Assessment of Human Health Risk due to Inhalation Exposure in Cattle and Pig Farms in South Moravia

P. ČUPR[1], M. ŠKAREK[1], T. BARTOŠ[1], M. CIGÁNEK[2], I. HOLOUBEK[1]

[1]RECETOX – Research Centre for Environmental Chemistry and Ecotoxicology, Masaryk University Brno, Czech Republic
[2]Veterinary Research Institute, Brno, Czech Republic

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Abstract

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The main topic of this study was human health risk assessment of defined inhalation exposure scenario in selected cattle and pig farms in south Moravia (Czech Republic). This exceptional evaluation of potential risks for farms manipulators was the main contribution of this study. Possible both human health risks, non-carcinogenic and carcinogenic (according to US EPA Human health risk assessment methodology), for feeders and other workers exposed to polluted indoor air in the farm stables were quantified in the selected pig and cattle farms with significantly increased concentrations mainly of carcinogenic PAHs and PCBs in the indoor air. No non-carcinogenic risks were determined in any of the localities, but also increased carcinogenic risks were observed. The highest carcinogenic health risk was found in the cattle stable ($MAX_{IECR} = 8.08 \cdot 10^{-6}$), the lowest one in the pig stable ($MIN_{IECR} = 2.57 \cdot 10^{-6}$). Carcinogenic risk values in the farms under study were not extremely high, but those were approximately twice higher than a median value of the risk determined for research workers from Košetice $IECR = 5.96 \cdot 10^{-7}$ (years 1996 – 1999), Central European background monitoring station of EMEP.

Carcinogenic and non-carcinogenic risk, PAHs, PCBs, farm stable

Air pollution is one of the most serious environmental problems. Due to various anthropogenic activities a broad spectrum of pollutants are emitted in huge amounts in the air. Nowadays a major concern is focused on organic pollutants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs). They are generally called persistent organic pollutants (POPs). These compounds are ubiquitous air pollutants and their presence in the air results from emissions from diverse sources (Buehler et al. 2001; Breivik et al. 2004). They are able to show serious toxic effects on humans as well as wildlife in very low concentrations (Holoubek et al. 1999). Moreover they persist for a long time in the environment and tend to bio-concentrate in animal tissues. Increased exposure to these chemicals may be associated with increased health and ecological risks (Eljarrat and Barcelo 2003).

While quite a lot of information about outdoor air concentrations of POPs and human exposure exist (Halsall et al. 1995; Buehler et al. 2001; Kim et al. 2004), not too much is known about their levels indoor and their health risks. Due to indispensable emissions of indoor sources and insufficient aeration, higher concentrations of air pollutants, including POPs, may be achieved indoor. Indoor inhalation exposure to air pollutants is one of significant factors that may increase health risks (Jones 1999). An emphasis is placed mainly on the occupational exposure, where there are efforts to recognize, monitor and eliminate high exposures that may cause serious damage of human health as described in numerous studies (Tucek et al. 1998; Sweeney et al. 2000; Palus et al. 2003; Turci et al. 2003).

Address for correspondence:
RNDr. Pavel Čupr Ph.D.
RECETOX, MU Brno
Kamenice 126/3,
625 00 Brno, Czech Republic

Phone: +420 549 493 511
Fax: +420 549 492 840
E-mail: cupr@recetox.muni.cz
http://www.vfu.cz/acta-vet/actavet.htm

For this purpose human health risks may be assessed. One of the approaches is based on assessment via determination of concentrations of priority pollutants. And then either the concentrations of the pollutants may be simply considered according to established limits or a complete health risk assessment may be performed. While the former approach is based on simple comparison of each of pollutants concentrations with safe levels, the latter enables to integrate exposures to several pollutants under exactly defined exposure conditions. The significance of the second approach is mainly emphasized by the fact that the limits are not very often available and persons are exposed usually to more than one pollutant. These assessments are done predominantly in risk workplaces such as hospitals and laboratories, chemical industry, steelworks, gas plants etc.

However there are many other workplaces that are not monitored and under any control from the point of exposure to such pollutants as POPs, because their high concentrations are unexpected there. This study presents one of the examples. Higher concentrations of PAHs (mainly carcinogenic PAHs), PCBs and OCPs in indoor air were detected in pig and cattle farms in the Hodonín District (see Table 1 and 2). Concentrations of individual PAH were 3–8 times higher than concentrations in the outdoor air. In the case of PCB congeners the indoor concentrations were 2–15 times higher. These data were obtained during the study focused on ecotoxicological assessment of carcinogenic PAHs in pig and cattle farms (Cigánek et al. 2000).

Table 1. Concentration of PAHs in indoor and outdoor air of pig and cattle farms

	Compounds	pig farm		cattle farm	
		indoor air[1]	outdoor air[1]	indoor air[1]	outdoor air[1]
1	Naphthalene	0.91 ± 0.36	0.90 ± 0.85	2.15 ± 0.57	1.69 ± 1.08
2	Acenaphthylene	0.26 ± 0.10	0.25 ± 0.27	2.97 ± 2.11	1.59 ± 1.40
3	Acenaphthene	0.19 ± 0.03	0.17 ± 0.11	1.18 ± 0.75	0.52 ± 0.35
4	Fluorene	1.44 ± 0.10	2.09 ± 1.13	10.7 ± 3.27	4.77 ± 3.25
5	Phenanthrene	9.48 ± 3.00	7.50 ± 2.75	26.9 ± 4.61	10.8 ± 5.17
6	Anthracene	0.59 ± 0.48	0.15 ± 0.01	1.65 ± 0.52	0.42 ± 0.19
7	Fluoranthene	4.07 ± 2.51	2.35 ± 0.50	7.79 ± 1.12	3.61 ± 1.22
8	Pyrene	2.64 ± 1.63	1.40 ± 0.22	6.80 ± 1.18	2.50 ± 0.89
9	Benz[a]anthracene	0.27 ± 0.15	0.11 ± 0.04	0.70 ± 0.10	0.34 ± 0.21
10	Chrysene	0.41 ± 0.21	0.24 ± 0.06	1.09 ± 0.17	0.59 ± 0.39
11	Benzo[b]fluoranthene	0.36 ± 0.22	0.25 ± 0.01	0.96 ± 0.14	0.52 ± 0.35
12	Benzo[k]fluoranthene	0.18 ± 0.12	0.14 ± 0.07	0.51 ± 0.07	0.27 ± 0.19
13	Benzo[a]pyrene	0.24 ± 0.15	0.09 ± 0.02	0.55 ± 0.06	0.26 ± 0.17
14	Indeno[1,2,3-cd]pyrene	0.28 ± 0.18	0.14 ± 0.08	0.79 ± 0.21	0.34 ± 0.24
15	Dibenz[a,h]anthracene	0.03 ± 0.03	0.01 ± 0.01	0.07 ± 0.01	0.04 ± 0.03
16	Benzo[g,h,i]perylene	0.25 ± 0.15	0.15 ± 0.08	0.98 ± 0.25	0.31 ± 0.22
	Σ of PAHs (Nos. 1-16)	**21.6 ± 8.5**	**15.9 ± 4.6**	**65.9 ± 7.23**	**28.5 ± 14.5**
	Σ of carc. PAHs (Nos. 9-15)	**1.76 ± 1.01**	**0.98 ± 0.36**	**4.66 ± 0.44**	**2.36 ± 1.58**

[1] concentration in $ng \cdot m^{-3}$, mean value from three analysis ± S.D. (standard deviation)

Determination of significantly increased concentrations mainly of carcinogenic PAHs and PCBs in the indoor air led us to attempt to quantify possible health risks for feeders and other workers exposed to polluted indoor air in the farm stables. This decission was reasonable due to the fact that the workplace has never been monitored from the point of health risks, even if high concentrations of dangerous pollutants are there and people spend long working hours there.

The mostly used approach for the risk assessment is an US EPA method of health risk assessment (EPA 1989). This method enables an effective quantification of both non-

Table 2. Concentration of PCB and chlorinated pesticides in indoor and outdoor air of pig and cattle farms

	Compounds	pig farm		cattle farm	
		indoor air[1]	outdoor air[1]	indoor air[1]	outdoor air[1]
1	PCB No. 28	75.0 ± 24.8	52.0 ± 23.3	57.0 ± 15.3	36,7 ± 20.1
2	PCB No. 52	63.3 ± 27.6	49.7 ± 26.4	54.3 ± 18.0	44.7 ± 25.1
3	PCB No. 101	59.0 ± 5.0	36.0 ± 17.3	42.3 ± 4.9	33.7 ± 13.2
4	PCB No. 118	13.7 ± 1.7	10.0 ± 4.9	9.7 ± 2.9	8.0 ± 2.2
5	PCB No. 153	61.0 ± 12.2	38.7 ± 15.6	41.7 ± 4.9	34.7 ± 5.0
6	PCB No. 138	45.7 ± 18.9	29.0 ± 17.7	28.0 ± 9.2	24.7 ± 7.3
7	PCB No. 180	18.7 ± 9.2	11.0 ± 5.7	11.3 ± 2.9	9.3 ± 2.1
	Σ of PCB (Nos. 1-7)	**336 ± 47.3**	**226 ± 97.1**	**244 ± 41.3**	**191 ± 65.4**
8	alfa-HCH	53.0 ± 38.7	28.0 ± 9.6	51.7 ± 23.6	25.0 ± 8.5
9	beta-HCH	6.3 ± 5.3	9.0 ± 7.5	4.3 ± 2.1	4.0 ± 2.2
10	gama-HCH=Lindane	1473 ± 1943	57.0 ± 26.5	493 ± 656	42.7 ± 13.8
11	delta-HCH	< 1.0	1.3 ± 1.9	< 1.0	< 1.0
	Σ of HCHs (Nos. 1-4)	**1533 ± 1981**	**95.3 ± 40.1**	**549 ± 679**	**71.7 ± 15.2**
12	p,p'-DDE	83.7 ± 12.6	94.3 ± 29.5	59.0 ± 6.4	56.7 ± 20.1
13	p,p'-DDD	4.7 ± 1.2	3.3 ± 2.1	2.7 ± 2.5	1.3 ± 1.9
14	p,p'-DDT	15.0 ± 5.7	14.3 ± 6.9	8.7 ± 2.5	12.0 ± 6.5
	Σ of DDT (Nos. 1-3)	**103 ± 17.9**	**112 ± 24.2**	**70.3 ± 8.7**	**70.0 ± 28.4**
	Hexachlorobenzene	57.7 ± 16.9	69.7 ± 42.1	91.7 ± 37.8	85.0 ± 53.2

[1] concentration in $pg \cdot m^{-3}$, mean value from three analysis ± S.D. (standard deviation)

carcinogenic and carcinogenic health risks. Moreover, the final risk is a result of an integration exposure to several pollutants. It consists of four basic steps: (i) hazard identification, (ii) dose-response assessment, (iii) exposure assessment, and (iv) risk characterization. Hazard identification is the qualitative assessment dealing with the inherent toxicity of an agent/stressor. This qualitative assessment addresses the question of whether there is any potential for human toxicity. Dose-response assessment serves for identification of the relationship between the dose of an agent/stressor and the induction of an adverse effect. Exposure assessment enables the determination of the extent of human exposure to an agent/stressor. In the end risk characterization describes the nature and likelihood of health risk to humans, including attendant uncertainties. If significant human health risks are identified, a risk management, suggesting actions for decrease of risks, must follow. This method was successfully used for risk assessment of different pollution exposure including outdoor and indoor air (Sweeney et al. 2000; Wcislo et al. 2002).

Materials and Methods

Site description

For the study 3 swine and 2 cattle farms were selected. They were located in the Hodonín District (eastern part of the Czech Republic) that belongs among agricultural regions of the Czech Republic. Indoor air samples were collected on places inside the buildings that fulfilled requirements for representative sampling. The samples were collected (1999 – 2000) in three campaigns (June 199; February 2000; November 2000) to find out indoor concentrations of selected persistent organic pollutants in warm and cold part of the year.

1. L1 (locality 1) was located in the pig farm in Milotice (Agropodnik Hodonín). Air samplers were placed in the middle of a pig fattening hall No. 7 (100·15·2.5 meters). The hall, where 1300 pigs were housed, was aerated with 32 air blowers and open small windows. During a cold period of the year the hall was heated with a gas bunner and the windows were closed.
2. L2 (locality 2) was located in the pig farm in Dubňany (Gigant Dubňany). Air samples were collected in the hall No. 16 (96·18·3 meters). The hall was divided into two halves and in each of parts there were 750 pigs. The collectors were placed in the middle of one part. 12 air blowers and 12 windows were used for aeration of each of the parts. During a cold period of the year the windows were closed.
3. L3 (locality 3) was located in the cattle farm in Nesyt (ZD Mikulčice) situated in a distance of 1.5 km from

a power-station Hodonín. Indoor air was sampled in the calving house (60·10·4 meters). The house was aerated with 7 vacuum ventilation blowers, 14 windows, 4 run gates and 3 entrance gates. In winter only vacuum ventilation blowers were used for the aeration. Every day a tractor operated for about an hour in the house (littering, cleaning, feed distribution).

4. L4 (locality 4) was located in a cattle farm in Násedlovice (ZEMAS Čejč). Air samplers were placed in the corner of cow house No. 1 (50·30·3.5 meters). About 160 heads of cattle were housed there. For the aeration only roof ventilation flaps and 4 run gates and 4 entrance gates. In a cold period all gates were closed. Every day a tractor operated for about an hour in the house (littering, cleaning, feed distribution).

5. L5 (locality 5) was located in a pig farm in Terezín (ZEMAS Čejč). Air samplers were placed in the middle of the hall No. 1 (70·8·2.8 meters). In the hall there were 500 pigs. The hall was aerated with 6 air blowers, roof ventilation flaps, small windows and entrance gates. In winter only air blowers were used for the aeration.

Stock feeders and other workers spend inside 6 hours per day and 6 days per week in average.

Besides indoor air samples collected inside farm buildings, reference outdoor samples were collected in parallel on two localities. L2b was located outdoor at the farm in Dubňany and L3b was located in the farm in Nesyt. Both of localities were affected by a traffic (tractors, lorries and other vehicles) at the farms.

Sample collection

The indoor and outdoor air samples were collected three times in the localities during 1999 – 2000. For a 24-hour sampling (350 – 450 m^3 per day) high-volume samplers PS-1 (Graseby-Anderson U.S.A.) were used. These samplers, with a tandem of filters, enable sampling of both gas-phase and particle phase semi-volatile organic compounds. The absorbed pollutants on particulate matter were collected on a quartz filter and pollutants in a vapour phase were collected on a PUF filter. All sample collections were done according to U.S. EPA recommendations. The exposed filters were extracted with DCM in the Soxhlet extractor. The extracts were then fractioned with different polarity solvents on a silicagel column for the chemical analysis of PAHs and their nitro- and oxy-derivates. For the analysis of OCPs and PCBs were organic extracts purified on H_2SO_4 modified silicagel column. PAHs (16 compounds according to U.S. EPA) and its derivates, OCPs (HCB, α-HCH, β-HCH, γ-HCH, δ-HCH, p,p'- DDT, p,p'-DDD and p,p'-DDE) and PCBs (PCB 28, PCB 52, PCB 101, PCB 118, PCB 153, PCB 138 and PCB 180) were analyzed with GC/MS (Finnigan MAT, Austin USA). All steps including sample collection, extraction and chemical analyses were done under QA/QC (Cigánek et al. 2000).

Risk assessment method

The risks were quantified under the present environmental conditions for the selected exposure scenario (Table 3). Indicator chemicals, also termed COPCs (*chemical of potential concern*), are typically selected as an initial step in a site-specific risk assessment in order to characterize the site and to focus assessment activities on those POPs compounds that may pose the most significant potential risks to humans. The risk characterization was considered separately for carcinogenic and non-carcinogenic effects, and includes a discussion on factors that may result in either an overestimation or an underestimation of the risks.

Table 3. Selected exposure scenario

Exposure parameter	**Value**	**Unit**	**Notice**
Body weight [BW]	70	kg	
Exposure time [ET]	6	hours per day	
Exposure frequency [EF]	200	days per year	
Inhalation rate [IR]	20	m^3 per day	
Exposure duration [ED]	30	years	
Lifetime expectancy [LA]	70	years	
Averaging time – non-cancer [AT-N]	10 950	days	(ED · 365 days)
Averaging time – cancer [AT-C]	25 550	days	(LA · 365 days)

Human health risks, both non-carcinogenic (*HI – hazard index*) and carcinogenic (*IECR – incremental probability of an individual developing cancer over a lifetime*) were computed according to US EPA methodology (EPA 1989) - upgraded for new reference values.

Potential non-cancer risks for exposure to COPCs were evaluated by comparison of the estimated contaminant intakes from inhalation exposure with the *RfD* to produce the *HQ*, defined as follows (EPA 1989):

$$HQ = \frac{CDI}{RfD}$$

where *HQ* is hazard quotient (unitless); *CDI*, chronic daily intake (mg/kg/day); *RfD*, reference dose (mg/kg/day).

The *HQ* assumes that there is a level of exposure (i.e., *RfD*) below which it is unlikely for even sensitive populations to expect any adverse health effects. If the HQ exceeds unity (a value of 1), there may be a concern for potential non-carcinogenic effects. To assess the overall potential for non-carcinogenic effects posed by more than one chemical, the *HQ* calculated for each chemical are summed (assuming additivity of effects) and expressed as *HI* (hazard index) (EPA 1989):

$$HI = \Sigma HQ_i$$

In cases where the non-cancer *HI* does not exceed unity (*HI* < 1), it is assumed that no chronic risks are likely to occur at the site (EPA 1989). If the *HI* is greater than unity as a consequence of summing several *HQs* it would be appropriate to segregate (separate) the compounds by effect and by mechanism of action and to derive specific *HIs* for each of target organ groups.

The health risk assessment has been carried on with the determination of the individual excess cancer risk index (*IECR*) (EPA 1996a, 1996b).

Cancer risks *IECR* were estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen; the following linear low-dose carcinogenic risk equation was used for each of exposure routes (EPA 1989):

$$IECR = 1 - e^{(-LAIC \cdot IUR)}$$

where *LAIC* is livetime average inhalation concentration ($\mu g \cdot m^{-3}$); *IUR*, inhalation unit risk ($1/\mu g \cdot m^{-3}$) – values used for calculation are summarized in Table 4. If a site has multiple carcinogenic contaminants, cancer risks for each carcinogens (assuming additivity of effects) and compared with the acceptable risk.

$$IERC = \Sigma IERC_i$$

Risks in the range of 1E-06 to 1E-04 typically have been judged to be acceptable by EU and US EPA (EPA 1991a, 1991b).

Table 4. RfDs and IURs for the selected COPCs

COPCs	RfD $[mg \cdot kg^{-1} \cdot day^{-1}]$	Ref.	IUR $[1/\mu g \cdot m^{-3}]$	Ref.
Naphthalene	9.00E-04	NCEA		
Acenaphthene	6.00E-02	IRIS		
Fluorene	4.00E-02	IRIS		
Anthracene	3.00E-01	IRIS		
Fluoranthene	4.00E-02	IRIS	8.70E-05	WHO
Pyrene	3.00E-02	IRIS		
Benz[a]anthracene			1.20E-04	WHO
Chrysene			8.70E-05	WHO
Benzo[b]fluoranthene			8.70E-03	WHO
Benzo[k]fluoranthene			8.70E-04	WHO
Benzo[a]pyrene			8.70E-02	WHO
Indeno[1,2,3-cd]pyrene			5.80E-03	WHO
Dibenz[a,h]anthracene			7.70E-02	WHO
PCB 28			1.00E-04	IRIS
PCB 52			1.00E-04	IRIS
PCB 101			1.00E-04	IRIS
PCB 118			1.00E-04	IRIS
PCB 153			1.00E-04	IRIS
PCB 138			1.00E-04	IRIS
PCB 180			1.00E-04	IRIS
alpha-HCH			1.80E-03	IRIS
beta-HCH			5.40E-04	IRIS
gamma-HCH	3.00E-04	IRIS		
p,p'-DDT	5.00E-04	NCEA	9.71E-05	NCEA
HCB	8.00E-04	IRIS	4.60E-04	IRIS

IRIS - Integrated Risk Information Systém (U.S.EPA, *http://www.epa.gov*)
WHO – World Health Organization (*http://www.who.int*)
HEAST - Health Effects Summary Tables (U.S.EPA, *http://www.epa.gov*)
NCEA - National Center for Environmental Assessment (U.S.EPA, *http://www.epa.gov*)

Results and Discussion

Analysis of indoor air in the stables of cattle and pig farms revealed increased concentrations of POPs in comparison to outdoor levels (Cigánek et al. 2000). Even if available data included only three one-day samplings for each of five analysed localities, non-carcinogenic and carcinogenic risks for feeders and other workers were assessed.

The values of *HI* and *IECR* for all samplings are in Fig. 1, Fig. 2 and Table 5. While no non-carcinogenic risks were determined in any of the localities, increased carcinogenic risks were observed. In same cases level of *IECR* = $1 \cdot 10^{-6}$ was passed over. The highest *IECR* was found in locality L4 in February 2000. The lowest IECR was found also in February 2000 and it was in locality L2.

Table 5. Summary of risk values for inhalation scenario (indoor and outdoor air)

Indoor air				Outdoor air			
Locality	Campaigns	*HI*	*IECR*	Locality	Campaigns	*HI*	*IECR*
L1	VI-99	0.00015	**1.153E-06**				
	II-00	0.00013	**3.611E-06**				
	XI-00	0.00018	7.189E-07				
L2	VI-99	0.00063	**2.646E-06**	L2b	VI-99	0.00003	9.303E-07
	II-00	0.00007	2.565E-07			0.00006	6.187E-07
	XI-00	0.00015	**2.179E-06**			0.00019	5.296E-07
L3	VI-99	0.00028	**4.248E-06**	L3b	VI-99	0.00004	3.271E-07
	II-00	0.00032	**4.849E-06**			0.00032	3.676E-06
	XI-00	0.00024	**4.025E-06**			0.00024	2.348E-06
L4	VI-99	0.00022	9.127E-07				
	II-00	0.00023	**8.08E-06**				
	II-00	0.00025	**2.372E-06**				
L5	VI-99	0.00042	3.93E-07				
	II-00	0.00008	3.031E-07				
	XI-00	0.00031	9.519E-07				

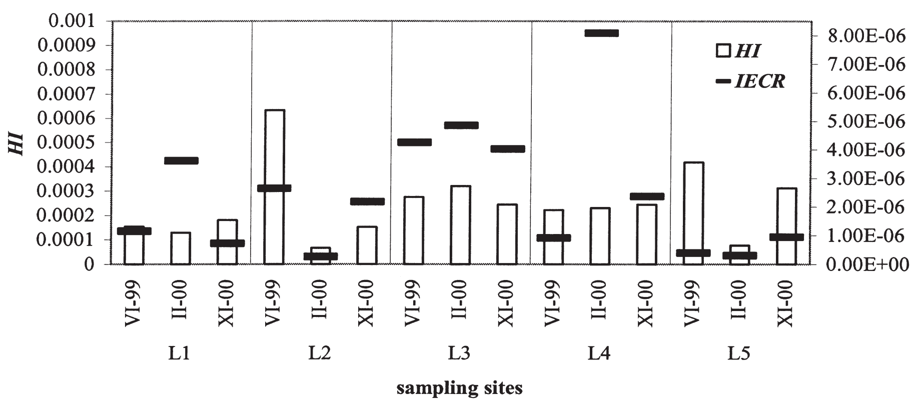

Fig. 1. Summary of risk values for inhalation scenario (indoor)

The average *IECR* levels for the investigated locality are graphically compared in Figs 1 and 2. The highest average carcinogenic risk was detected in locality L3. On the other hand the lowest average level of *IERC* was in locality L5.

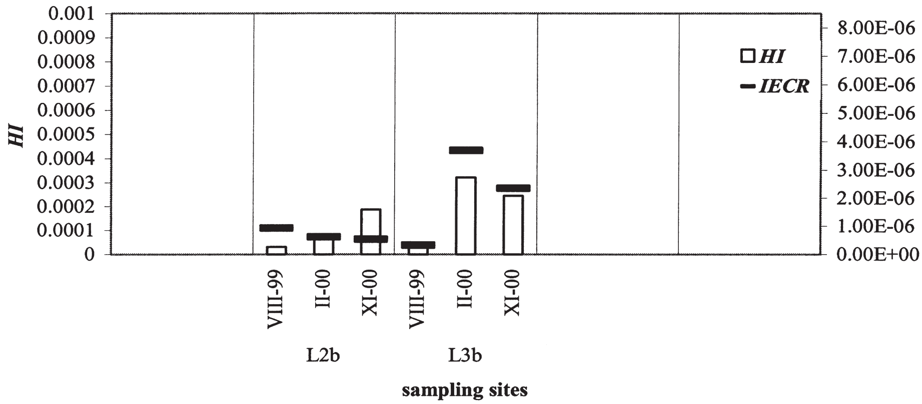

Fig. 2. Summary of risk values for inhalation scenario (outdoor)

In the carcinogenic risks, the most important role was played by PAHs. The influence of other measured POPs was only marginal.

Any clear difference between the samplings in warm and cold part of the year was not observed. Neither an open-fire heating nor decreased aeration in the cold periods increased the health risks. The pig farms did not differ significantly from the cattle farms.

Even if outdoor air was sampled only on two farms, health risk assessment showed that non-carcinogenic as well as carcinogenic risks for indoor air were only slightly higher or comparable with the outdoor risks.

In case of pesticide risks, any demands to reduce contamination are not necessary because of their low indoor concentrations. The main contributors to human health risk are PAHs. Therefore ventilation while tractors, lorries and other vehicles are running should be the main purpose how to decrease estimated human health risk, mainly in winter season.

In comparison with a median value of *IECR* for research workers from Košetice (years 1996 – 1999), Central European background monitoring station of EMEP, that achieves $5.96 \cdot 10^{-7}$ (Holoubek et al. 2003), the carcinogenic risks in farms are approximately twice higher.

As a specific result of the risk assessment for the case-study area, obtained in line with the applied principle of reasonable maximum exposure scenarios, it has been shown that used indoor inhalation exposure pathway in the farms may pose increased carcinogenic health risk ($MAX_{IECR} = 8.08 \cdot 10^{-6}$).

Hodnocení zdravotních rizik z inhalační expozice ve stájích prasat a skotu na jižní Moravě

Hlavním tématem této studie bylo hodnocení zdravotních rizik z inhalačního expozičního scénáře na vybraných vepřínech a kravínech na jižní Moravě (Česká republika). Toto výjimečné hodnocení potenciálních rizik pracovníků farem bylo hlavním přínosem této studie. Ve vybraných vepřínech a kravínech tedy byly hodnoceny možné nekarcinogenní i karcinogenní zdravotní rizika (podle metodiky Hodnocení zdravotních rizik US EPA) pro profese krmiče a ostatní zaměstnance těchto farem s významně vyššími koncentracemi především karcinogenních PAHs a PCBs v ovzduší vnitřního pracovního prostředí. Nekarcinogenní rizika nebyla zjištěna ani na jedné z hodnocených lokalit, ale zvýšená karcinogenní rizika byla pozorována. Nejvyšší karcinogenní rizika byla nalezena v prostorech stájí krav ($MAX_{IECR} = 8.08 \cdot 10^{-6}$), nejnižší ve vepřínech ($MIN_{IECR} = 2.57 \cdot 10^{-6}$).

Hodnoty karcinogenních rizik z vnitřních prostor hodnocených stájí této studie však nebyly extrémně vysoké, ale přibližně dvakrát vyšší než je hodnota mediánu rizika, determinovaného pro výzkumné pracovníky Středoevropské pozaďové monitorovací stanice sítě EMEP v Košeticích $IECR$=5.96·10^{-7} (1996 - 1999).

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