmental media and risk assessment model
- ◆ CALPUFF implementation – data and modeling protocol
- ◆ CALPUFF sensitivity testing related to the source and receptor configuration
- ◆ EMERAM exposure data
- ◆ Detailed summary of the risk characterization results

DESIGN OF PROTOTYPE VILLAGES

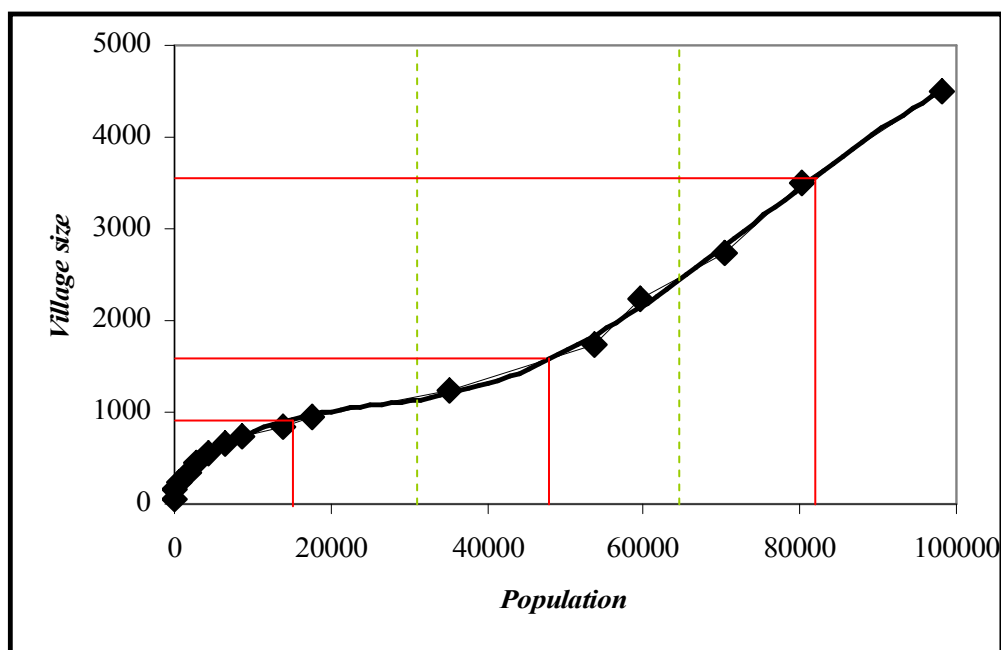
As we want to quantify the problem of open burning on a regional scale, this cannot be done selecting a real village and computing the risks. The assessment of risks will be based on a more general concept of synthetic villages representing a statistical size distribution of the settlement clusters.

Based on the size distribution of the settlement clusters, three prototypes (MIN, MOD and MAX) will represent all of the rural villages in the country. Specifying the emissions relies on the knowledge of the population (to determine the waste load) and the area (to establish the area source size) of each prototype village. We assign the populations of the three to represent the first, second and third tertiles of the regional demographics. Data from the population and housing census of the Slovak Republic (SOSR, 2001) formed the basis of the frequency distribution of village populations. Figure 2 summarizes these data assuming a cut-off of 5,000 for village population.

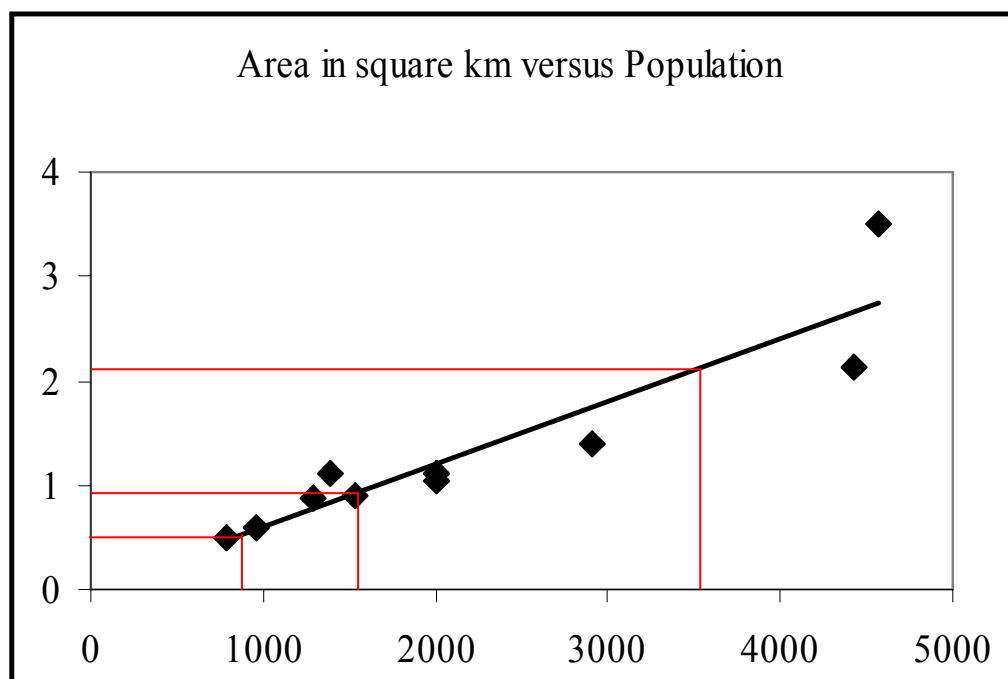
For ease in statistical analysis we fit the data in Figure 1 with a 5th order polynomial fit yielding $R^2=0.998$. Two brief examples illustrate simple ways to interpret the graph. At the extreme upper end of the curve we see that 100,000 persons live in villages of about 4,500 population or smaller. At the lower end, we see that 20,000 persons live in villages of about 1,000 population or smaller.

We trisected this distribution and established midpoint village populations, each representing one third of the total; hence each prototype represents about 30,000 persons in the region. The three prototype populations are: MIN = 959, MOD = 1630 and MAX = 3601.

Figure 1. Village population distribution by village size in Bratislavský Kraj (SOSR, 2001).



Next, we turn to the calculation of village areas. Another regression approximation of village area on population illustrated in Figure 2 provides a linear relationship with $R^2=0.845$. The three prototype areas are: MIN = 0.582 km², MOD = 0.986 km² and MAX = 2.17 km². These data provide information needed for the specification of the burn barrel emissions in the model inputs.

Figure 2. Village area distribution by population

Waste Streams in Villages

To estimate how much waste is burned in each of the villages, we link the total waste stream to population by application of the Slovak national average generation factor of 208 kilograms per person per year (SAŽP, 2000) averaged over 1992 to 1997. Next, it is necessary to estimate what fraction of the waste in each village ends up in the burn barrels. In an effort to resolve the large disparity of available data, we assume that 10% of the waste generated in the villages is burned in barrels as a first approximation. Thus, MIN burns 20.7 tons/yr; MOD, 35.2; and MAX, 77.9 tons/yr.

Emission sources formulation

Because backyard burning of household waste may be responsible for a large portion of PCDD/Fs released to the environment if practiced on a large scale, US EPA has performed a series of tests including simulations of open burning of household waste. The aim was to qualitatively identify and quantitatively measure the emissions from open burning of residential solid waste in burn barrels (US EPA, 1997a). They used 208 l steel barrel with 24 ventilation holes placed near the ground. The mass of waste burned ranged from 6.4 to 13.6 kg. The composition of waste was based on the typical percentages of various materials in the household waste of New York State citizens. Two scenarios were simulated: waste burned by people who remove most of the recyclable content of the waste before combustion, and waste burned by non-recyclers.

There is not enough reliable information on the composition of Slovak waste, and it is only available for cities. Table 1 contains the composition of waste of New York citizens as well as Slovak data which we were able to obtain. The composition of waste of rural citizens may differ. One could argue, for example, that people logically prefer to burn combustible material for burning. It is highly probable that the food waste is not burned but rather disposed of by composting or feeding home animals. Removing the food waste portion from Slovak data would bring them closer to those which served for the US EPA burn barrel simulations. We assume that the composition of waste is similar enough that the emission factors from the US EPA burn barrel study can be justified.

Other aspects of the open burning are physical configuration of the sources and their time distribution.

Based on observations, burning usually takes place any time during the daytime when the weather is convenient (no rain), although it seems that the times between noon and late afternoon are preferred. Waste is burned either in metal barrels (households that burn waste regularly) or simply on the ground, sometimes mixed with tree branches and other gardening refuse. Burning usually does not take more than an hour, but smoldering of the residuals can take more. In reality, it is probable that there are people that do not burn their waste at all and others who burn waste regularly. As we are interested in long-term assessment in artificially designed villages, we will assume that each household practices open burning. If we suppose 10% of the waste stream is open-burned, an average family of 4 persons would burn their waste about 9 times per year (assuming that about 10 kg of waste at a time is burned in a barrel). This would mean that 9 to 33 burns happen each dry day during the year in our synthetic MIN, MOD and MAX villages.

Table 1. Composition of household waste used for deriving the open burning emission factors (US EPA, 1997a), as compared to the available information on the composition of municipal waste in Slovakia

Type of waste	Non-recycler (%)	Rybar et al.* (Kosice)	VUSAPL** (Nitra)
Paper		20	14
newspaper, books, office paper	32.7		
magazines, junk mail	11.1		
corrugated cardboard and kraft paper	7.6		
paperboard, milk cartons, drink boxes	10.3		
Plastic		7	10
PET	0.6		
HDPE, LDPE, PP	6.6		
PVC	0.2		
PS	0.1		
Mixed	0.1		
Food waste	5.7	45	38
Textile/leather	3.7	4	-
Wood (treated/untreated)	1.1	3	-
Glass/ceramics		12	8
bottles/jars	9.7		
ceramics (broken plates and cups)	0.4		
Metal, ferrous		4	3
iron, cans	7.3		
Metal, non-ferrous			
aluminium (cans, foil)	1.7		
other non-iron (wire, copper pipe, batteries)	1.1		
Inorganic material	-	4	-
Dangerous waste	-	1	-
Other waste	-	-	27
Total	100	100	100

* <http://www.biospotrebitel.sk>

** VUSAPL, Inc., which references the source of the data as a combination of internal VUSAPL information and the Ministry of the Environment

NOTE: Neither of above sources can be considered completely reliable as we were not able to obtain full reference to original data

Receptor configuration

Analyses of the burn barrel cases include two types of receptor: village receptors and agricultural receptors. Each village population determines the land areas occupied by agricultural receptors. The allocations rely on factors derived from national scale land-use statistics (Hamnett, 2001). Table 1a lists the distribution of agricultural land use on a per capita basis among inhabitants of villages having 5,000 population or less.

The land use model allocates the agricultural land use to arable (field crops) and grassland (animal feed and fodder) on a per capita basis. Concentric circles bound the agricultural land and the village land. Table 2b summarizes the results of this calculation.

Table 2a. Slovak land use for agricultural production (Hamnett, 2001)

Classification	Area -km ²	Area/Capita - km ²
Arable	14490	0.00611
Grassland	8350	0.00352
Vineyards	230	0.00010
Kitchen gardens	780	0.00033
"other"	560	0.00024
Total agriculture	24410	0.01029

Table 2b. Land use allocations in and around prototype villages

Village	MIN	MOD	MAX
Village Area - km ²	0.582	0.986	2.170
Arable land - km ²	5.86	9.96	22.00
Grassland – km ²	3.38	5.74	12.68
Agriculture Radius - km	1.77	2.30	3.43
Village Radius – km	0.43	0.56	0.83

The physical dimensions in Table 2b establish the boundaries of the receptor fields. The agricultural receptors in the annuli bounded by the last two radii in the table contribute to the indirect exposure pathways. The village receptors receive exposures from inhalation, agricultural diet items and kitchen garden diet items. If all of the kitchen garden land use is assigned to the population in villages of 5,000 and smaller, and if there are 4 persons per kitchen garden, the average plot size is 1316 m² per plot. A 15 by 88m plot would occupy this area. This would be 13.5% of the land area corresponding to 4 persons in the village, say in a single dwelling unit. Perhaps the kitchen garden land use from Hamnett (2001) includes substantial contributions from urban as well as rural gardens. This would result in an over estimate of the plot size in the rural villages, which would make the risk results health conservative.

Table 3. Burn barrel parameters (US EPA, 1997b)

Stack Parameter	Value
Height (m):	0.81
Exit velocity (m s ⁻¹):	0.025
Temperature (oK):	381
Diameter (m):	0.51

MUNICIPAL WASTE COMBUSTOR

Emission source and receptor specifications

The public solid waste management company, Odvoz a Likvidacia Odpadu (OLO), operates the municipal waste combustor located in Bratislava just about 2.5 km from the largest and a densely populated residential city district of Petržalka. After 23 years of operation as an incinerator, it was upgraded to a modern waste-to-energy facility equipped with the state-of-the-art air pollution cleaning system in 2003. In addition to the steam supply it generates 5.4 MW of electrical power and, operating for 7500 hours per year, can process 134,000 metric tons (tonnes) of municipal solid waste. A design objective of the new facility is to achieve emissions that comply with European Union limits (EC, 2000a) governing new plants built after 28 December 2004. Table 3 compares the MWI and WTE stack parameters.

Figure 3. CALPUFF modeling domain of Bratislava for MWC runs with terrain height scale.

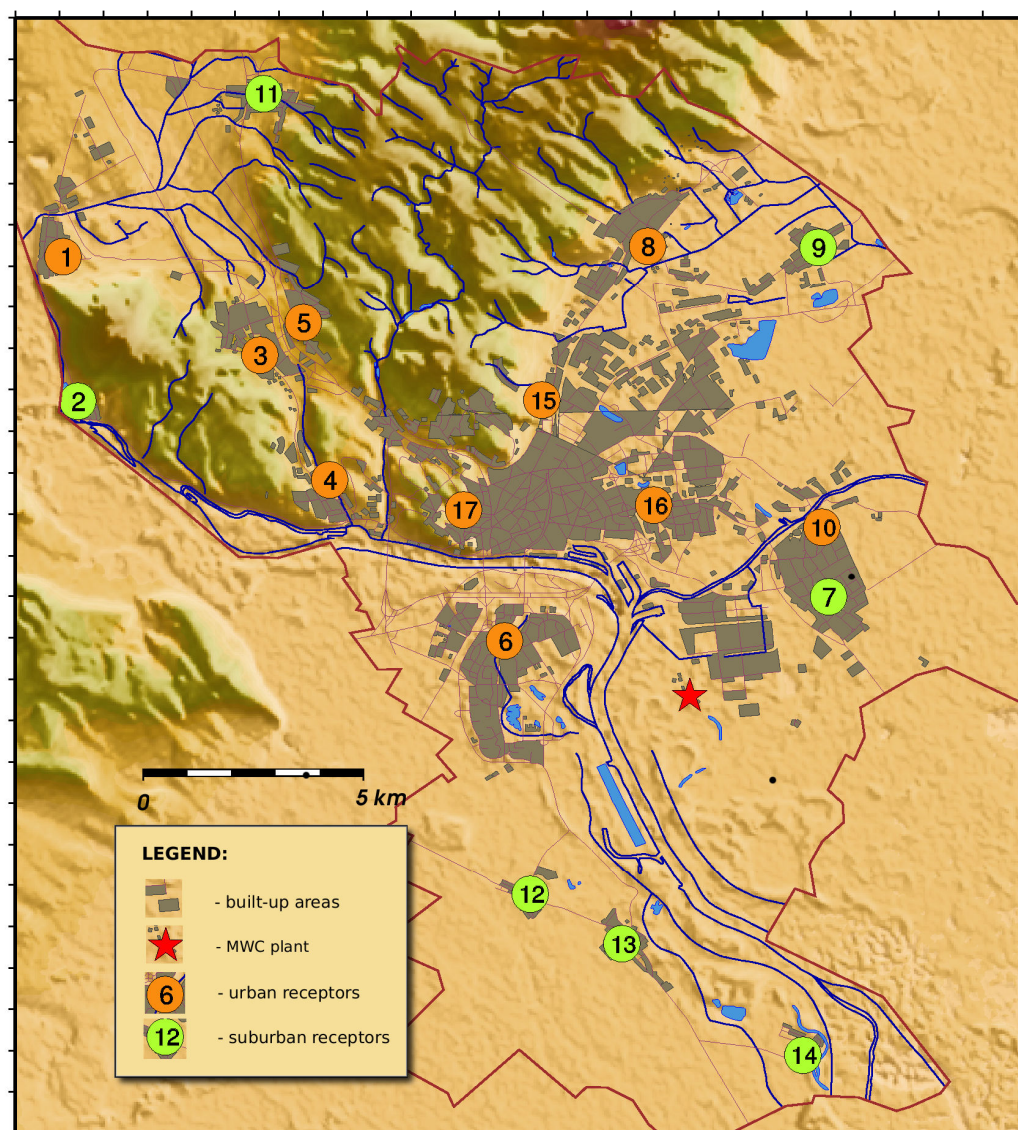


Table 3. OLO Bratislava MWI parameters versus WTE parameters

Stack Parameter	MWI	WTE
Height (m):	120	120
Exit velocity (m.s ⁻¹):	6	4.4
Temperature (°K):	396	373
Diameter (m):	2.5	2.5

Table 4. Discrete receptors for municipal waste combustor assessments

No	Municipality	Population	Category
1	DNV	16652	urban
2	Devín	737	suburban
3	Dúbravka	38920	urban
4	Karlova Ves	31662	urban
5	Lamač	7224	urban
6	Petržalka	126469	urban
7	Podunajské Biskupice	20586	suburban
8	Rača	21068	urban
9	Vajnory	3399	suburban
10	Vrakuňa	18523	urban
11	Záhorská Bystrica	1827	suburban
12	Jarovce	1087	suburban
13	Rusovce	1700	suburban
14	Čunovo	783	suburban
15	Nové Mesto	39977	urban
16	Ružinov	73847	urban
17	Staré Mesto	47817	urban

CHEMICALS OF POTENTIAL CONCERN (COPC)

Based on source emissions, toxicity and experience with similar risk assessments, the number of chemical pollutants considered is reduced to form a short list. These COPCs essentially drive the main quantitative outcome of the risk assessment.

Polychlorinated Dibenzo(p)dioxins and Dibenzofurans (PCDD/Fs)

PCDDs and PCDFs are among the most important chemicals of concern emitted during municipal waste combustion. They form as a result of fly ash catalyzed reactions between chlorine-containing chemicals and organic material. Their concentration in the flue gas depends on the combination of temperature, residence time and particulate level in the post-combustion zones.

In evaluating fate-and-transport pathways, they are primarily associated with particulate and organic matter because of their high lipophilicity and low water solubility. Higher chlorinated congeners (hexa–hepta) are predominantly sorbed to airborne particulates, tetra- and penta-congeners are mostly partitioned to the vapor phase.

There is evidence that exposure to PCDD/Fs results in a broad spectrum of cancer and noncancer effects in animals, some of which may occur to humans.

There are 210 individual congeners of PCDD/Fs, from which the most toxic are those with chlorine molecules substituted in the 2, 3, 7, and 8 positions. The most toxic of all is 2,3,7,8-TCDD. There are other 16 PCDDs and PCDFs with toxicity similar to 2,3,7,8-TCDD (so called “dioxin-like” toxicity). Risks associated with dioxin-like PCDD/Fs are assessed based

on their toxicity relative to that of 2,3,7,8-TCDD. Each congener is assigned a value, referred to as toxicity equivalency factor (TEQ) corresponding to their toxicity relative to 2,3,7,8-TCDD. TEQ values of the 17 congeners is listed in Table 8.

Cancer risk calculation: Fate and transport properties considerably differ among individual congeners. Therefore, the exposure media concentrations should be computed for individual congeners using congener-specific emission rates and fate and transport properties. If fate and transport data are incomplete for individual congeners, the exposure media concentrations should be evaluated separately at least to individual homologues level. These individual concentrations should then be converted to TEQ and lifetime incremental cancer risk should be computed using CSF for 2,3,7,8-TCDD.

Table 5. PCDD/PCDF congeners and their TEQ¹ values (US EPA, 1998)

	TEQ	FURAN CONGENER	TEQ
2,3,7,8-Tetrachlorodibenzo(p)dioxin	1	2,3,7,8-Tetrachlorodibenzofuran	0.1
1,2,3,7,8-Pentachlorodibenzo(p)dioxin	0.5	1,2,3,7,8-Pentachlorodibenzofuran	0.05
1,2,3,4,7,8-Hexachlorodibenzo(p)dioxin	0.1	2,3,4,7,8-Pentachlorodibenzofuran	0.5
1,2,3,6,7,8-Hexachlorodibenzo(p)dioxin	0.1	1,2,3,4,7,8-Hexachlorodibenzofuran	0.1
1,2,3,7,8,9-Hexachlorodibenzo(p)dioxin	0.1	1,2,3,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,4,6,7,8-Heptachlorodibenzo(p)dioxin	0.01	1,2,3,7,8,9-Hexachlorodibenzofuran	0.1
1,2,3,4,6,7,8,9-Octachlorodibenzo(p)dioxin	0.001	2,3,4,6,7,8-Hexachlorodibenzofuran	0.1
		1,2,3,4,6,7,8-Heptachlorodibenzofuran	0.01
		1,2,3,4,7,8,9-Heptachlorodibenzofuran	0.01
		1,2,3,4,6,7,8,9-Octachlorodibenzofuran	0.001

¹Toxic Equivalency Factor relates the toxicity of an individual congener to the toxicity of 2,3,7,8-TCDD. The toxicity of 1 gram of a congener with TEQ = 0.1 equals the toxicity of 0.1 gram of 2,3,7,8-TCDD.

Polynuclear Aromatic Hydrocarbons (PAHs)

PAHs are well-known as one of the principal semi-volatile aromatic components of emissions from all combustion sources. Some of them are considered carcinogenic. Benzo(a)pyrene is the most studied PAH and the only one for which both inhalation and oral cancer slopes are available. Table 6 lists the most commonly detected PAHs together with their relative potency factors (RPF) relating their toxicity to benzo(a)pyrene in a similar way as the TEQ relates various PCDD/Fs congeners to 2,3,7,8-TCDD. However, unlike the TEQ method, the RPF method relating the concentration of PAHs to benzo(a)pyrene at the emission point and using benzo(a)pyrene fate-and-transport properties for exposure quantification.

For some of other PAHs, such as naphthalene, pyrene, fluorene, fluoranthene which are detected in open-burning emissions, only non-carcinogenic health effects are known and should be evaluated in the risk assessment.

Table 6 The most commonly detected PAHs and their relative potency factors. (US EPA, 1998)

COMPOUND	RPF
Benzo(a)pyrene	1
Benzo(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.01
Chrysene	0.001
Dibenz(a,b)anthracene	1
Indeno(1,2,3-cd)pyrene	0.1

Polychlorinated Biphenyls (PCBs)

In the past, PCBs were produced commercially. Their most commercially useful property is that they are chemically stable at high temperatures in an oxygen-containing atmosphere. That also means that their destruction requires high temperature (at least 1200 °C) and extended time.

Some of the moderately chlorinated PCB congeners can have dioxin-like effects and were assigned the TEQ values. The remaining PCB mixture (if present) should be evaluated according the degree of chlorination:

- if the mixture contains less than 0.5 % of congeners with more than 4 chlorines, fate-and-transport properties of Aroclor 1016, and CSF of 0.07 (mg/kg-day)⁻¹ be used in the modeling
- if the mixture contains more than 0.5 % of congeners with more than 4 chlorines, fate-and-transport properties of Aroclor 1254, and CSF of 2 (mg/kg-day)⁻¹ be used in the modeling.

Noncancer hazards should be evaluated for those Aroclors having RfDs and RfCs. The fate-and-transport properties rules are the same as for carcinogenic risk assessment.

Volatile Organic Compounds (VOCs)

Some of them, such as benzene, are carcinogenic, many of them have non-cancer health effects. Due to their volatility, only direct inhalation pathway is relevant for inclusion into the their risk assessment. It is supposed that only products of VOC decomposition enter the indirect pathways, but their fate-and-transport properties are poorly understood, so the indirect pathways are not included in the risk assessment.

Metals

Hazard identification should be focused on the following metals with carcinogenic health effects: antimony, arsenic, barium, beryllium, cadmium, hexavalent chromium, lead, mercury (elemental and divalent), nickel, selenium, silver, thallium, and zinc. All of these metals except mercury are assumed to exist in the condensed phase of the particulate matter.

Some of them are to be treated in special ways, which will be discussed in the following paragraphs.

Chromium - Its toxicity is determined by its oxidation state. Hexavalent Chromium is the most toxic valence state of chromium and has been shown to be a human carcinogen through inhalation exposure. Trivalent chromium has not been shown to be carcinogenic. Only a small part of the total chromium emissions is in hexavalent form. In case of lack of detailed chromium speciation, a value of 3% is used in some waste combustion studies (Eschenroeder et al, 1999), based on measured data.

Lead - Lead has both non-carcinogenic and carcinogenic effects on human health. However, it differs from other carcinogenic metals in that serious non-carcinogenic effects develop at low doses, especially in highly sensitive sub-populations such as children. It has been found that neurobehavioral effects have been observed in children with blood lead levels below those that have caused carcinogenic effects in laboratory animals. As stated in US EPA (2006), current knowledge of lead pharmacokinetics indicates that risk values derived by standard procedures would not truly indicate the potential risk, because of the difficulty in accounting for pre-existing body burdens of lead. Lead bioaccumulates in the body, primarily

in the skeleton. Lead body burdens vary significantly with age, health status, nutritional state, maternal body burden during gestation and lactation, etc. For this reason, and because of the continued apparent lack of threshold, the method based on reference doses and concentrations is not recommended for lead risk assessment.

Special models have been developed for lead risk assessment, based on predicting the blood lead levels associated with exposure to lead. However, as lead was not a chemical of primary concern in this study due to its relatively low emission rates, an alternative simpler method is applied to the non-cancer risk evaluation via ingestion pathway, developed by Eschenroeder (Eschenroeder et al., 1999), based on Maximum Contaminant Level for lead in drinking water of 0.02 mg/L, and an action level of 0.015 mg (US EPA, 1991). The action level for drinking water is converted to a conservative oral RfD by assuming the average water consumption of 2L/day, 100% absorption of the ingested lead, and average human body weight of 70 kg. The obtained value of 1.1×10^{-3} mg/kg-day is lower and so more conservative than the value which is obtained when child parameters are used for the calculation.

Mercury - Mercury is present in the emissions in vapor phase and bound to particles. Mercury vapor is emitted either in elemental form or as divalent mercury (usually as mercuric chloride). Only one percent of elemental mercury is supposed to be deposited, therefore it is supposed that all deposited mercury is in divalent form.

In addition to the two chemical states, mercury is chemically transformed to its organic form, so-called methylmercury, in soil, water and biota. The degree of methylation differs among the media and their physical and chemical properties. Methylmercury is the most toxic of all above-mentioned forms. Table 7 lists the partitioning of mercury as recommended by US EPA (1998) and Eschenroeder (1999).

Table 7 Mercury partitioning

	Air	Deposited	Soil	Water	Plants
Mercury 100%	80% vapor: 20% elemental 60% divalent 20% particle bound: divalent	Divalent	2% converted to methylmercury	15% converted to methylmercury	22% converted to methylmercury

Methylmercury is a highly toxic substance; a number of adverse health effects associated with exposure to it have been identified in humans and in animal studies. Most extensive are the data on neurotoxicity, particularly in developing organisms. The nervous system is considered to be the most sensitive target organ for which there are data suitable for derivation of an RfD.

2.3.6 Fine Particulate Matter (PM_{2.5})

PM_{2.5} is all condensed material suspended in air that has a mean aerodynamic diameter of 2.5 micrometers or less. When inhaled by humans, 40% of 2.5 µm particles reach the lung (Dinman, 1978). Adverse effects of particulates depend on their chemical nature (Dinman, 1978), which results in a wide range of toxicity associated with them. That is the reason why they are not assessed as a separate COPC for chronic carcinogenic or non-carcinogenic toxicity. However, several epidemiologic studies have been performed in the past relating PM_{2.5} exposure to premature mortality. Several such studies are evaluated in Levy and Spengler (2002). They selected American Cancer Society (ACS) study (Pope et al, 1995) results as the most reliable with the value of relative risk falling between the other two studies. ACS study was a retrospective analysis of a cohort of more than 500 000 adults across the US followed from 1982 to 1989. Relative risk of 1.12 have been calculated for a

24.5 $\mu\text{g}\cdot\text{m}^{-3}$ increase in annual mean $\text{PM}_{2.5}$ concentrations, corresponding to 0.5% increase in premature mortality per 1 $\mu\text{g}\cdot\text{m}^{-3}$ (Levy and Spengler, 2002).

Tables 8 and 9 list the annual emissions of the chemicals from open burning and from MWC.

Table 8 Annual emissions of contaminants of potential concern from open burning of waste in three hypothetical villages – based on open burning emission factors (US EPA, 1997b)

AIR CONTAMINANT	Annual emissions (kg year^{-1})		
	MIN	MOD	MAX
benzene	246.58	419.00	925.76
acetone	187.13	317.98	702.56
styrene	146.43	248.83	549.77
naphthalene	37.11	63.05	139.31
toluene	94.76	161.03	355.78
phenol	30.92	52.55	116.10
PAHs	13.17	22.38	49.46
acetaldehyde	167.10	283.95	627.36
benzaldehyde	56.66	96.28	212.72
formaldehyde	171.57	291.54	644.14
total PCDD/F	0.01	0.01	0.03
total PCB	0.57	0.97	2.14
PM_{10}	3741.62	6357.95	14047.50
$\text{PM}_{2.5}$	3479.28	5912.16	13062.56
HCl	56.66	96.28	212.72
Arsenic	0.45	0.76	1.68
Cadmium	0.03	0.05	0.10
Chromium	0.04	0.06	0.13
Lead	0.08	0.13	0.29
Nickel	0.05	0.08	0.19
Zinc	0.01	0.02	0.05

Table 9 OLO Bratislava (incinerator vs. WTE plant)

Pollutant		OLO Bratislava combustor (kg year^{-1})	
		MWI ^a	WTE ^c
Metals	Cd	18.3	2.0 (19.5 ^a)
	As	31.3	3.2 (126 ^a)
	Cr VI	0.6	0.04
	Ni	5.7	3.84
	Pb	25.0	19.5 (212 ^a)
	Zn	0.7	58.95
	Hg	2.0	163
Organics	benzene	57.7	-
	naphthalene	22.7	-
	toluene	297.0	-
	PCB	1.8 ^b	-
	PCDD/F ^d	0.09 ^b	1.1E-04
	PAH	164.5 ^b	-
Acids	HCl	56500	15780 (4260 ^a)
PM	TSP	69300	4630 (1430 ^a)

^a NEIS database (NEIS, 2005)

^b PHARE Project EU/93/AIR/22 (PHARE, 1997)

^c AP 42 (U.S. EPA, 1985)

^d in Toxic Equivalence (iTEQ) units

SOURCES OF THE DOSE-RESPONSE DATA USED IN THE STUDY

IRIS database (US EPA, 2006) was the primary source of dose-response data except for the PCDD/F cancer slope factors, which were obtained from US EPA (2000), and non-cancer reference dose and concentration for benzo(a)pyrene, retrieved from Holstein (1985). Current knowledge of lead pharmacokinetics indicates that risk values derived by standard procedures would not truly indicate the potential risk, because of the difficulty in accounting for pre-existing body burdens of lead (US EPA, 2006). However, as lead was not a chemical of primary concern due to its relatively low emission rate, a reference dose for lead was adopted from Eschenroeder et al. (1999), and the premature mortality relative risk for PM_{2.5} relies on the study of Levy and Spengler (2002).

Table 10 COPC for the municipal waste combustion risk assessment

CONTAMINANT	TOXICITY	CANCER EFFECTS		NON-CANCER EFFECTS	
		CSF		RfD	RfC
		Ingestion (mg/kg-day) ⁻¹	Inhalation (mg/kg-day) ⁻¹	Ingestion (mg/kg-day)	Inhalation (mg/m ³)
Arsenic	C, NC*	1.5	15	0.0003	0.0011
Cadmium	C, NC		6.3		0.0035
Chromium VI	C, NC		41		0.018
Lead	NC			0.09 ^a	0.09 ^a
Mercury - methylated	NC			0.0001	
Mercury - elemental	NC				0.0003
Mercury - divalent	NC			0.0002	0.0011
Nickel	C, NC		0.84		0.07
Zinc	NC			0.3	1.1
PAHs as benzo(a)pyrene	C, NC	7.3	7.3	0.04 ^c	0.04 ^c
PCB (Aroclor 1254)	NC			0.00002	0.00007
PCDD/F	C	1.5E+05 ^b	1.5E+05 ^b		
Formaldehyde	C, NC	0.045	0.045	0.2	0.7
Hydrogen Chloride	C, NC				20

* C – cancer, NC – non-cancer, ^a Eschenroeder et al. (1999), ^b US EPA (2000), ^c Holstein (1985)

Table 11 COPCs for the open burning risk assessment

CONTAMINANT	TOXICITY	CANCER EFFECTS		NON-CANCER EFFECTS	
		CSF		RfD	RfC
		Ingestion (mg/kg-day) ⁻¹	Inhalation (mg/kg-day) ⁻¹	Ingestion (mg/kg-day)	Inhalation (mg/m ³)
Arsenic	C, NC	1.5	15	0.0003	0.0011
Cadmium	C, NC		6.3		0.0035
Chromium VI	C, NC		41		0.018
Lead	NC			0.09 ^a	0.09 ^a
Nickel	C, NC		0.84		0.07
Zinc	NC			0.3	1.1
benzene	C, NC	0.03	0.03	0.02	0.06
acetone	NC			0.1	0.35
styrene	NC			0.2	1
naphthalene	NC			0.04	0.14
toluene	NC			0.2	0.4
phenol	NC			0.6	2.1
pyrene	NC			0.03	0.11
fluoranthene	NC			0.04	0.14
fluorene	NC			0.04	0.14
acetaldehyde	C, NC	0.0077	0.0077	0.0026	0.009
benzaldehyde	NC			0.101	0.35
formaldehyde	C, NC	0.045	0.045	0.2	0.7
PAHs as benzo(a)pyrene	C, NC	7.3	7.3	0.04 ^c	0.04 ^c
PCDD/F	C	1.5E+05 ^b	1.5E+05 ^b		
PCB (Aroclor 1254)	NC			0.00002	0.00007
hydrogen chloride	NC			0.0057	0.02
hydrogen cyanide	NC			0.02	0.07

* C – cancer, NC – non-cancer, ^a Eschenroeder et al. (1999), ^b US EPA (2000), ^c Holstein (1985)

Tables 8 and 9 list the toxicity data for COPCs. Data obtained from other sources than IRIS are marked by superscripts which are explained below the tables. Pollutants having annual air quality standards according to national and European legislation (see Table 10) will be also compared to these values.

In addition to the risk assessment of substances listed in the tables, an increased mortality caused by PM_{2.5} (Levy and Spengler, 2002) will be explored, as was mentioned previously.

Table 12 National and European air quality standards for selected COPCs

Air pollutant	Annual limit value		Legislation
PM ₁₀	40 - 20 ^a	µg.m ⁻³	<i>Decree 705/2002 of the Ministry of the Environment</i>
Pb	0.5 ^b	µg.m ⁻³	
benzene	5 - 0 ^a	µg.m ⁻³	
As	6	ng.m ⁻³	<i>Directive 2004/107/EC</i>
Cd	5	ng.m ⁻³	
Ni	20	ng.m ⁻³	
BaP	1	ng.m ⁻³	

^aTarget values to be reached on 1.1.2005 and 1.1.2010, respectively

^bTarget value to be reached on 1.1.2005

MODELING TOOLS USED FOR THE EXPOSURE ASSESSMENT

CALPUFF air dispersion model

As was already mentioned, an air dispersion model is used to determine average annual concentrations and deposition fluxes. Existing atmospheric dispersion models differ in various aspects, such as physical approach to the modeling, the level of detail in the description of the physical processes in the atmospheric boundary layer, or the capability to treat reactive pollutants. The selection of the most appropriate dispersion model depends in part on the size of the region to be modeled (computational domain size), the time intervals of interest, its specifics (e.g., emission source(s) properties and the properties of emitted species), and the desired output.

For the needs of risk assessment, US EPA recommends using of ISCST3 model (Bowers et al., 1979), which is a steady-state gaussian model widely used in the US as well as in Europe. This model would be applicable to the MWC emissions simulation, because it includes a tall point source with continuous emissions. However, open burning of household waste involves a large number ground-level point sources with time-varying emissions. Use of a steady-state model for such emission settings does not afford the flexibility of short-term time dependence. Therefore, CALPUFF model (Scire et al, 2000a,b) was selected for modeling both MWC and the open burning, meeting the criteria determined by the special nature of the open burning emission settings. It is a US EPA model, and one of its advantages is that it is available together with its source code, leaving the opportunity for modifications or adjustments.

CALPUFF as a modeling system consists of three main programs:

1. CALMET is a meteorological model that develops hourly wind and temperature fields on a three-dimensional gridded modeling domain, with the terrain-following vertical

coordinate. It also produces two-dimensional fields such as mixing height, surface characteristics and dispersion properties (Scire et al., 2000).

CALMET reads ASCII files with hourly surface data, twice-daily upper air soundings and gridded topographic data and produces one binary file containing hourly gridded three-dimensional wind fields and two-dimensional parameters of the boundary layer.

2. CALPUFF is a multi-layer multi-species non-steady-state puff dispersion model which can simulate time- and space-varying meteorological conditions on the pollutant transport, transformation and removal (Scire et al., 2000). CALPUFF uses the meteorological binary file from CALMET as an input, and produces a binary file containing hourly gridded values of concentration, and other binary files with wet and dry deposition fluxes according to user's specification in the control file.
3. CALPOST is a postprocessor; it serves for computation of desired averages specified in its input file. CALPOST outputs are ASCII or binary grid files of gridded fields of specified average concentrations.

An air dispersion model for calculation of concentrations and deposition is a complex system and is described in more detail in Appendix A.

Meteorological, geophysical and species data used for CALPUFF simulation for both OLO facility and open burning are discussed in Appendix B. Appendix B also contains model run protocol explaining the method used for processing of large number of chemical species involved in the risk assessment.

EMERAM – environmental media and risk assessment model

EMERAM model, developed in the course of this study, is a computer program involving a system of models of fate and transport of chemicals in all environmental media but air. Annual air concentrations and deposition fluxes enter EMERAM as inputs, together with the exposure data discussed later in this document. EMERAM calculates the exposures to COPCs for all receptors through all environmental pathways specified by the user. The end product of the program is a set of tables of detailed pathway-specific ILCR and HQ (for explanation see Chapter 5) tables for each COPC, as well as summary tables for each COPC group, containing total COPC-specific values of ILCR and HIs for each receptor. A set of post-processors computes grand totals for each receptor, detailed pathway-specific totals for maximally impacted receptors, and risk profiles.

Media concentration equations used in EMERAM model:

Environmental fate and transport models, calculating the concentration of contaminants in soil, water and food-chain, use annual air concentrations and deposition as inputs. Unlike atmospheric models, they are box or compartment models based on mass balance equations and equilibrium state conditions. They are largely dependent on empirical parameters (Eschenroeder et al, 1999). The equations for calculating the concentrations for exposure assessment are listed in the following text. The adaptation and explanation of these exposure equations is organized along the lines followed by Eschenroeder et al (1999).

Soil concentration

$$C_s = \frac{100D_y}{k_s Z \rho_b} \cdot \frac{k_s t_D (1 - e^{-k_s t_D}) e^{-k_s (t_E - t_D)}}{k_s t_E} \quad (11)$$

where

C_s	is the concentration of contaminant in the soil (mg.kg ⁻¹),
100	is units conversion factor ((m ² .cm ⁻²)(mg.kg ⁻¹)),
D_y	is deposition flux (g.m ⁻² yr ⁻¹),
k_s	is soil loss constant (yr ⁻¹),
Z	is depth of soil mixed layer (cm),
ρ_b	is bulk density of the soil (g.cm ⁻³),
t_E	is time of exposure, and
t_D	is time of deposition.

The soil loss constant expresses the rate at which contaminant is lost from the soil; it may be done by leaching, runoff, erosion, biotic and abiotic degradation and volatilization.

For conservative cases of zero soil loss, the concentration is computed using the following formula:

$$C_s = \left(t_E - \frac{t_D}{2} \right) \frac{D_y}{Z \rho_b} \quad (12)$$

Eq. (11) is appropriate to obtain a high estimate for organic pollutant exposure influenced by a combination of deposition and biodegradation. Eq. (12) gives an upper bound exposure estimate for most inorganic pollutants.

Concentration in plant tissue

Generally, the concentration in plant tissue can be expressed as:

$$C_p = C_{pr} + C_{pd} + C_{pv} \quad (13)$$

Where

C_p	is the contaminant concentration due to all processes,
C_{pr}	is the contaminant concentration due to root uptake,
C_{pd}	is the contaminant concentration due to particle deposition on the exposed parts of the plant, and
C_{pv}	is the contaminant concentration due to air-to-plant transfer.

Various types of plants enter the food chain, differing in various aspects that influence the concentration in their edible parts; namely, the amount of biomass grown on a unit area, position of the edible part relative to the ground, protection of the edible part, etc. For our purposes, the two broad categories are either aboveground produce or below-ground produce. The aboveground produce can be divided into protected (e.g., covered with a shell or peel) and exposed. It is assumed that while all three processes are relevant for the aboveground exposed produce, only root uptake is considered for aboveground protected and below-ground produce.

The concentration due to root uptake is computed as:

$$C_{pr} = C_s B_r \quad (14)$$

Where

C_s is the soil concentration (mg.kg⁻¹), and
 B_r is the plant-soil bioconcentration factor (unitless).

Uptake response slopes are the sources of inorganic contaminant bioconcentration factors; for organic pollutants, it can be calculated from the formula (Travis and Arms, 1988):

$$\log B_{rj} = 1.588 - 0.578 \log K_{owj} \quad (15)$$

Where

K_{owj} is the octanol-water partition coefficient for jth chemical contaminant (unitless)

The concentration due to direct deposition is calculated as:

$$C_{pd} = \frac{1000 R_{pi} (D_{yd} + F_w D_{yw}) (1 - e^{-k_p T_p})}{k_p Y_{pi}} \quad (16) \quad \text{Where}$$

D_{yd} is annual dry deposition rate (g.m⁻²yr⁻¹),
 D_{yw} is annual wet deposition rate (g.m⁻²yr⁻¹),
 R_{pi} is interception fraction of ith plant group (unitless),
 F_w is fraction of wet deposition that adheres to plant surface (unitless),
 k_p is plant surface loss coefficient (yr⁻¹),
 T_{pi} is exposure time of the ith plant group edible parts to the deposition (yr), and
 Y_{pi} is yield of standing crop edible biomass of the ith plant group.

The concentration due to air-to-plant transfer is:

$$C_{pv} = \frac{C_{av} B_{vi} V G_{ag}}{\rho_a} \quad (17)$$

Where

C_{av} is annual vapor concentration of the contaminant (μg.m⁻³),
 B_{vi} is air-to-plant biotransfer factor for the ith plant group ((μg.g⁻¹ DW)/(μg.g⁻¹ air)),
 $V G_{ag}$ is empirical aboveground vegetation correction factor (unitless), and
 ρ_a is the density of air (1190g.m⁻³).

Air to plant biotransfer factor is calculated as:

$$B_{vi} = \frac{\rho_a B_{vol}}{\frac{100 - M_l}{100} \rho_p} \quad (18)$$

Where

M_l is moisture content of leaf (% water),
 ρ_p is leaf density with normal moisture content (μg.L⁻¹ leaf), and
 B_{vol} is the volumetric air-to-leaf biotransfer factor ((μg.L⁻¹ leaf)/(μg.L⁻¹ air)),

calculated as (Bacci et al, 1992):

$$\log B_{vol} = 1.065 \log K_{ow} - \log \left(\frac{H}{RT} \right) - 1.654 \quad (19)$$

where

H is Henry's law constant ($\text{Pa m}^3 \cdot \text{mol}^{-1}$),
 R is Ideal Gas constant ($\text{Pa m}^3 \cdot \text{mol}^{-1}$), and
 T is absolute temperature (293 K).

Concentration in animal tissues

Animal tissues entering human food chain include beef, pork, poultry, eggs and dairy products. A general equation for the concentration in an animal tissue can be written as

$$A = B_a \left[\sum_{i=1}^n (C_{pi} Q_{pi} F_i) + (C_s Q_s B_s) \right] \quad (20)$$

Where

A is concentration of contaminant in an animal tissue group ($\text{mg} \cdot \text{kg}^{-1}$),
 B_a is biotransfer factor for the animal tissue group ($(\text{mg} \cdot \text{kg}^{-1}) / (\text{mg ingested} \cdot \text{day}^{-1})$),
 C_{pi} is concentration in i^{th} plant group eaten by the animal ($\text{mg} \cdot \text{kg}^{-1} \text{ DW}$),
 Q_{pi} is quantity of i^{th} plant group eaten by the animal ($\text{kg DW} \cdot \text{day}^{-1}$),
 F_i is fraction of i^{th} plant group from contaminated soil eaten by the animal (unitless),
 C_s is concentration of the contaminant in soil,
 Q_s is daily quantity of soil eaten by the animal ($\text{kg} \cdot \text{day}^{-1}$),
 B_s is bioavailability of contaminant in soil relative to plant (unitless), and
 n is number of plant groups consumed by the animal.

C_{pi} and C_s are computed from the equations (4), and (2) or (3).

Water concentration

A contaminant is entering a water body through deposition on the water surface. The outflow of the chemical from the water column depends on the volumetric flow rate through the compartment.

Water compartment can be divided into water column and adjacent sediment layer at the bottom. The sediment layer that takes part in the water chemistry is assumed to be 0.1 m thick. Sediment is an important part of water compartment, because most of chemicals of potential concern are not easily soluble in water and they end up at the bottom.

Fugacity model developed by Mackay (1979) is used for calculation of contaminant concentration in water and sediment. According to that, the concentrations can be written as:

$$C_w = \frac{f \cdot M}{H} \quad (21)$$

$$C_s = \frac{f \cdot M \cdot 2K_{oc} f_{ocs}}{H}$$

$$f = \frac{A_w(D_{yds} + D_{yws})}{M(V_w Z_w K_w + V_s Z_s K_s)} \quad (22)$$

Where

- M is molecular weight of chemical (g.mol^{-1}),
- H is Henry's law constant ($\text{Pa m}^3.\text{mol}^{-1}$),
- K_{oc} is organic carbon partitioning coefficient (mL.g^{-1}),
- f_{ocs} is organic carbon mass fraction in the sediment (unitless),
- f is fugacity (Pa).
- A_w is the surface area of the water body (m^2),
- D_{yds} is the dry deposition flux of the contaminant ($\text{g.m}^{-2}\text{yr}^{-1}$),
- D_{yws} is the wet deposition flux of the contaminant ($\text{g.m}^{-2}\text{yr}^{-1}$),
- V_w, V_s are the volumes of the water and sediment columns of the compartment respectively (m^3),
- Z_w, Z_s are the fugacity capacity constants of water and sediment columns respectively ($\text{Pa m}^3.\text{mol}^{-1}$)⁻¹,
- K_w is the water turnover constant, defined as the ratio of the volume flow rate of water and the volume of the water column (yr^{-1}), and
- K_s is the biodegradation rate in the sediment (yr^{-1}).

The fugacity capacity constants are defined as:

$$Z_w = \frac{1}{H} \quad \text{and} \quad Z_s = \frac{10^{-8} f_{ocs} K_{oc} \rho_s}{H} \quad (23)$$

Where ρ_s is the density of the sediment (g/cm^3).

The above formulae do not apply to inorganic substances, such as metals, for which the Henry's Law constant is zero. In such case a simple mass-balance can be used:

$$C_w = \frac{A_w(D_{yds} + D_{yws})}{Flw} \quad (24)$$

$$C_s = Kds \cdot C_w$$

Where

- Flw is flow rate of the water ($\text{m}^3.\text{yr}^{-1}$),
- Kds is soil-water partitioning coefficient (cm^3 water per g soil).

Fish concentration

The following formula relates the contaminant concentration in edible fish tissue to that in the water:

$$C_f = BAF \cdot C_w \quad (25)$$

Where

- C_f is the contaminant concentration in fish (mg.kg^{-1}),

C_w is the contaminant concentration in water (mg.L^{-1}), and
 $BASF$ is bioaccumulation factor ($(\text{mg.kg}^{-1})/(\text{mg.L}^{-1})$).

For PCDD/Fs, which are bound to sediment rather than diluted or suspended in water, a formula related to sediment concentration is used:

$$C_f = f_L \cdot BASF \cdot K_{oc} \cdot C_w \quad (26)$$

Where

f_L is fraction by weight of lipid tissue in the fish (kg lipid.kg^{-1} fish),
 $BASF$ is biota-sediment accumulation factor ($(\text{mg.kg}^{-1} \text{ lipid})/(\text{mg.kg}^{-1} \text{ sediment org C})$),
 K_{oc} is organic carbon partition coefficient ($(\text{mg.kg}^{-1} \text{ sediment org C})/(\text{mg.L}^{-1})$).

Maternal milk concentration

The formula is based on the theory (Smith, 1987) of equilibrium between the mother's body fat and the fat in her milk. This is especially important with the lipophilic contaminants such as PCDD/Fs and PCBs.

$$C_m = \frac{I_m B_f P_f T_{1/2}}{0.693 P_w} \quad (27)$$

Where

C_m is contaminant concentration in maternal breast milk (mg.kg^{-1}),
 I_m is contaminant intake rate by the mother ($\text{mg.kg}^{-1} \text{ day}^{-1}$),
 B_f is mass fraction of fat in the breast milk (0.04),
 P_f is proportion of contaminant distributed to fat (0.8),
 $t_{1/2}$ is half life of contaminant in the mother's body,
0.693 conversion from half life to first order rate constant ($\ln 2$), and
 P_w mass fraction of fat in the mother's body (0.3).

CALPUFF IMPLEMENTATION - DATA AND MODELING PROTOCOL

Following sections describe meteorological, geophysical and species data needed for running CALPUFF model. Modeling protocol will explain the approach adopted to treat the large number of chemical species involved in the HRA.

CALPUFF data requirements

CALMET is a meteorological model that develops hourly wind and temperature fields on a three-dimensional grided modeling domain, with the terrain-following vertical coordinate (Scire et al, 2000a). It generates these data along with two-dimensional fields such as mixing height, surface characteristics and dispersion properties. These outputs drive the atmospheric dispersion and transport algorithms in CALPUFF.

Optimum data requirements are such that enable capitalizing on all powers and capacity of the CALPUFF modeling system. Taking into account the desired output, the necessary input data

are organized in Table 13. To achieve the most realistic results, it is desirable to use data from all available surface, upper air and precipitation stations in the concerned region.

Table 13. *CALMET/CALPUFF data requirements*

	CALMET – data requirements	Source of data
Meteorological data	Hourly surface observations (wind speed and direction, cloud base height, opaque sky cover, temperature, relative humidity)	KMIS ^a database: measurements from 2 synoptic surface stations
	Hourly data on precipitation intensity and precipitation type	KMIS ^a database: measurements from 2 automatic surface stations and respective daily climatological reports
	Twice-daily upper-air soundings	upper air soundings from 1 aerological station and pseudo-soundings generated by ALADIN LAM ^b prognostic model
Geophysical data	Terrain model	USGS SRTM ^c data
	Grided landuse	detailed maps (VKU, 1994, 1999), villages – simplified based on statistical data

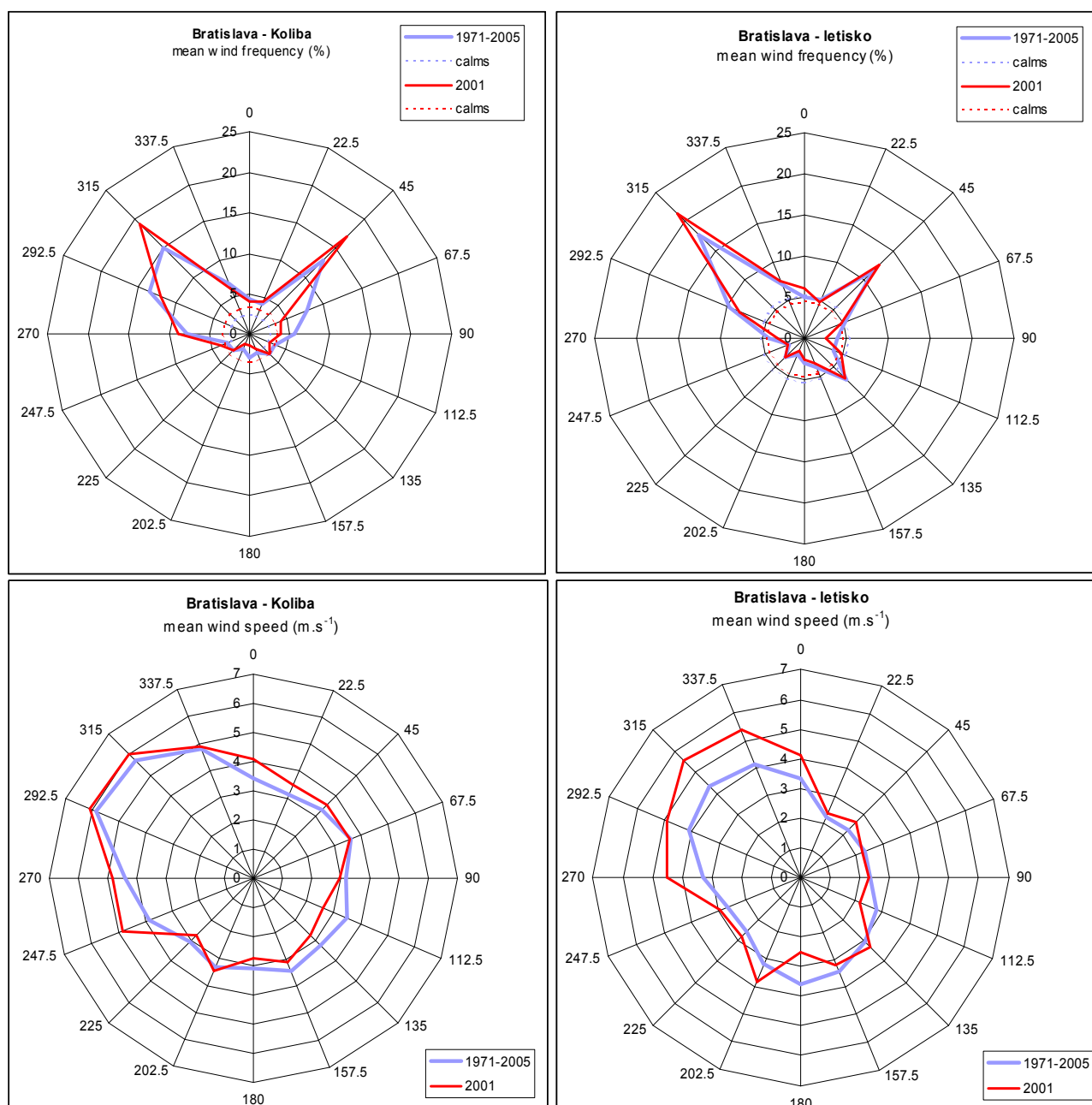
^a Climatological and meteorological information system

^b Limited area model

^c US GeoShuttle Radar Topographic Mission (web page <http://srtm.usgs.gov/>)

Since this modeling system was designed primarily for use in the US, its pre-processors transform the meteorological data from the formats readily available in the National Climatic Data Center or EPA Support Center for Regulatory air Models web site, into the form that is compatible with CALMET. It became necessary to design a new system of pre-processors to be applied on Slovak data which is archived in different formats.

Sequential data are not routinely used for dispersion modeling in Slovakia. Thus, unlikely to US, there is no unified database which would provide a collection of sequential meteorological data necessary for dispersion modeling. Although some data are available through an INGRES based KMIS database, only some of the hourly parameters are checked for quality (i.e., SYNOP surface observations). Data from the automatic stations, particularly precipitation intensity, are not checked for completeness or quality, therefore, methods had to be developed for checking the data and adjusting them to the most realistic values. The required completeness and quality checks were two of the important factors determining the selection of the year of simulation and the number of meteorological stations used for CALMET runs. The year 2001 was chosen for analysis, since it seemed sufficiently consistent with long term averages of wind speed and directions, as can be seen on Figure 4. This particular year had a minimum of data problems such as inconsistent entries and data gaps.

Figure 4. Wind roses for Bratislava – Koliba and Bratislava – airport meteorological stations.

For the sake of comparison, the same set of meteorological data is used as input to CALMET for both OLO facility and the open burning. These meteorological data consist of Bratislava Airport and Koliba SYNOP and automatic station reports, and Vienna upper air soundings complemented by pseudotemps generated by the ALADIN prognostic LAM model, after their pre-processing into the formats desired by CALMET. The default values of albedo, Bowen ratio, soil heat flux parameter, anthropogenic heat flux and leaf area index are related to the grided landuse categories.

The data listed above are the same for both settings. However, Bratislava domain was modeled realistically with complex terrain, while flat terrain setting was used for the prototype villages. Geographically, the villages were sited inside of Bratislava city area.

Terrain heights were extracted from USGS GTOPO 30 database covering the entire world with the resolution of 30 arc seconds (~ 900 m); the database is publicly available from the internet. (<http://edcwww.cr.usgs.gov/landdaac/gtopo30.html>).

Although landuse data were also available from the above-mentioned public source, the data used for this modeling were generated from a 1:50 000 geographical map and aerial map of Bratislava surroundings (VKÚ, 1994, 1999). Currently, a high-quality CORINE land cover 2000 data are available at the institute and are used for CALPUFF applications.

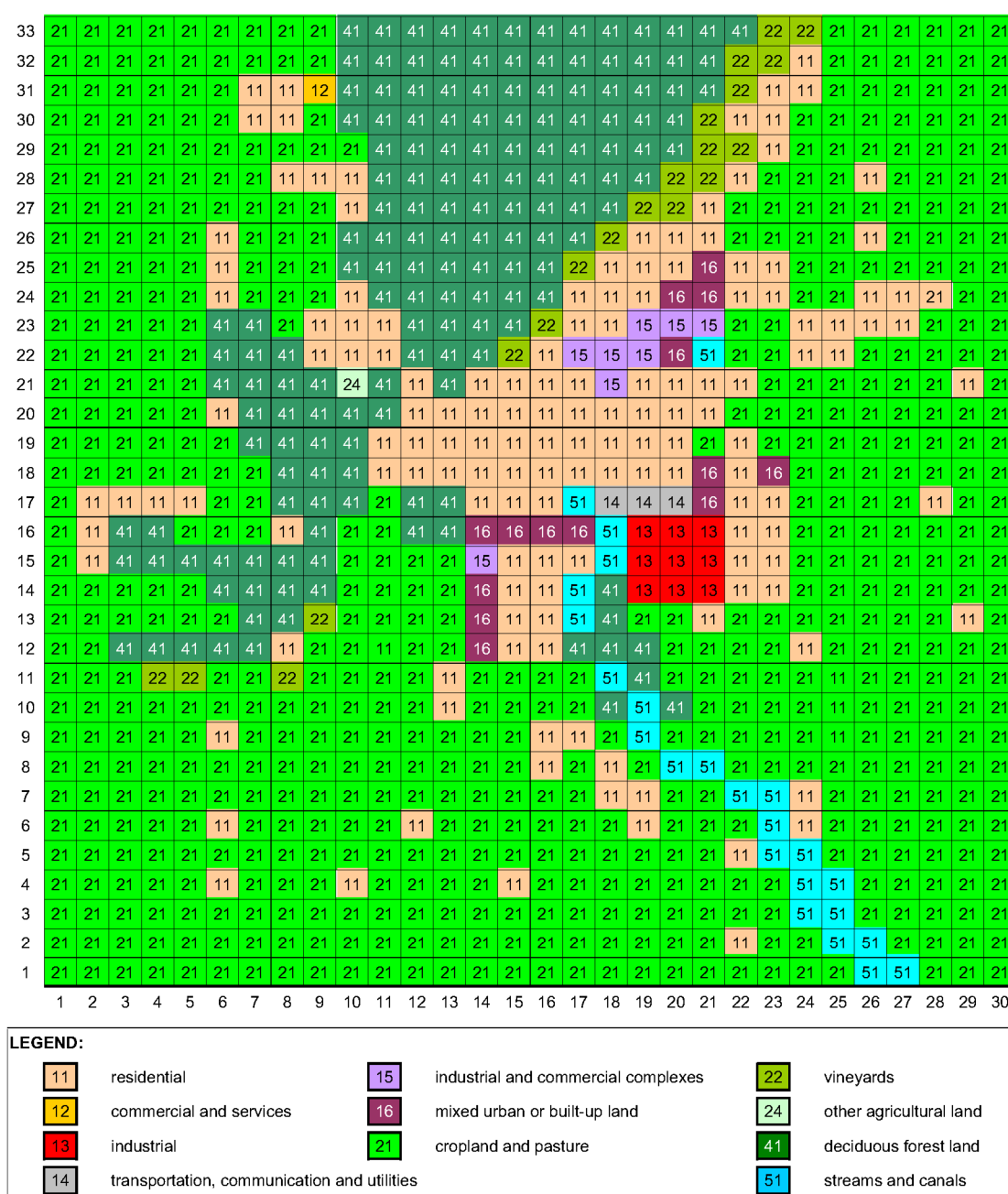
Table 14 lists some basic model parameter values for OLO MWC and village CALPUFF runs.

Table 14. Basic CALPUFF settings for MWC and villages

CALPUFF settings		MWC	Villages		
			MIN	MOD	MA.
Computational domain		30 x 33 km	4 x 4 km	5 x 5 km	7 x 7 km
Grid size		1 km	0.5 km		
Vertical layers		6			
Top layer height		3 300 m	1 000 m		
Gridded receptor spacing		1 km	500 m		
Discrete receptors		17	86	148	320
Discrete receptors spacing		-	80 m		
Terrain scheme		complex terrain	flat terrain		
Landuse scheme		gridded landuse categories			
Deposition	wet	yes	no		
	dry	yes	yes		
Species modeled		1 gas, 3 particle			
Emissions	No. of sources	1	13	24	52
	Source spacing	-	200 m		
	Time depend.	continuous	variable		

Landuse categories for the prototype villages are determined by the radii of village and agricultural land as stated in Table 2. Geographically, the synthetic villages are “sited” on the flat area of Bratislava. They have a common center, but the diameters of the villages and their agricultural surroundings differ in sizes and receptor fields, which results in different CALMET meteorological files.

Figure 5 shows the domain landuse categories.

Figure 5 CALMET domain with landuse categories

Vapor-to-particle partitioning and particle distributions

Chemical species released from a combustion source can be emitted either as vapors, particles, or bound to particulate matter. Metals are assumed to occur only in particle phase (with the exception of mercury, as was described in Chapter 3), while organic pollutants are released in vapor phase, or condensed on the surface of particles (US EPA, 1998). Semivolatile organic compounds, including PAHs, PCBs and PCDD/Fs, can exist in both phases, and their vapor-to-particle ratio is controlled by their vapor pressure and the total suspended particle concentration (Bidleman, 1988).

Chemicals emitted as particles are modeled with different mass fractions allocated to each particle size than the mass fractions for the particle-bound organics (US EPA, 1998). While for the first group are the fractions allocated to each particle size interval mass (volume) weighted, for the second group they are surface area weighted, since the organic compounds are adhered to the surface of particles.

Table 15 shows the particle size intervals and the respective mass fractions for OLO MWC and burn barrel emissions. Particulate emission factors for OLO facility are based on AP 42 Compilation of Air Pollutant Emission Factors (US EPA, 1985). In case of burn barrel particulate emissions, data on the first two particle size intervals were obtained from Lemieux (2000), the largest particle emissions are based on (US EPA, 1985).

Table 15. Mass and area distributed particulate matter emissions for the OLO facility and burn barrel emissions.

Particle size interval (μm)	Geometric mean within the interval (μm)	Mass fractions of particulates within particle size interval (unitless)			
		OLO facility		Burn barrel	
		mass weighted	area weighted	mass weighted	Area weighted
1 - 2.5	1.6	0.260	0.733	0.498	0.902
2.5 - 10	5.0	0.120	0.107	0.038	0.022
10 - 30	17.3	0.620	0.160	0.464	0.077

Area weighted fractions were computed using the method described in US EPA (1998).

Columns 3 and 4 are valid for both the old incinerator and the new WTE unit equipped with fabric filter technology for removal of particulates from the emission stream. Although fabric filters remove up to 99.55% of the particulate matter (Eschenroeder, 1985), the efficiency of removal is assumed to be independent of particle size (EPRI, 1978).

Table 16 lists the vapor-to-particle partitioning of COPC included in this risk assessment.

Table 16. Vapor-to-particle partitioning of modeled chemical groups.

AIR CONTAMINANT	Vapor	Particle	Particle-bound
VOCs	✓	-	-
Chlorobenzenes	✓	-	-
aldehydes & ketones	✓	-	-
PAHs	✓	-	✓
PCDDs	✓	-	✓
PCDFs	✓	-	✓
PCBs	-	-	✓
HCl	✓	-	-
HCN	✓	-	-
metals (except for Hg)	-	✓	-
Mercury	✓	✓	-

Model run protocol

The number of chemical species included in the risk assessment is so large that it is

impractical, and in reality almost impossible, to run the atmospheric dispersion model separately for all phases of all chemical species with their actual emission rates. Fortunately, under certain conditions, this procedure can be simplified, using a unit emission rate for each phase (vapor, particulate, particle-bound):

Let U_{ij} be the concentration contribution resulting from unit emission rate from j -th source at i -th receptor. Let $U_i = \sum_j U_{ij}$ be the total concentration from all sources at i -th receptor. Let K_j be the scaling factor (or actual emission rate) for j -th source. Then total scaled (actual) concentration from all sources at i -th receptor is $C_i = \sum_j K_j U_{ij}$. Unfortunately, the dispersion model is not able to output concentration contributions from each emission source separately. Even if it is, it would result in increased computational time and an enormous amount of data. However, in case of identical emission sources $K_1 = K_2 = \dots = K_j = K$, then $C_i = \sum_j K U_{ij} = K \sum_j U_{ij} = K U_i$.

So, in case of a single emission source, or multiple sources with identical emission rates, resulting concentration and deposition fields are multiplied by actual emission rates of each chemical species included in the risk assessment.

CALPUFF dispersion model can process a number of vapor and particulate phase chemicals in a single run. To obtain unit concentration and deposition matrices for all phases for the two OLO scenarios and three synthetic villages, five CALPUFF model runs had to be performed, each of them modeling 1 vapor and 3 particle phases. Two additional runs simulated elemental mercury dispersion from MWC which is in vapor phase and is subject to long distance transport rather than deposition. Emission of mercury from village burn barrels was so low that the elemental mercury dispersion has been neglected. Table 17 summarizes the CALPUFF model runs and their outputs. A set of postprocessors is then applied on CALPUFF binary output files, including CALPOST as a first step, followed by application of particle distribution coefficients in order to obtain separate values for mass distributed and area distributed particle phases, and preparation of input files for EMERAM model. Resulting EMERAM concentration/deposition input files in ASCII format contain receptors as lines and annual averages of unit gas, volume and area distributed particle concentrations, wet and dry depositions, respectively, as columns.

Table 17. *Atmospheric dispersion model run table*

Run #	Emission sources	Vapor Phase	Particle Phase		
			Fine	Coarse	Large
1	OLO MWI	CONC, DDEP, WDEP	CONC, DDEP, WDEP	CONC, DDEP, WDEP	CONC, DDEP, WDEP
2	OLO WTE	CONC, DDEP, WDEP	CONC, DDEP, WDEP	CONC, DDEP, WDEP	CONC, DDEP, WDEP
3	MIN	CONC, DDEP	CONC, DDEP	CONC, DDEP	CONC, DDEP
4	MOD	CONC, DDEP	CONC, DDEP	CONC, DDEP	CONC, DDEP
5	MAX	CONC, DDEP	CONC, DDEP	CONC, DDEP	CONC, DDEP
6	OLO MWI	CONC	-	-	-
7	OLO WTE	CONC	-	-	-
Phase number		1	2	3	4

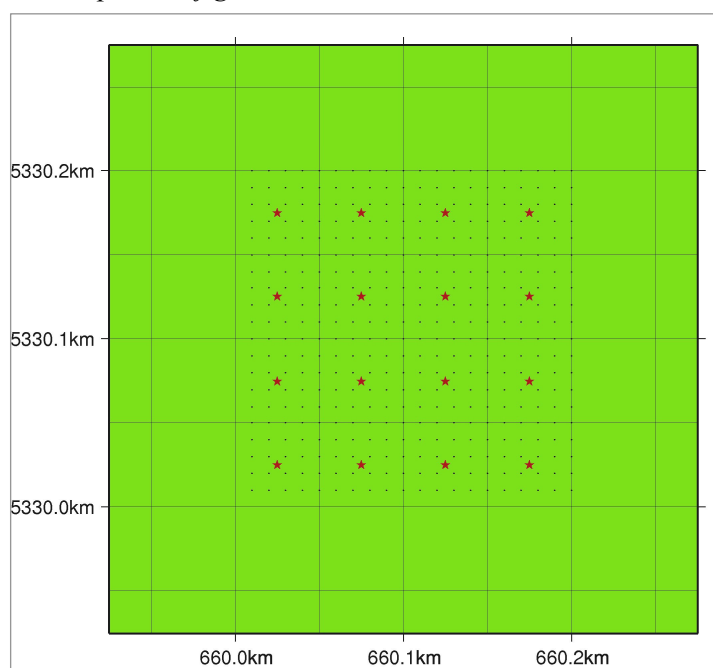
CALPUFF SENSITIVITY TESTING RELATED TO THE VILLAGE SOURCE AND RECEPTOR CONFIGURATION

The simulation of dispersion from open burning is specific in that the height of the sources is small and the concentration near the earth surface is strongly dependent on the distance from the source. The desire for computer efficiency/reasonable computing times has led to the design of so-called “grouped” sources. We were interested in the effect of such grouping on the computed concentrations. To explore this issue, an experiment has been designed involving a small domain covering the “area” served by 1 grouped source. This area was divided into finer mesh with 50 m grid spacing and 16 “real” (ungrouped) sources as illustrated in Figure 6. A mesh of receptors with 10 m spacing uniformly covered the sources area. Three full-year simulations were performed on this small domain:

- SMALL - 16 sources configured as in Figure 5
- SMALL1 - 1 source in the center (with the emission rate equal to the sum of the 16 sources), representing the configuration used in MIN, MOD and MAX villages
- SMALL1c - as above, with the same annual emissions, but distributed continuously throughout the whole year (instead of variable emissions used in all previous simulations)

Figure 7 shows a graph of maximum and median values of annual concentrations for all simulations, including the MIN, MOD, and MAX. Figure 8 shows the same graph for first highest 1-hour concentrations.

Figure 6. Domain for testing the sensitivity to the source and receptor configuration



The annual concentration and deposition medians are 30 to 40% higher in case of “ungrouped” sources, which better represent the real settings. The maximum values are, quite logically, higher in grouped source case, and so is the spread of the values.

SMALL1 simulation was performed as a basis for comparison with SMALL and SMALL1c. It has lower annual concentrations median compared to the MIN, MOD, and MAX simulations which it represents – it only represents 1 grouped source instead of the many included in village simulations. On the other hand – it has higher maximum values – this is caused by the receptors, which are 8 times denser in SMALL simulations than in villages, situated as near as 5 meters from the source compared to 40 meters in big villages.

Figure 7. *Statistics of annual values of concentrations – sensitivity to the source and receptor time and space configuration*

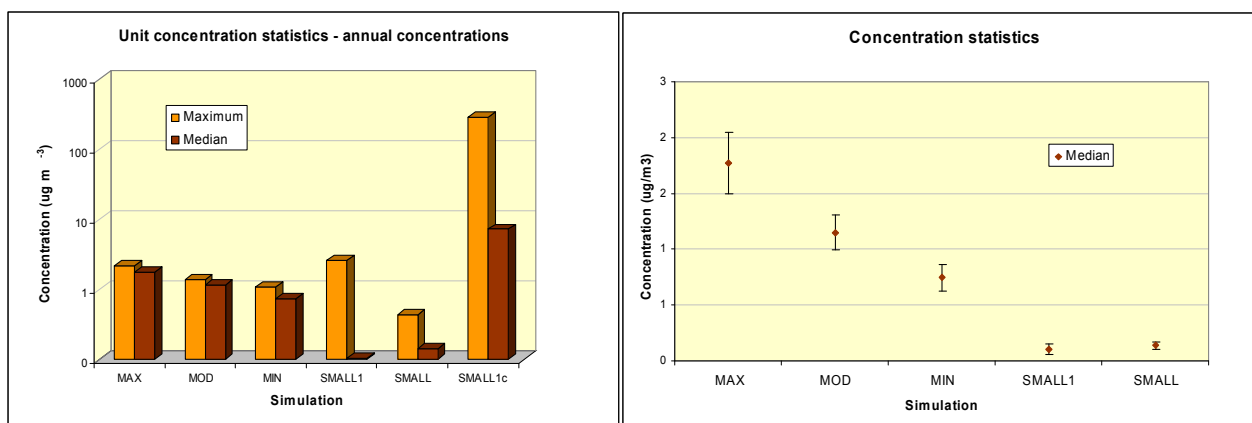
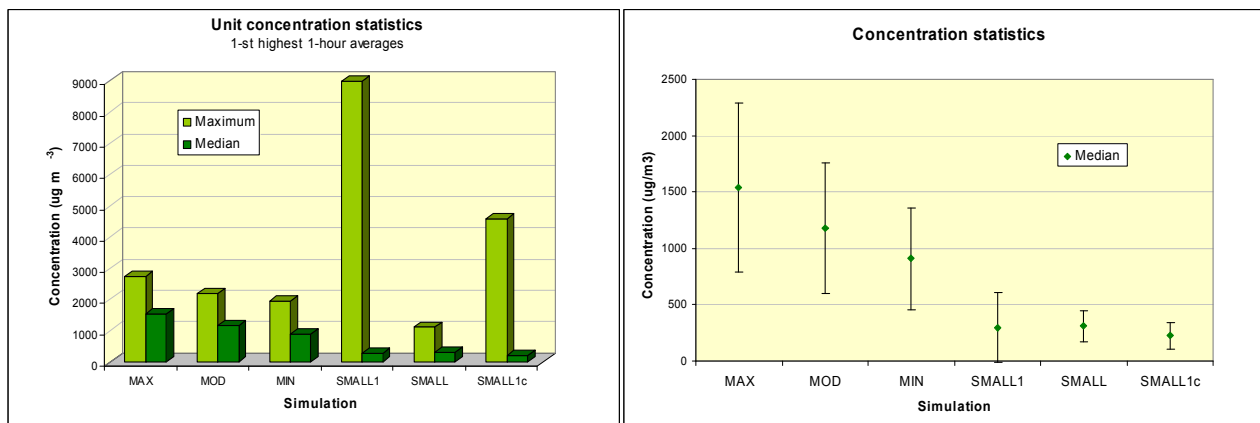


Figure 8. *Statistics of first highest 1-hour values of concentrations – sensitivity to the source and receptor time and space configuration*



EMERAM EXPOSURE DATA

Data needed for quantification of exposure to COPC through various environmental media can be divided into several groups:

- **Chemical-specific data** –they include physical and chemical parameters such as Henry's law constants, soil loss constants, various environmental partitioning coefficients, bioconcentration and biotransfer factors, reference doses and concentrations, cancer slope

factors, etc. They do not depend on geographical location, population and environmental settings, nor on the specifics of the problem studied. They can be found in literature or computed using methodologies recommended in US EPA (1998).

- **Generic data**, including parameters such as densities of air, soil and water, plant interception fractions, etc. They are not chemical-specific and they do not depend on the geographical location, population and environmental settings, nor on the specifics of the problem studied. They can be found in scientific literature. Recommended values can be found again in US EPA (1998).
- **Problem-specific data**, which are related to the definition of the studied problem itself, such as total time of exposure and total time of deposition.
- **Geographically or population-specific data**, such as consumption rates and agricultural productivity; they are derived from available Slovakia-specific statistical sources
- Data which may fall in the previous category, although their relation to geographical and population specifics is not clear. We did not find their Slovak-specific values, therefore we use data adopted from US EPA (1997a). These data include such parameters as infant milk consumption rate while nursing, length of nursing, commercially grown animal consumption rates, etc.

Sources of data

Most chemical-specific parameters are adopted from US EPA (1998), except for the half-life of contaminants in mother for PCB and PCDD/F, and BCF values for leafy and non-leafy aboveground produce, which were taken from Eschenroeder et al. (1999). IRIS database (US EPA, 2006) was the primary source of dose-response data except for the PCDD/F cancer slope factors, which were obtained from US EPA (2000), and non-cancer reference dose and concentration for benzo(a)pyrene, retrieved from Holstein (1985). Current knowledge of lead pharmacokinetics indicates that risk values derived by standard procedures would not truly indicate the potential risk, because of the difficulty in accounting for pre-existing body burdens of lead (US EPA, 2006). However, as lead was not a chemical of primary concern due to its relatively low emission rate, a reference dose for lead was adopted from Eschenroeder et al. (1999). Premature mortality relative risk for PM_{2.5} relies on the study of Levy and Spengler (2002).

There were several different sources of exposure data used in the study. The Exposure Factors Handbook (US EPA, 1997a) was the primary source for general parameters, such as human body weights and life spans, skin surface areas, air inhalation rates, breast feeding parameters, bulk density of soil and soil mixing depths and child-to-adult ingestion ratios. The same source was used also for other parameters for which no national statistics are available, such as various plant parameters (e.g., interception fractions, adherence factors, correction factors for belowground, exposed, protected plants, forage, silage and grain) and food consumption rates of commercially grown animals.

Human consumption rates were derived from national statistics data, e.g., Statistical Yearbook of Slovak Republic (SOSR, 2002a), Structured Survey of Farms (SOSR, 2002b), The Ministry of Agriculture Green Report (MoA, 2000), and Jamborova et al. (2004).

Human and home-grown animal consumption rates in villages

Human and home-grown animal consumption rates in villages are a special category of data. As was already mentioned, most of the village people grow a considerable part of fruit and vegetable in their kitchen gardens. In addition, they also grow some poultry and many of them grow rabbits and pigs. Unfortunately, there is no specialized statistics available on the average consumption of home grown produce and animals, nor on the particular animal diet composition, although we know that it considerably differs from the composition of animal feed in commercial farms. While the commercial farms are driven by maximum efficiency, the feeding habits of village farmers are strongly influenced by convenience. We dealt with the lack of data as follows:

- Several village inhabitants experienced in growing poultry, rabbits and pigs were interviewed; they were encouraged to generalize their knowledge based on what they know from their own experience as well as about the practices of their neighbors. The results allowed us to make some assumptions about the composition and amount of animal food, and also about the typical size and composition of the “backyard farms”.
- It has been assumed that the human vegetable and fruit consumption rates do not differ from the national averages, and that all this is supplied by their kitchen gardens.

Following assumptions resulted from the sources of data above, taking into account the fact that a certain degree of conservativeness is needed in order to involve the most affected individuals:

- A typical household comprises 6 persons: 4 adults (grandparents and parents) and 2 children
- The household is self-sufficient in the vegetable and fruit production
- Each year, the household consumes certain amount of meat from their own production: 16 hens kept for egg production, which are ultimately killed and their meat eaten; 10 geese; 16 ducks; 16 rabbits; 2 pigs
- The household is self-sufficient in egg production; it is assumed that the eggs consumption rate is identical with the nation-wide consumption rate given in Jamborova (2004)

Table 19 lists the consumption rates resulting from the assumptions above. Data on the child/adult ingestion ratios are listed in Table 18 Typical weights of animals are taken from the literature. Their relation to the typical weights of the home-fed animals is associated with uncertainties. It needs to be noted, that Brestensky (2001) gives the typical pig weight for animals with carcass weight up to 110 kg. However, home-fed pigs are not slaughtered before they reach at least 200 kg, in some cases even 250kg. Such heavy animals are likely to contain lower percentage of meat due to high portion of bacon (lard). The lard is also consumed in the household. It may be an important contributor to the exposure to the lipophilic COPCs, such as PCB and PCDD/F. However, as no data had been available on the ratio of lard obtained from the pork processing and on the amount which is actually entering human ingestion system (it is usually used for frying, not for direct consuming), this pathway was excluded from the study. Nevertheless, due to the above-mentioned reasons, it is worth of further studying in the future.

No data have been found on the fishing habits and efficiency of Slovak fishing enthusiasts. We considered catching a 2 kg fish once a week, which means 53 fish per year consumed by all members of the household as a rational assumption.

Table 18. Child to adult intake ratios (US EPA, 1997a)

Child/adult intake ratios	
fruit&vegetables	0.3
Beef	0.096
Pork	0.161
Poultry	0.149
Rabbit and other	0.149
Fish	0.139
Milk	0.473
Eggs	0.151

Table 19. Home-produced meat and animal products ingestion rates of village inhabitants

	Number per year per household	Typical weight (kg)	Net meat (%)	Net meat (kg/year)	Net meat (kg/day)	Child IR	Adult IR
						(kg/person-day)	
Hens	16 ^a	2.5 ^b	68	27.2	0.07452	0.00258	0.01734
geese	10 ^a	6 ^b	75	45	0.12329	0.00427	0.02868
ducks	16 ^a	3 ^b	68	32.64	0.08942	0.00310	0.02081
rabbits	16 ^c	1.3 ^c	87.5	18.2	0.04986	0.00173	0.01160
pigs	2 ^a	200 ^a	50	200	0.54795	0.02041	0.12678
eggs	-	-	-	-	-	4.3E-06 ^d	28E-06 ^d
fish		2	80	84.8	0.23233	0.00747	0.05431

^a Personal communication of village inhabitants^b Brestenský et al. (2001)^c Bianospino et. al. (2006)^d VUEPP (Jamborová, 2004)

The next issue for which no official data exists is the diet of home-fed animals.

Pigs grown in villages are fed until they reach weight at least 200 kg, which is twice the weight of pigs produced by commercial farms. There is also a difference in their diet – besides corn and grain they also get green food (forage), and swill from kitchen. Only information from local people is available on the estimated amounts of consumed food. According to them, one pig consumes 200 kg of barley and 250 kg of corn per year, and cca 2 kg of green food daily. Plus some amount of swill, which is not considered to be contaminated. It can be assumed that the green food (e.g., weeds) are grown in backyards and kitchen-gardens, so they are 100 percent contaminated, while only portion (0 - 50 %) of grain (corn) is contaminated in such a way (again, this is only based on personal experience).

Geese in villages are grown big to get large liver and a lot of grease. Their diet roughly corresponds to Brestensky (2001). Their lifespan is approximately 14 weeks, most of it they are foraging. During their life they consume about 25 kg of green stuff (grass), grain mixtures and corn.

Ducks are fed using a similar method as is used for geese. As there is no published reference, the same ingestion rates are used per kg of weight as for geese.

Hens are kept in open air yards. They consume grain and green plants, the amounts of which can only be roughly estimated as 50 g per day of grain, corn or mixtures and 500 g per day of green stuff.

Rabbits consume cca 300g of dry alfalfa, 100 g of belowground produce (carrot, cohlrabi, turnip, etc.) and 100 g of grain mixture per day.

Animal soil ingestion rates are taken from US EPA (1998a). Table 22 summarizes the village data. Table 21 lists the values from US EPA (1998a), used for the IRT risk assessment.

Because of unavailability of specific biotransfer factors for goose, duck and rabbit, all were included in poultry category. As geese and ducks, which contain more fat, form a larger mass part of the total poultry consumed, the hen forage ingestion rate was used for total poultry and grain in order to account for that fact at least using more conservative values of ingestion rates.

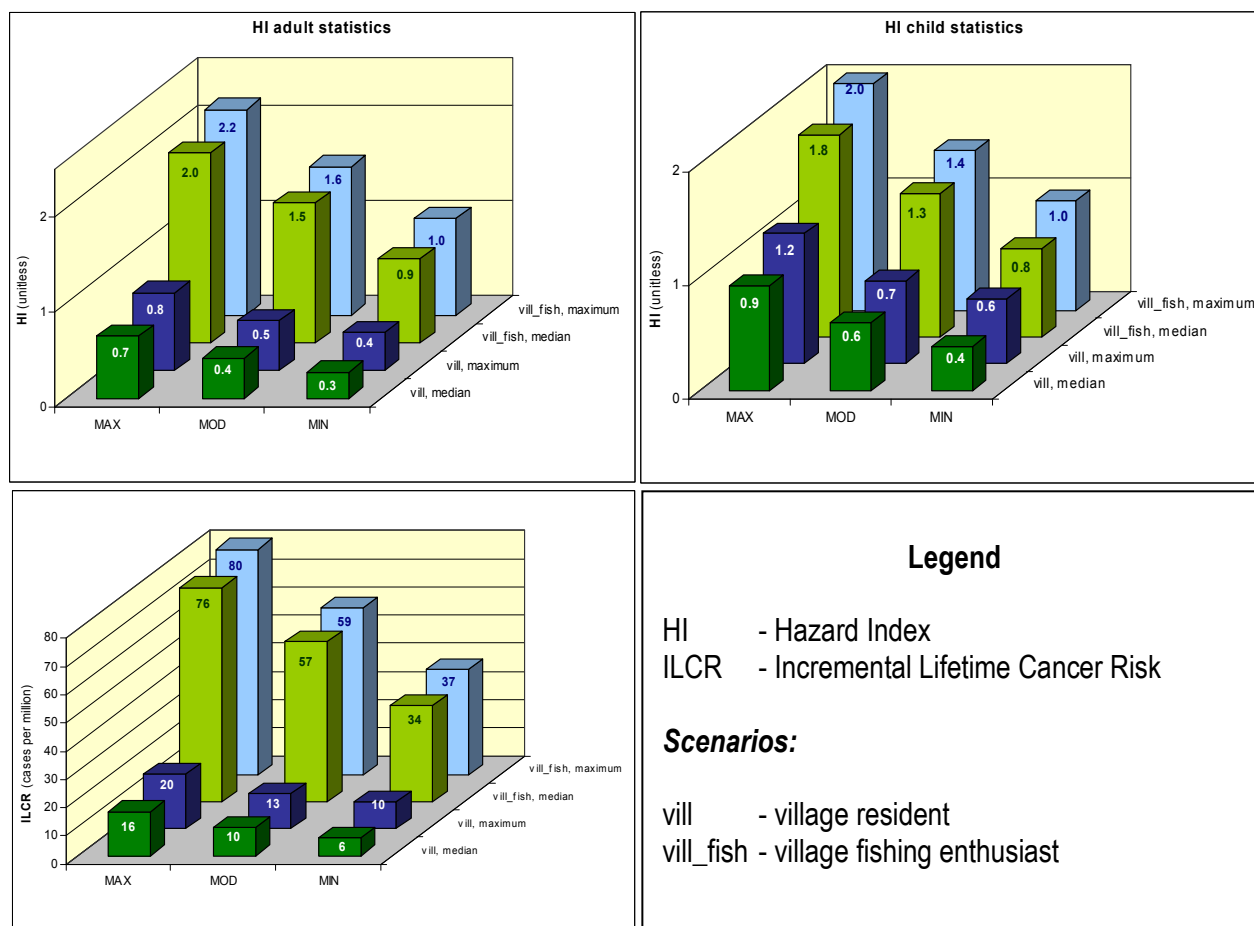
Table 20 Home-fed village animal consumption rates

Animal	Typical weight (kg/animal)	Forage (kg DW/day)	Forage (kg DW/kg.day)	Grain (kg DW/day)
hens	2.5	0.100	0.0400	0.050
geese	6	0.051	0.0085	
ducks	3	0.026	0.0085	
rabbits	1.3	0.309	0.2377	
pigs	200	0.400	0.0020	0.001

Table 21 Animal consumption rates - US EPA (1998a) values

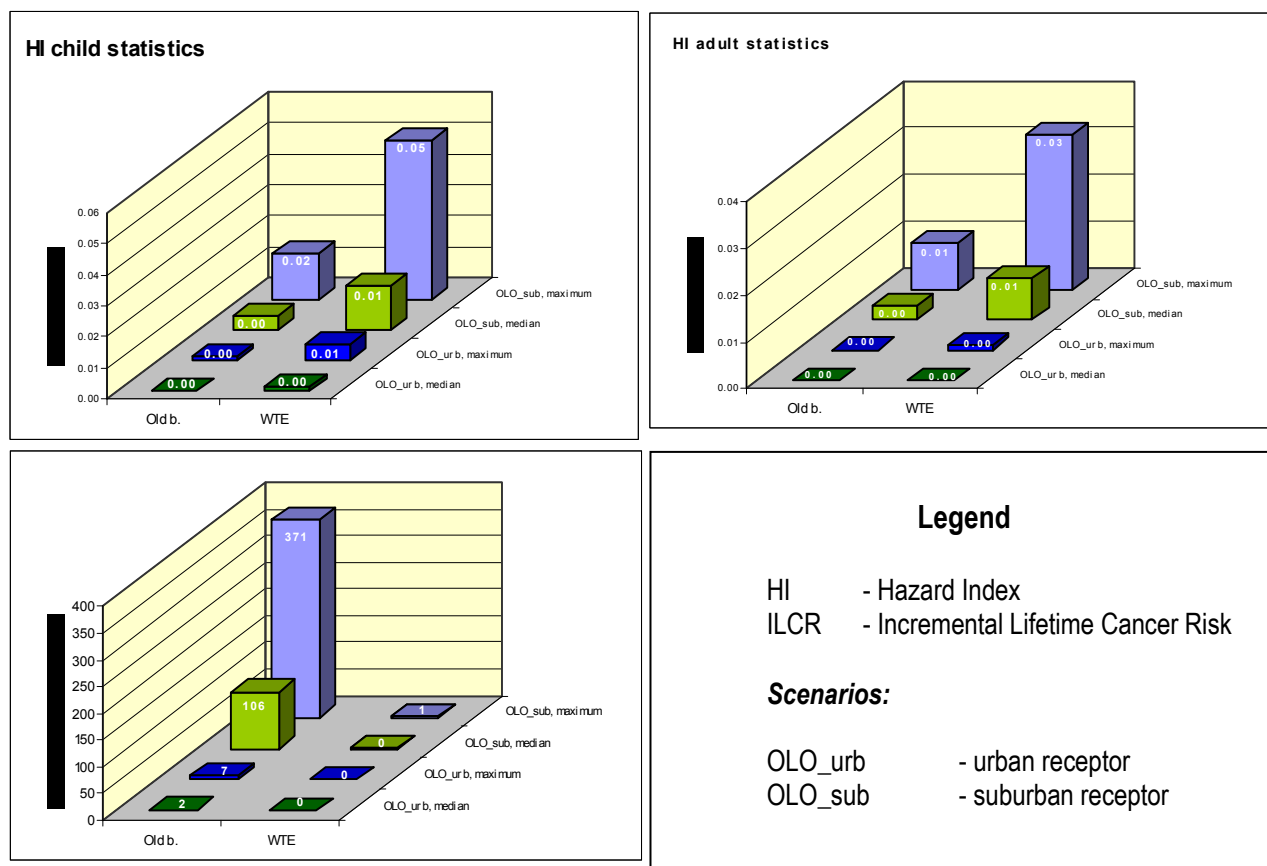
Animal	Forage (kg DW/day)	Grain (kg DW/day)	Silage (kg DW/day)	Soil (kg DW/day)
beef cattle	8.8	0	2.5	0.5
dairy cattle	13.2	3	4.1	0.4
pig	0	0	1.6	0.34
poultry	0	0.8	0	0.01

DETAILED SUMMARY OF RESULTS

Figure 9. Total HIs and ILCRs for village scenarios – maximum and median values for each scenario and each village size interval**Table 22.** Maximum and median values of ILCR and HIs for all settings and scenarios modeled in the study^c

Settings	Scenarios	ILCR ^a		HI ^b – adult		HI ^b – child	
		Max	median	max	median	max	median
OLO - MWI	Suburban resident	371	106	0.0	0.0	0.0	0.0
	urban resident	7	2	0.0	0.0	0.0	0.0
OLO – WTE	Suburban resident	0.8	0.2	0.0	0.0	0.0	0.0
	urban resident	0.0	0.0	0.0	0.0	0.0	0.0
MAX village	village resident	20	16	0.8	0.7	1.2	0.9
	village fishing enthusiast	80	75	2.2	2.0	2.0	1.8
MOD village	village resident	13	10	0.5	0.4	0.7	0.6
	village fishing enthusiast	59	57	1.6	1.5	1.4	1.3
MIN village	village resident	10	6	0.4	0.3	0.6	0.4
	village fishing enthusiast	37	34	1.0	0.9	1.0	0.8

^a Incremental life-time cancer risk^b Hazard index^c Numbers in bold show the hazard indices with values above 1

Figure 10. Total HIs and ILCRs for OLO – MWI and WTE, maximum and median values**General notes to Tables 23 – 34:**

- Tables listing pathway-specific HIs contain a number of values expressed as “0.0”; they are actually very small values (lower than 0.1), which can be considered negligible. Scientific number format is avoided intentionally in the tables, as normal formatting of rounded values enables quick identification of the non-zero risk pathways and chemicals. Zero (0) values in HI tables indicate that the pathway is not defined for the particular COPC.
- Following pathway abbreviations are listed in HI and ILCR tables: **inh** – inhalation, **sing** – soil ingestion, **plant** – plant ingestion, **anim** – meat and animal products ingestion, **fish** – fish ingestion and **bmilk** – maternal breast milk ingestion.

MAXIMALLY IMPACTED RECEPTORS - Hazard Indices**Table 23** HI for MAX village for a maximally impacted fishing enthusiast receptor – contributions of each COPC through particular exposure pathways

MAX village	HI adult							HI child						
	inh	sing	plant	anim	fish	bmilk	TOTAL	inh	sing	plant	anim	fish	bmilk	TOTAL
Aro_1254	0.0	0.0	0.0	0.0	1.3	0.0	1.3	0.0	0.0	0.0	0.0	0.8	0.0	0.8
PAHs_as_BaP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyrene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluoran	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Naphtalene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Toluene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acetone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Styrene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phenol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acetaldehyde	0.0	0.0	0.8	0.0	0.0	0.0	0.8	0.0	0.0	1.1	0.0	0.0	0.0	1.1
Benzaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Formaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
As	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cr_VI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hg_II	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Methyl_Hg	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1
TOTAL	0.0	0.0	0.8	0.0	1.3	0.0	2.2	0.0	0.0	1.1	0.0	0.9	0.0	2.0

Table 24 HI for MOD village for a maximally impacted fishing enthusiast – contributions of each COPC through particular exposure pathways

MOD village	HI adult							HI child						
	inh	sing	plant	anim	fish	bmilk	TOTAL	inh	sing	plant	anim	fish	bmilk	TOTAL
Aro_1254	0.0	0.0	0.0	0.0	1.0	0	1.0	0.0	0.0	0.0	0.0	0.6	0	0.6
PAHs_as_BaP	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Pyrene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Fluoran	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Fluorene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Benzene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Naphtalene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Toluene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Acetone	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Styrene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Phenol	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Acetaldehyde	0.0	0.0	0.5	0.0	0.0	0	0.5	0.0	0.0	0.7	0.0	0.0	0	0.7
Benzaldehyde	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Formaldehyde	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Cd	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
As	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Cr_VI	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Ni	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Zn	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Pb	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Hg_II	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Methyl_Hg	0.0	0.0	0.0	0.0	0.1	0	0.1	0.0	0.0	0.0	0.0	0.0	0	0.0
TOTAL	0.0	0.0	0.5	0.0	1.0	0	1.6	0.0	0.0	0.7	0.0	0.7	0	1.4

Table 25 HI for MIN village for a maximally impacted fishing enthusiast receptor – contributions of each COPC through particular exposure pathways

MIN village	HI adult							HI child						
	inh	sing	plant	anim	fish	bmilk	TOTAL	inh	sing	plant	anim	fish	bmilk	TOTAL
Aro_1254	0.0	0.0	0.0	0.0	0.6	0	0.6	0.0	0.0	0.0	0.0	0.4	0	0.4
PAHs_as_BaP	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Pyrene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Fluoran	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Fluorene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Benzene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Naphtalene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Toluene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Acetone	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Styrene	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Phenol	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Acetaldehyde	0.0	0.0	0.4	0.0	0.0	0	0.4	0.0	0.0	0.6	0.0	0.0	0	0.6
Benzaldehyde	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Formaldehyde	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Cd	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
As	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Cr_VI	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Ni	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Zn	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Pb	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Hg_II	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Methyl_Hg	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
TOTAL	0.0	0.0	0.4	0.0	0.6	0	1.0	0.0	0.0	0.6	0.0	0.4	0	1.0

Table 26 HI for OLO – MWI for a maximally impacted suburban receptor – contributions of each COPC through particular exposure pathways

OLO - MWI	HI adult							HI child						
	inh	sing	plant	anim	fish	bmilk	TOTAL	inh	Sing	plant	anim	fish	bmilk	TOTAL
PCB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PAHs as BaP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naphtalene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Toluene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Cr VI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg element.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methyl. Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01

Table 27 HI for OLO - WTE for a maximally impacted suburban receptor - contributions of each COPC through particular exposure pathways

OLO - WTE	HI adult							HI child						
	inh	sing	plant	anim	fish	bmilk	TOTAL	inh	Sing	plant	anim	fish	bmilk	TOTAL
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr VI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg II	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.02
Hg element.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methyl. Hg	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.03
TOTAL	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.05

MAXIMALLY IMPACTED RECEPTORS - Incremental Lifetime Cancer Risks**Table 28** ILCR for MAX village for a maximally impacted fishing enthusiast receptor – contributions of each COPC through particular exposure pathways

MAX village	PATHWAY CONTRIBUTIONS TO ILCR (cases per million)						TOTAL
	inh	sing	plant	anim	fish	bmilk	
Aro_1254	0.0	0.0	0.0	0.0	48.5	10.0	58.5
PAHs as BaP	0.0	0.0	0.5	0.4	1.4	0.0	2.3
Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acetaldehyde	0.0	0.0	16.9	0.0	0.0	0.0	16.9
Formaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0
As	0.0	0.0	0.5	0.0	0.0	0.0	0.5
Cr VI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCDD/F	0.0	0.0	1.2	0.1	0.0	0.3	1.6
TOTAL	0.0	0.0	19.0	0.5	49.9	10.3	79.9

Table 29 ILCR for MOD village for a maximally impacted fishing enthusiast receptor – contributions of each COPC through particular exposure pathways

MOD village	PATHWAY CONTRIBUTIONS TO ILCR (cases per million)						TOTAL
	inh	sing	plant	anim	fish	bmilk	
Aro_1254	0.0	0.0	0.0	0.0	37.6	7.8	45.4
PAHs as BaP	0.0	0.0	0.3	0.3	1.1	0.0	1.7
Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acetaldehyde	0.0	0.0	10.8	0.0	0.0	0.0	10.8
Formaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0
As	0.0	0.0	0.3	0.0	0.0	0.0	0.3
Cr VI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCDD/F	0.0	0.0	0.7	0.0	0.0	0.2	1.0
TOTAL	0.0	0.0	12.2	0.3	38.7	8.0	59.2

Table 30 ILCR for MIN village for a maximally impacted fishing enthusiast receptor – contributions of each COPC through particular exposure pathways

MIN village	PATHWAY CONTRIBUTIONS TO ILCR (cases per million)						TOTAL
	inh	sing	plant	anim	fish	bmilk	
Aro_1254	0.0	0.0	0.0	0.0	22.4	4.6	27.0
PAHs as BaP	0.0	0.0	0.2	0.2	0.6	0.0	1.0
Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acetaldehyde	0.0	0.0	8.4	0.0	0.0	0.0	8.4
Formaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0
As	0.0	0.0	0.2	0.0	0.0	0.0	0.2
Cr VI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCDD/F	0.0	0.0	0.5	0.0	0.0	0.1	0.7
TOTAL	0.0	0.0	9.3	0.2	23.0	4.8	37.4

Table 31 ILCR for OLO – MWI for a maximally impacted suburban receptor – contributions of each COPC through particular exposure pathways

OLO – MWI	PATHWAY CONTRIBUTIONS TO ILCR (cases per million)						TOTAL
	inh	sing	plant	anim	fish	bmilk	
Aro_1254	0	0	0	0	0	0	0
PAHs as BaP	0	0	22	0	0	0	22
Benzene	0	0	0	0	0	0	0
Cd	0	0	0	0	0	0	0
As	0	0	3	0	0	0	4
Cr VI	0	0	0	0	0	0	0
PCDD/F	1	5	265	0	0	73	344
TOTAL	1	5	290	0	0	73	370

Table 32 ILCR for OLO – WTE plant for a maximally impacted suburban receptor – contributions of each COPC through particular exposure pathways

OLO - WTE	PATHWAY CONTRIBUTIONS TO ILCR (cases per million)						TOTAL
	inh	sing	plant	anim	fish	bmilk	
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0
As ^a	0.0	0.0	0.4	0.0	0.0	0.0	0.4
Cr VI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCDD/F ^b	0.0	0.0	0.3	0.0	0.0	0.1	0.4
TOTAL	0.0	0.0	0.7	0.0	0.0	0.1	0.8

^a Arsenic emission rate from NEIS database gives ILCR of 15 cases per million

^b At the beginning of the operation, OLO company stated that the WTE plant PCDD/F emissions will be below the EU standards (EU, 2000a). Using the emission rate based on the EU limit instead of AP 42 would lower the ILCR value for PCDD/F to 0.1 and the total ILCR to 0.5 per million

INTER-ZONE RISK TRANSFERS**Table 33** *Inter zone risk transfers from village agricultural lands to city inhabitants through consumption of commercially produced food*

Statistic	Hlchild	Hladult	ILCR (cases per million)
Minimum value	0.02	0.02	0.4
Maximum value	0.69	0.49	14.0
Arithmetic mean	0.17	0.12	3.1
Median	0.14	0.10	2.4
Median – median absolute deviation	0.02	0.02	0.4
Median + median absolute deviation	0.25	0.18	4.5

Table 34 *Inter zone risk transfers from village agricultural lands to village inhabitants through consumption of commercially produced beef and milk products*

Statistic	Hlchild	Hladult	ILCR (cases per million)
Minimum value	0.00	0.00	0.0
Maximum value	0.00	0.00	2.0
Arithmetic mean	0.00	0.00	0.3
Median	0.00	0.00	0.2
Median – median absolute deviation	0.00	0.00	0.0

REFERENCES

- Bacci, E., Cerejeira, M.J., Gaggi, C., Chemello, G., Calamari D., 1992:** *Chlorinated Dioxins: Volatilization from Soils and Bioconcentration in Plant Leaves*. Bulletin of Environmental Contamination and Toxicology, 48, 401-408
- Bianospino et al, 2006:** Carcass And Meat Quality of Straightbred and Crossbred Rabbits, (web: www.dcam.upv.es/8wrc/docs/)
- Bidleman, T.F., 1988:** *Atmospheric processes*. Environ. Sci. Technol., 22, 361-367
- Bowers, J.F., J.R. Bjorklund and C.S. Cheney, 1979:** Industrial Source Complex (ISC) Dispersion Model User's Guide. EPA-450/4-79-030, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711
- Brestenský V. et al., 2001:** Sprievodca chovateľ'a hospodárskych zvierat. Výskumný ústav živočíšnej výroby NITRA (web: www.agroporadenstvo.sk)
- Dinman, B.D., 1978:** *The mode of entry and action of toxic materials*. Patty's Industrial Hygiene and Toxicology, John Wiley & Sons, New York, New York. Volume 1
- Eschenroeder A., von Stackelberg K., Holstein E.C., 1999:** *Health risk assessment of the proposed Renova resource recovery facility in Arecibo*, Puerto Rico
- Hamnett R.G., 2001:** *Grassland and Pasture Crops*. Slovak Republic Agriculture 21, Food and Agriculture Organisation, United Nations at <http://www.fao.org/AGP/AGPC/doc/Counprof/slovakia.htm>
- Holstein, E.C., 1995:** *Health Risk Assessment for the Proposed West Suburban Recycling and Energy Center*, Environmental Health Associates Report.
- Jamborova M. et al., 2004:** *Komoditne situacne a vyhladove spravy*, VUEPP (Agriculture and Food Economics Research Institute), <http://www.vuepp.sk>
- Lemieux P.M., Lutes, C.C., Abbott, J.A., and Aldous, K.M., 2000:** *Emissions of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans from the Open Burning of Household Waste in Barrels*. Environ. Sci. Technol. 34, 377 - 384.
- Levy, J.I., Spengler, J.D., 2002:** *Modeling the benefits of power plant emission controls in Massachusetts*. J. Air & Waste Manage. Assoc., Volume 52, 5-18.
- Ministry of Agriculture of the Slovak Republic, 2000:** *Report on Agriculture and Food Sector in the Slovak Republic 2000 (GREEN REPORT)*, Bratislava, at <http://www.mpsr.sk/english/dok/zs/gr2000.htm>
- NEIS - National Emission Information System.** http://www.air.sk/projects/neis/s_neis.html
- PHARE, 1995:** Study on Health Impact of Environmental Pollution. Final Conference Proceedings, Bojnice PHARE Project EC/91/HEA/18
- Pope, C.A., Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., Heath, C.W., Jr., 1995:** *Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults*, Am. J. Respir. Crit. Care Med 151, 669 – 674.
- Scire J.S., Robe F.R., Fernau M.E., Yamartino R.J., 2000a:** *A user's guide for the CALMET meteorological model*, Earth Tech, Inc., Concord, MA
- Scire J.S., Schulman L.L., 1980:** *Modeling plume rise from low-level buoyant line and point sources*. Proceedings Second Point Conference on Applications of Air Pollution Meteorology, 24-28 March, New Orleans, LA, 133-139.

Smith A.H., 1987: *Infant exposure assessment for breast milk dioxins and furans derived from waste incineration emissions.* Risk Analysis 7:347.

Statistical Office of the Slovak Republic, 2002a: *Statistical Yearbook of Slovak Republic*, Statistical office of Slovak Republic

Statistical Office of the Slovak Republic, 2002b: *Structured Survey of Farms*, Statistical Office of SR <http://www.statistics.sk/webdata/slov/cenzfarm/publ.htm>

U. S. EPA, 1998: *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Vols. I, II and III.* Peer Review Draft. EPA530-D-98-001A, B and C. Office of Solid Waste and Emergency Response, July 1998.

U.S. EPA, 1985: *Compilation of Air Pollutant Emission Factors: Volume I: Stationary Point and Area Sources*, AP-42, U.S. Environmental Protection Agency, Office of Air and Radiation, September 1985.

U.S. EPA, 1991: *Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper.* Final rule. Fed. Reg. 56:26460-26664.

U.S. EPA, 1997a: *Exposure Factors Handbook Volume I - General Factors* - EPA/600/P-95/002Ba *Volume II - Food Ingestion Factors* - EPA/600-P-95/002Bb *Volume III - Activity Factors* - EPA/600/P-95/002Bc

<http://www.epa.gov/ordntrnt/ORD/WebPubs/exposure/index.html>

U.S. EPA, 1997b: *Evaluation of Emissions from the Open Burning of Household Waste in Barrels, Volume 1: Technical Report.* U.S. Environmental Protection Agency, Control Technology Center, Washington, D.C. EPA600/R-97-134a

U.S. EPA, 2000: *Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds, Part 1: Estimating Exposure to Dioxin-Like Compounds, Volume 2: Sources of Dioxin-Like Compounds in the United States (DRAFT)* EPA/600/P-00/001Bb 2000- at <http://www.epa.gov/ncea/pcdfs/dioxin>.

US EPA, 2006: Integrated Risk Information System, <http://www.epa.gov/iris>

VKÚ, 1994: Malé Karpaty - Bratislava. Turistická mapa 1:50 000. Vojenský kartografický ústav Harmanec

VKÚ, 1999: Bratislava – atlas ortofotomáp 1: 6 000. Vojenský kartografický ústav Harmanec