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Use of biocidal products (insect sprays and electro-vaporizer) in indoor areas – Exposure scenarios and exposure modeling

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Abstract

Five commercially available insect sprays were applied in a model room. Spraying was performed in accordance with the manufacturers' instructions and in an overdosed manner in order to simulate worst-case conditions or an unforeseeable misuse. In addition, we examined electro-vaporizers. The Respicon^{TM} aerosol monitoring system was applied to determine inhalation exposure. During normal spraying (10 seconds) and during the following 2–3 minutes, exposure concentrations ranged from 70 to 590 μg/m^3 for the pyrethroids tetramethrin, d-phenothrin, cyfluthrin, bioallethrin, and the pyrethrins. Calculated inhalable doses were 2–16 μg. A concentration of approximately 850 μg chlorpyrifos/m^3 (inhalable dose: approximately 20 μg) was determined when the "Contra insect fly spray" was applied. Highest exposure concentrations (1100–2100 μg/m^3) were measured for piperonyl butoxide (PBO), corresponding to an inhalation intake of 30–60 μg. When simulating worst-case conditions, exposure concentrations of 200–3400 μg/m^3 and inhalable doses of 10–210 μg were determined for the various active substances. Highest concentrations (4800–8000 μg/m^3) were measured for PBO (inhalable: 290–480 μg).

By applying the electro-vaporizer "Nexa Lotte" plug-in mosquito killer concentrations for d-allethrin were in the range of 5–12 μg/m^3 and 0.5–2 μg/m^3 for PBO while with the "Paral" plug-in mosquito killer concentrations of 0.4–5 μg/m^3 for pyrethrins and 1–7 μg/m^3 for PBO were measured.

Potential dermal exposures were determined using exposure pads. Between 80 and 1000 μg active substance (tetramethrin, phenothrin, cyfluthrin, bioallethrin, pyrethrins, chlorpyrifos) were deposited on the clothing of the total body surface area of the spray user. Highest levels (up to 3000 μg) were determined for PBO. Worst-case uses of the sprays led to 5–9 times higher concentrations.

Also a 2-hour stay nearby an operating electro-vaporizer led to a contamination of the clothing (total amounts on the whole body were 450 μg d-allethrin and 50 μg PBO for "Nexa Lotte" plug-in mosquito killer and 80 μg pyrethrins and 190 μg PBO for "Paral" plug-in mosquito killer).

Human biomonitoring data revealed urine concentrations of the metabolite (E)-trans-chrysanthemum dicarboxylic acid ((E)-trans-CDCA) between 1.7 μg/l and 7.1 μg/l after 5 minutes of exposure to the different sprays. Also the use of electro-vaporizers led to (E)-trans-CDCA concentrations in the urine in the range of 1.0 μg/l to 6.2 μg/l (1–3 hours exposure period).

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The exposure data presented can be used for performing human risk assessment when these biocidal products were applied indoors.

The airborne concentrations of the non-volatile active chemical compounds could be predicted from first principles using a deterministic exposure model (SprayExpo).

Keywords: Insect sprays; Electro-vaporizers; Pyrethroids; Pyrethrum; Piperonyl butoxide; Chlorpyrifos; Indoor use; Dermal exposure; Inhalation exposure; Exposure modeling

Introduction

Human risk assessment of possible health hazards is based on two basic elements: hazard characterization and exposure quantification, leading to an integration of the exposure findings and toxicological effects of the substance in question in order to reach a characterization of possible health risks. Assessment of chemical risks by inhalation as the only exposure route takes into consideration the concentrations of substances in the air which can be inhaled. Biocidal products like sprays or electro-vaporizers are used to control pests in indoor areas. They contain insecticidal substances like pyrethrum, pyrethroids, organophosphates, and carbamates. When they are applied the consumer is exposed to these biocides and various other ingredients because inhalation of the aerosol will take place. In particular a non-foreseeable misuse can lead to high indoor concentrations which may affect human health.

For scenarios involving such exposure conditions, risk assessment may need to address those effects which are of potential concern after single (e.g. acute toxicity, irritation) and repeated exposures. With respect to single exposures the scenarios presented here are certainly realistic and probably also representative. But the data may also be valuable for an exposure estimation, when biocidal products will repeatedly be applied.

The aim of this study was therefore to quantify and characterize the extent and level of exposure to those biocidal products which are applied indoors. It was not intended to perform a comprehensive human risk assessment, which would have to take into account the toxicological effects of these biocides. Therefore, in this research project we present data for various exposure scenarios in conjunction with the self-use of biocidal consumer products (sprays, electro-vaporizers) in private indoor areas. These data describe the indoor air contamination and the exposure of users and occupants with regard to inhalation and potential dermal exposures. Furthermore, metabolite concentrations are reported which were determined in the urine of spray users or bystanders after exposure.

There is good agreement that careful consideration is necessary in the exposure assessment for consumer subpopulations with a particular exposure pattern, and this should also be reflected in the risk assessment. Especially with regard to children a foreseeable misuse has to be considered. Therefore, conditions of exposure representing worst-case conditions were also simulated. Furthermore, it must be borne in mind that numerous biocidal substances are persistent in indoor areas, which means that frequent use may result in an accumulation indoors.

For consumers the risk assessment procedure will often rely on modeled exposure estimates which are based on product/article specifications (e.g. the content of the substance in the product/article) and assumptions on intended and other reasonably foreseeable uses. Therefore, the experimental data obtained here in connection with spraying were compared with results from calculations using a deterministic model on spray dispersion for the use of biocidal consumer sprays in private indoor areas.

Materials and methods

Model rooms

The aerosol sprays and electro-vaporizers were applied in equally sized model rooms (area 16 m^2, volume about 40 m^3) which were furnished like normal living rooms.

Walls and ceilings were covered with woodchip wall paper, and floors with textile carpets. In each room there was a cupboard, shelves, a sofa, a coffee table, a chair, a dining table as well as a window and radiator.

During the experiments, a ventilator was constantly operated in the rooms in order to simulate air circulation. The temperature, relative air humidity, and air pressure were monitored continuously in the rooms.

Each spray product was applied in the middle of the room between the door and window. The electro-vaporizers were plugged into a power outlet in the wall.

Applications

Insect sprays

Five different insect sprays, which are intended for use as room sprays, were used:

''Amisia insect spray'', ''Blattanex fly spray'', ''Blattanex fly spray'' (new formulation) ''Paral insect spray'',

"Contra insect fly spray". Detailed information on active ingredient concentrations is given in Table 1.

For simulating the correct use, each product was applied in a separate room using the amount recommended by the manufacturers ("Amisia insect spray" was sprayed in the room for 20 seconds, the other sprays for 10 seconds.) Then the rooms were kept closed for 20 minutes and after that they were ventilated for 30 minutes.

In a second experiment an overdose of each spray was applied (simulating worst-case conditions). In this case, the products were sprayed for 2 minutes and the rooms were not ventilated.

Electro-vaporizers

Two different electro-vaporizers were used in separate model rooms for 6 hours per day according to the manufacturers' instructions.

"Paral", containing 20 mg pyrethrum extract and 40 mg PBO per pad and "Nexa Lotte", containing 4.6% d-allethrin and 4.6% PBO per pad (manufacturer declaration) or about 38 mg of each substance per pad.

Spray characterization

The sprays were characterized with respect to the particle diameter of the released droplets. Measurements were carried out with a laser diffraction spectrometer (HELOS (1269), Sympatec GmbH). The size distribution was calculated using a mathematical inversion method. The cumulative volume distribution Q_3 as a function of the droplet size is shown in Fig. 1. Table 2 presents the percentiles for the distribution of the aerosol particles in the sprays.

Inhalation exposure

During the spraying procedure (see above), the inhalation exposure of the spray user was recorded with the personal aerosol exposure monitor Respicon^{TM} 3-F (Hund, Wetzlar, Germany), which was developed at the Fraunhofer Institute of Toxicology and Experimental Medicine (Koch et al., 1999). This device allows the simultaneous sampling and on-line concentration monitoring of the three health-relevant particle size fractions according to the CEN convention 481: the respirable (C_R), the thoracic (C_{Th}), and the inhalable fractions (C_I) (CEN, 1992, 1993). Using three glass fiber filters (37 mm), in a special case followed by polyurethane foam (PUF) plugs (sampling of chlorpyrifos), the different aerosol fractions were separated. Online detection was performed by three built-in light-scattering photometers.

During application according to the manufacturers' instructions personal measurements were done during the spraying operation and for up to 2–3 minutes thereafter.

When spraying under worst-case conditions, measurements with the personal Respicon^{TM} were carried out over a period of a total of 5 minutes. In addition, a stationary Respicon^{TM} was positioned in the middle of the room, and sampling was done over a period of 60 minutes.

Filters were extracted and analyzed (see below). Results are given as exposure concentrations in µg active substance/m^3 inhaled air and as doses (respiratory

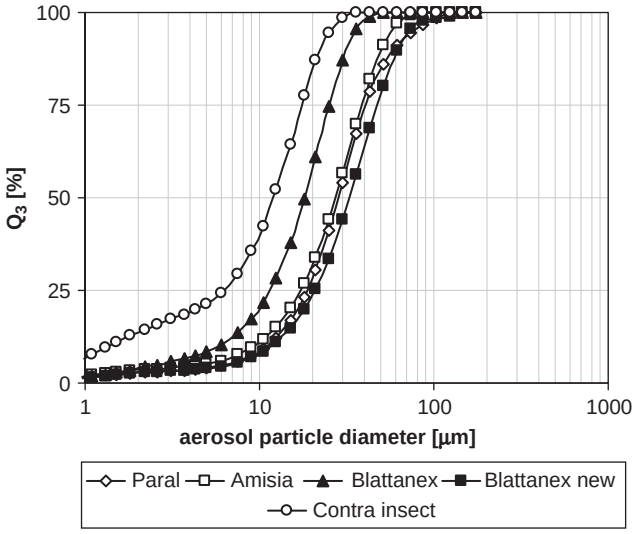

Fig. 1. Spray characterization using laser diffraction spectrometry. Cumulative volume distribution Q_3 as a function of the aerosol particle diameter.

Table 1. Overview of active substance concentrations in the sprays used.

"Amisia insect spray"	"Blattanex fly spray"	"Blattanex fly spray" (new)	"Paral insect spray"	"Contra insect fly spray"
d-Tetramethrin (0.04 g/100 g) d-Phenothrin (0.06 g/100 g)	Cyfluthrin (0.04 g/100 g) Tetramethrin (0.2 g/100 g) PBO (1 g/100 g)	d-Tetramethrin (0.15 g/100 g) d-Phenothrin (0.15 g/100 g)	Pyrethrum extract (0.25 g/100 g) PBO (1 g/100 g)	Chlorpyriphos (0.5 g/100 g) Bioallethrin (0.15 g/100 g) PBO

Table 2. Percentiles (as μm) and geometric standard deviations (distribution range) of the distributions given in Fig. 1 (σg is the geometric standard deviation of the droplet size distribution).

Product	x_{16}	x_{50}	x_{84}	σg
Amisia insect spray	13.45 ± 0.19	27.94 ± 0,73	44.00 ± 1.57	1.81 ± 0.035
Paral insect spray	14.61 ± 0.31	28.41 ± 0.44	48.79 ± 8.47	1.83 ± 0.160
Blattanex fly spray	8.51 ± 0.15	18.14 ± 0.35	28.67 ± 0.74	1.84 ± 0.029
Blattanex fly spray (new)	15.75 ± 0.28	33.02 ± 0.76	55.08 ± 2.01	1.87 ± 0.038
Contra insect fly spray	2.67 ± 0.13	12.07 ± 0.33	19.98 ± 0.52	2.72 ± 0.074

minute volume: 12 l/min) related to the duration of exposure (see Table 3).

Potential dermal exposure

Exposure pads made from filter paper (Macherey-Nagel, type 1640 m, size 10 × 10 cm, back covered with aluminum foil) were positioned on the sprayer's overall at the following positions (= 8% of total body surface): head, back, chest, upper left arm, upper right arm, left forearm, right forearm, left thigh, right thigh, left shin, right shin according to ECB, 1998, DIN CEN, 2006 and OECD, 1997.

After the respective spraying procedure and a short stay in the room, the pads were removed (2–3 minutes after correct use, and after 5 minutes in the case of overdose), extracted, and active substance concentrations were measured (see below).

The substance amount per pad was related to the area of the respective part of the body using standard factors and the resulting amounts were added up to determine the potential total dermal body dose. The results are given as dermal doses related to the duration of exposure.

Extraction and analysis of samples

The filters, PUF plugs, or the cut exposure pads were extracted three times (10 minutes) using *n*-hexane or ethyl acetate in an ultrasonic bath. The extracts were combined, reduced in volume using N_2 (TurboVap II), and filtered through silanized glass wool. Final volumes of 1 or 5 ml were adjusted.

Pyrethrins were determined using a gas chromatograph with an electron capture detector (GC/ECD). GC analysis was carried out employing an instrument from Hewlett Packard (5890 series II), using a DB5.625 column (length: 10–12 m, i. d. 0.25 mm, $d_f = 0.25$ μm), a deactivated retention gap, and helium as carrier gas. The sample was injected on-column. The following temperature program was used: 60 °C (1 minutes), 10 °C/min up to 180 °C, 6 °C/min up to 270 °C (3 minutes). Analytical details were already described previously (Berger-Preiß et al., 1997).

The individual spray ingredients (phenothrin, tetramethrin, cyfluthrin, chlorpyrifos, bioallethrin, PBO) were measured using a gas chromatograph which was equipped with a mass-selective detector (MSD/EI). GC analysis was carried out employing an instrument from Agilent Technologies (6890N), using an HP-5MS column (30 m length, i.d.: 0.25 mm, $d_f = 0.25$ μm) and helium as carrier gas (constant flow, 1.4 ml/min). The following temperature program was used: 50 °C (0 minutes), 10 °C/min up to 280 °C (5 minutes). The sample was injected in split/splitless mode (injector temperature: 250 °C) and detected using an Agilent 5975 mass-selective detector.

The MSD fitted with a quadrupole mass filter was used in electron impact (EI) mode. EI mass spectra were obtained at 70 eV. MSD temperatures were as follows: transfer line: 280 °C; ion source: 230 °C; quadrupole: 150 °C. The MSD was run in selected ion monitoring (SIM) mode. The following target and qualifier ions (m/z) were monitored: phenothrin (123/183), tetramethrin (164/123), cyfluthrin (163/215), chlorpyrifos (197/314), bioallethrin (123/79), and PBO (176/119).

Quantification was done by means of a characteristic target mass using external calibration curves for the individual compounds.

Biomonitoring

Metabolite concentrations in the urine of the spray user and of a second person (bystander) were determined after 10 seconds of spraying and staying in the room for 5 minutes. Twenty-four-hour urine was collected. The metabolites (E)-cis/trans-chrysanthemum dicarboxylic acid ((E)-cis/trans-CDCA), cis/trans-3-(2,2-dichlorovinyl) -2,2-dimethylcyclopropane carboxylic acid (cis/trans-DCCA), and 4-fluoro-3-phenoxybenzoic acid (4-F-3-PBA) were analyzed using gas chromatography-mass spectrometry (GC/MS (NCI)) (Elflein et al., 2003; Barr et al., 2007).

Exposure modeling

The model SprayExpo was used for exposure modeling. The model calculates the airborne concentrations of the respirable, the thoracic, and the inhalable, or any

Table 3. Description of individual spray scenarios and results of inhalation exposure (exposure concentrations and calculated doses for the inhalable, thoracic, and respirable fractions of active substances, mean values of 2 spray applications in each case) and potential total dermal exposures.

Insect spray scenario ID	Spray time [s]	Active substance a.s.	Time[a]	Average exposure concentration [µg a.s./m^3]			Inhalable dose [µg a.s./application[b]]			Dermal dose[c]
	Amount [g]		[min]	Inhalable	Thoracic	Respirable	Inhalable	Thoracic	Respirable	[µg a.s./application]
Amisia										
S1 (A)	20	d-Tetramethrin	3	67.7	49.4	20.1	2.4	1.8	0.7	80
	23.8	d-Phenothrin		85.6	66.7	26.3	3.1	2.4	0.9	100
S2 (A)	120	d-Tetramethrin	5	231.2	163.7	93.6	13.9	9.8	5.6	267
	114.4	d-Phenothrin		306.2	229.7	131.2	18.4	13.8	7.9	360
S3 (A)	120	d-Tetramethrin	60	114.1	87.8	49.4	82.2	63.2	35.6	NA[d]
	111.4	d-Phenothrin		176.8	136.8	77.3	127.3	98.5	55.6	NA
Blattanex										
S1 (B)	10	Cyfluthrin	2.2	120.9	82.6	34.2	3.2	2.2	0.9	114
	11.4	Tetramethrin		587.1	397.7	166.6	15.5	10.5	4.4	334
		PBO		2122	1425	598.9	56.0	37.6	15.8	1138
S2 (B)	120	Cyfluthrin	5	424.4	329.0	172.6	25.5	19.7	10.4	712
	110.3	Tetramethrin		3223	2342	1212	193.4	140.5	72.7	1973
		PBO		8014	5629	2952	480.8	337.7	177.1	6328
S3 (B)	120	Cyfluthrin	60	267.4	245.8	177.3	192.5	177.0	127.7	NA
	110.3	Tetramethrin		1992	1681	1108	1434	1210	798.0	NA
		PBO		4518	3614	2305	3253	2602	1659	NA
Blattanex (new)										
S1 (BN)	10	d-Phenothrin	3	144.5	85.6	25.7	5.2	3.1	0.9	722
	16.3	d-Tetramethrin		147.4	87.8	28.8	5.3	3.2	1.0	752
S2 (BN)	120	d-Phenothrin	5	1416	815.0	265.0	84.9	48.9	15.9	4017
	189.2	d-Tetramethrin		1935	1104	357.9	116.1	66.2	21.5	3931
S3 (BN)	120	d-Phenothrin	60	538.3	403.0	181.4	387.6	290.1	130.6	NA
	189.2	d-Tetramethrin		695.6	520.0	236.5	500.8	374.4	170.3	NA

Table 3. (*continued*)

Insect spray scenario ID	Spray time [s]	Active substance a.s.	Time[a]	Average exposure concentration [µg a.s./m^3]			Inhalable dose [µg a.s./application[b]]			Dermal dose[c]
	Amount [g]		[min]	Inhalable	Thoracic	Respirable	Inhalable	Thoracic	Respirable	[µg a.s./application]
Paral										
S1 (P)	10	Pyrethrins	3	344.7	208.3	99.4	12.4	7.5	3.6	1086
	19.8	PBO		1467	917.8	381.0	52.8	33.0	13.7	2969
S2 (P)	120	Pyrethrins	5	2616	1573	736.5	156.9	94.4	44.2	4736
	162.4	PBO		5920	3343	1594	355.2	200.6	95.6	20895
S3 (P)	120	Pyrethrins	60	753.3	541.3	305.8	542.4	389.7	220.2	NA
	162.4	PBO		2466	1658	802.6	1775	1193	577.9	NA
Contra insect										
S1 (C)	10	Chlorpyrifos	2.2	845.5	661.4	397.3	22.3	17.5	10.5	249
	9.5	Bioallethrin		426.9	303.8	178.6	11.3	8.0	4.7	124
		PBO		1167	944.0	569.9	30.8	24.9	15.0	264
S2 (C)	120	Chlorpyrifos	5	3444	2907	1723	206.6	174.4	103.4	1817
	89.2	Bioallethrin		1565	1329	793.3	93.9	79.7	47.6	571
		PBO		4831	4021	2356	289.9	241.2	141.4	1792
S3 (C)	120	Chlorpyrifos	60	2036	1750	1236	1466	1260	890.1	NA
	91.6	Bioallethrin		888.6	779.2	555.8	639.8	561.0	400.1	NA
		PBO		3578	3159	2315	2576	2274	1667	NA

[a]Time of application – air sampling time or duration of exposure (spraying procedure and minutes thereafter).
[b]Application – duration of exposure (spraying procedure and minutes thereafter).
[c]µg active substance per application, whole body without hands.
[d]No measurements were carried out.

other meaningful size fractions of aerosols generated during the spraying processes. The model is a short-term exposure model covering time scales typical for the release process. Long-term emissions of vapors from walls and other surfaces are not included.

It is assumed that the sprayed product is composed of a non-volatile active substance dissolved in a solvent with known volatility. The model is based on a simulation of the motion of released droplets, taking into account gravitational settling, turbulent mixing with the surrounding air, and droplet evaporation. In the model continuous spatial release patterns can be simulated. No artificial distribution volumes need to be defined. In the calculation of the inhaled and dermal doses the spatial distribution of the concentration is explicitly taken into account.

The main input parameters are: released droplet spectrum, release rate, concentration of the active substance, spatial and temporal pattern of the release process (surface spraying against floor, ceiling, wall; room spraying, ….), vapor pressure of the liquid, size of the room, and ventilation rate. The path of the sprayer can be explicitly included into the model.

For more information on the model SprayExpo see http://www.baua.de/nn_8514/sid_10332B0486A46C197D6FA71879F0A6BF/de/Publikationen/Fachbeitraege/Gd35.html__nnn = true.

Results

Inhalation exposure

In order to describe the inhalation exposure three fractions of the inhalable aerosol were determined: the respirable fraction (the mass fraction of inhaled particles penetrating to non-cilicated airways (alveoli), $C_R \leqslant 5$ μm), the thoracic fraction (the mass fraction of inhaled particles penetrating beyond the larynx, $C_{Th} \leqslant 10$ μm), and the inhalable fraction (the mass fraction of total airborne particles that are inhaled through the mouth and nose, C_I) according to CEN 481, 1993. The data shown in Table 3 are given as exposure concentrations in μg active substance (a.s.)/m^3 (average concentration during spraying and the following time (2–5 minutes and 60 minutes, as described in column 4 of Table 3)) and as inhalable doses in μg active substance/application (duration of exposure).

During correct use of the ''Amisia insect spray'', exposure concentrations of 68 μg/m^3 and 86 μg/m^3 were determined for d-tetramethrin and d-phenothrin, and the inhalable doses were 2–3 μg of active substances. When simulating worst-case conditions the active substance concentrations were 231 μg/m^3 and 306 μg/m^3, respectively (inhalable doses during 5 minutes: 14 and 18 μg of each substance). However, after a longer stay in the room (one hour) the inhalable doses of the active substances are 6–7 times higher.

On average, 36% of the active substance from the inhalable aerosol particles were found in the respirable fraction.

When spraying the ''Blattanex fly spray'' (10 seconds according to the manufacturer's instructions), exposure concentrations for cyfluthrin, tetramethrin, and PBO were 121 μg/m^3, 587 μg/m^3, and 2122 μg/m^3, respectively. In the case of correct use of the spray and short-term stay in the room, approximately 3 and 16 μg (cyfluthrin, tetramethrin) and 56 μg PBO were inhalable.

The worst-case spray application scenario (2 minutes of spraying and 3 minutes thereafter) led to 4–5 times higher exposures. In the first 5 minutes, 26 μg cyfluthrin, 193 μg tetramethrin, and 481 μg PBO were inhalable. In the case of a 1-hour stay, active substance intake is correspondingly higher.

For ''Blattanex fly spray'', on average 33% of the active substance-carrying particles were in the respirable fraction.

Furthermore, a ''Blattanex fly spray'' with a different active substance composition (d-phenothrin and d-tetramethrin) was studied. Exposure concentrations between 145 μg/m^3 and 147 μg/m^3 were determined for the active substances during correct use of the spray. In conjunction with this procedure and during a stay of 3 minutes in the room, approximately 5 μg of each active substance were inhalable.

After the worst-case application of the spray, concentrations were 1416 μg/m^3 and 1935 μg/m^3 (short-time measurement). Overdosing of the spray led to an intake of active substance doses between 85–116 μg in conjunction with a 5-minute stay in the room. Active substance doses were approximately 4 times higher when the spray user stayed in the room for one hour.

On average, 19% of the active substance-carrying particles were in the respirable fraction.

In the case of the consumer spray ''Paral'' exposure concentrations of 345 μg/m^3 (pyrethrins) and 1467 μg/m^3 (PBO) were determined for correct use during the spraying process and the next 3 minutes. The inhalable doses during this period were calculated to be 12 μg pyrethrins and 53 μg synergist.

Worst-case conditions led to far higher exposure concentrations. Inhalable doses increased from 157 μg to 542 μg (pyrethrins) and from 355 μg to 1775 μg (PBO) during an exposure time from 5 minutes to one hour.

In the case of the ''Paral insect spray'', on average 28% of the active substance-carrying particles were in the respirable fraction.

When applying ''Contra insect fly spray'' (10 seconds of spraying and during the next 2.2 minutes), active substance concentrations of 846 μg/m^3 (chlorpyrifos), 427 μg/m^3 (bioallethrin), and 1167 μg/m^3 (PBO) were

measured. The inhalable doses during this period for these three substances were calculated to be in the range of 11–31 µg. During the worst-case use of the spray, four times higher exposure concentrations could be measured which decreased only slightly during one hour. Inhalable doses of the active substance were 94–290 µg during the first 5 minutes and seven times higher when staying in the room for one hour.

In the case of the "Contra insect fly spray", on average 48% of the active substance-carrying particles were in the respirable fraction.

To summarize, all results are presented in Fig. 2 (exposure concentrations) and Fig. 3 (calculated inhalable doses). During correct spraying (normally 10 seconds of spraying) and the next 2–3 minutes, average exposure concentrations of the pyrethroids tetramethrin, d-phenothrin, cyfluthrin, bioallethrin, and the pyrethrins were between 70–590 µg/m^3. Calculated inhalable active substance doses ranged from 2–16 µg. The exposure concentration of the organophosphate chlorpyriphos was approximately 850 µg/m^3 (inhalable dose: 20 µg). Highest concentrations were measured for the synergist PBO (1100–2100 µg/m^3), leading to an inhalation intake of 30–60 µg.

During spray applications under worst-case conditions active substance concentrations measured for 5 minutes ranged from 200–3400 µg/m^3 (inhalable doses: 10–210 µg). The highest values (concentrations: 4800–8000 µg/m^3, inhalable doses: 290–480 µg) were obtained for PBO. In the case of longer stays in overdosed rooms (1 hour) up to approximately 1500 µg active substance and 3250 µg synergist may be inhaled.

As an example, Fig. 4 represents the behavior of spray particles in the air during release of "Blattanex fly spray" (worst-case conditions). As shown by the time-resolved concentration curves recorded with the Respicon^{TM}, concentrations of non- or semivolatile compounds of the aerosol (d-phenothrin, d-tetramethrin) increased from the beginning of spraying up to the end of release (120 seconds). Thereafter, due to air exchange and particle deposition on surfaces, the concentrations of the individual particle fractions decreased at different rates.

Summarizing all results, it can be concluded that between 19–48% of the active substance-carrying particles were in the respirable fraction and 59–80% in the thoracic fraction.

Measurements were also performed during use of biocide-containing electro-vaporizers. Measurements which were carried out to determine inhalation exposure when using the aerosol monitoring system Respicon^{TM} could not be reliably evaluated, because active substance concentrations were too low. For this reason particulate matter was collected by the small filter instrument GS050 equipped with a glass fiber filter. Applying this method indoor air concentrations could be measured.

During operation of the "Nexa Lotte" plug-in mosquito killer in the above mentioned model room on several days, indoor air concentrations ranged from 5–12 µg/m^3 (d-allethrin) and 0.5–2 µg/m^3 (PBO). When using the "Paral" plug-in mosquito killer, pyrethrin

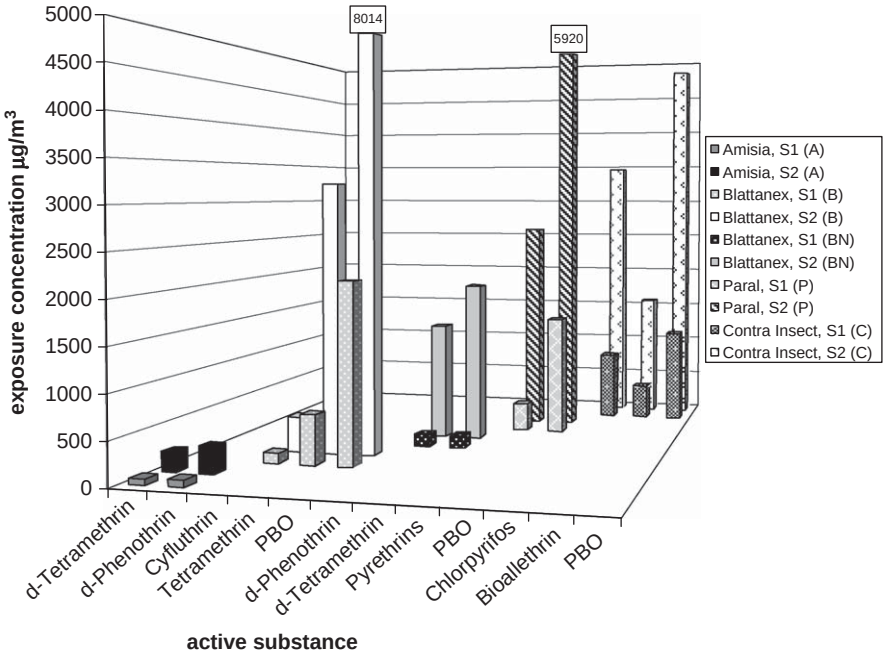

Fig. 2. Exposure concentrations of active substances during application of different consumer sprays after correct use and under worst-case conditions in model rooms (for a scenario description, see Table 3).

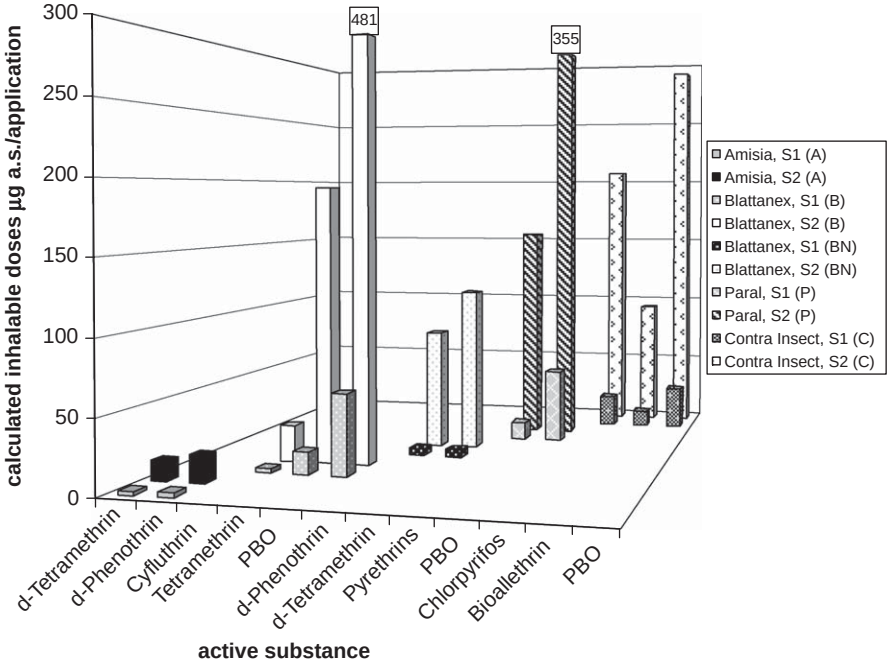

Fig. 3. Calculated inhalable doses of active substances per application during use of different consumer sprays after correct use and under worst-case conditions in model rooms (for a scenario description, see Table 3).

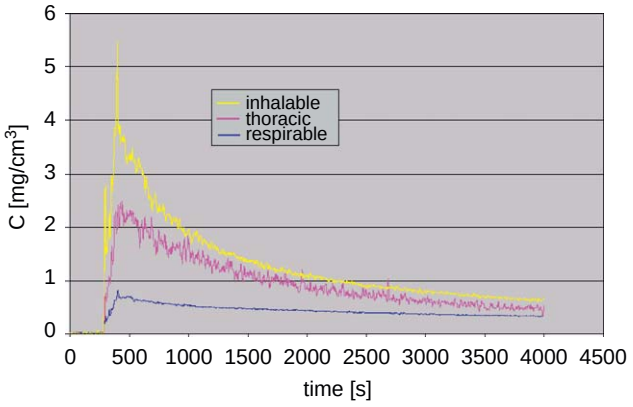

Fig. 4. Time-resolved concentration curves (respirable, thoracic, and inhalable fractions) for non- or semivolatile compounds (d-phenothrin, d-tetramethrin) measured with Respicon™ during worst-case application of the "Blattanex fly spray" (new).

concentrations were between 0.4–5 µg/m^3 and PBO concentrations between 1–7 µg/m^3.

Dermal exposure

The potential dermal exposure was determined during correct use of the sprays and during spraying under worst-case conditions. After spraying the user remained in the room for a short period of time (see Table 3).

Table 3 and Fig. 5 report the results for potential total dermal exposure for all spray scenarios. During correct use of the sprays, between 80 and 1086 µg active substance/application (d-tetramethrin, d-phenothrin, cyfluthrin, bioallethrin, pyrethrins, chlorpyrifos) were deposited on the clothing (whole body) of the sprayer. Highest levels (up to 3000 µg/application) were determined for the synergist PBO. Active substance concentrations, which vary considerably in the different spray formulations, had an important influence on the level of contamination.

The potential total dermal exposure was far higher when spraying was performed under worst-case conditions. In most cases, the calculated potential dermal doses of single active substances were about 5–7 times higher than during correct application (exception: "Amisia insect spray", 3 times).

Regarding the contamination of individual body parts, the results showed that upper body parts were contaminated more strongly than lower ones. In most cases, contamination decreased in the order: upper arms > back or chest, head > thighs ⩾ forearms > shins. Fig. 6, as an example, gives the distribution of the active substance tetramethrin during spraying of "Blattanex fly spray".

The potential dermal exposure was also determined after operation of electro-vaporizers in the model room. A 2-hour stay in the room close to the vaporizer led to potential total dermal doses of approximately 450 µg d-allethrin and 50 µg PBO ("Nexa Lotte" plug-in mosquito killer), and of approximately 80 µg pyrethrins and 190 µg PBO ("Paral" plug-in mosquito killer).

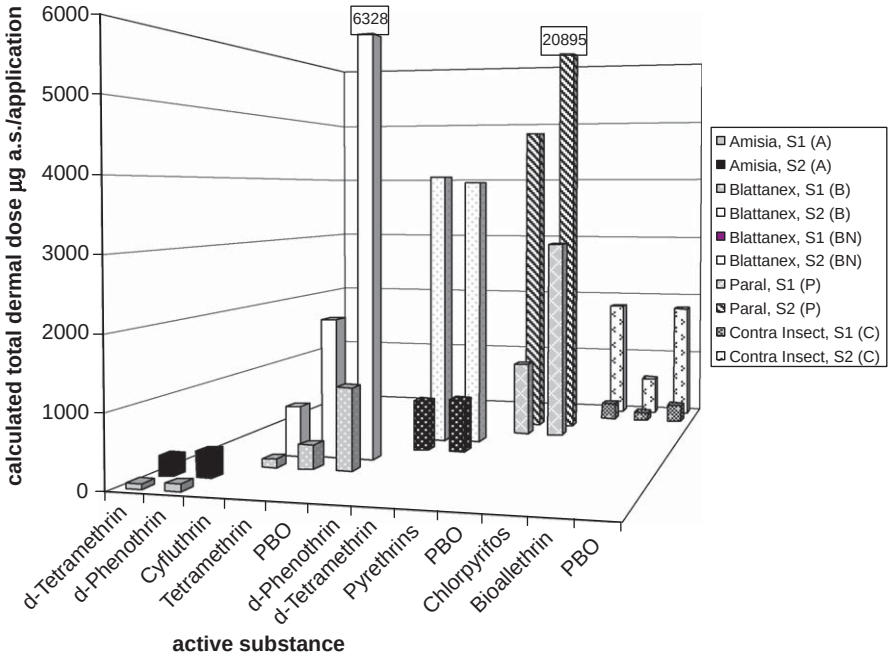

Fig. 5. Potential dermal exposure (whole body) to active substances during application of different consumer sprays after correct use and under worst-case conditions in model rooms (for a scenario description, see Table 3).

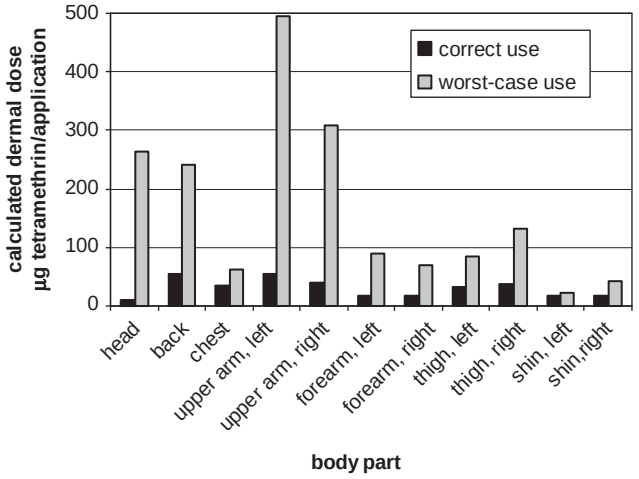

Fig. 6. Contamination of individual body parts after application of ''Blattanex fly spray'' during correct use and under worst-case conditions.

Biomonitoring

Metabolite concentrations were determined in the urine of the spray users and/or bystanders after correct use of ''Amisia insect spray'', ''Blattanex fly spray'', ''Blattanex fly spray'' (new), and ''Paral insect spray''. The active substances contained in these consumer sprays are shown in Table 1. After exposure to tetramethrin, phenothrin, allethrin, and pyrethrum (pyrethrins), determination of (E)-cis/trans-chrysanthemum dicarboxylic acid ((E)-cis/trans-CDCA), is suitable as a biomarker for internal exposure. Furthermore, cis/trans-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (cis/trans-DCCA) and 4-fluoro-3-phenoxybenzoic acid (4-F-3-PBA) should be detectable in urine after cyfluthrin exposure.

The results regarding metabolite concentrations in 24-hour urine are given in Table 4. After exposure to the different sprays, concentrations of (E)-trans-CDCA in urine were between 1.7 and 7.1 µg/l. (E)-cis-CDCA was not found in any of the urine samples. Concentrations in the urine of the user were slightly lower than in the urine of bystanders. The metabolites cis/trans-DCCA and 4-F-3-PBA were below the limit of detection. This may be due to the fact that the cyfluthrin concentration in the ''Blattanex'' product is five times lower than the tetramethrin concentration.

Furthermore, metabolite concentrations were determined in the urine of consumers after operating electrovaporizers which contain d-allethrin and pyrethrum. (E)-trans-CDCA concentrations were between 1.0 µg/l and 6.2 µg/l, depending on the period spent in the room, which was between 1–3 hours.

Exposure modeling

Results of the exposure modeling for Blattanex release are shown in Fig. 7. The concentration pattern is characterized by an increase in concentration during the release process, followed by a decrease afterwards,

Table 4. Concentrations of (E)-trans-chrysanthemum dicarboxylic acid in urine of spray users and bystanders.

Insect spray		24-h urine volume [l]	(E)-trans-CDCA concentration [μg/l]
Amisia	Sprayer	1.3	1.7
	Bystander	1.2	2.3
Blattanex	Sprayer	1.3	2.4
Blattanex (new)	Sprayer	1.5	4.4
	Bystander	1.3	7.1
Paral	Sprayer	1.2	4.7

mainly due to air exchange and particle settling. A comparison with the experimental curves (Fig. 4) shows reasonable agreement. Further comparisons were made on the basis of the average concentrations during correct use of the sprays. These are shown in Fig. 8. Except for the spray with the largest droplets, agreement between the ab initio model calculations and the experimental results is quite reasonable.

Discussion

Applying household insecticide products raises several important considerations concerning safety. These are related to the difficulty of controlling the use of these products. Especially the extent and duration of the user's potential exposure to the active ingredients can hardly be controlled. Insecticidal substances contained in vaporizers are released slowly and have a particular potential for long-term low-level exposure (minimum 6 hours per day). On the other hand, with regard to spray cans and aerosol formulations short-term high-level exposure may be of more concern. But also with these products it should be taken into account that spraying is frequently performed over a longer time period (e.g. summer time). The extent and duration of the exposure are therefore also highly product-specific. Exposure concentrations have to be safe, when such household products are applied by the consumer. As for risk assessment, both concentration-dependent as well as concentration x time-related effects have to be considered. Knowledge about the extent and time period of exposure is of paramount importance. It should be pointed out that it was not the intention of this study to perform comprehensive risk evaluations. Therefore any toxicological data referring to the active substances tested were not considered. Risk assessment should be a separate task for each of the insecticide for which an exposure scenario was studied here.

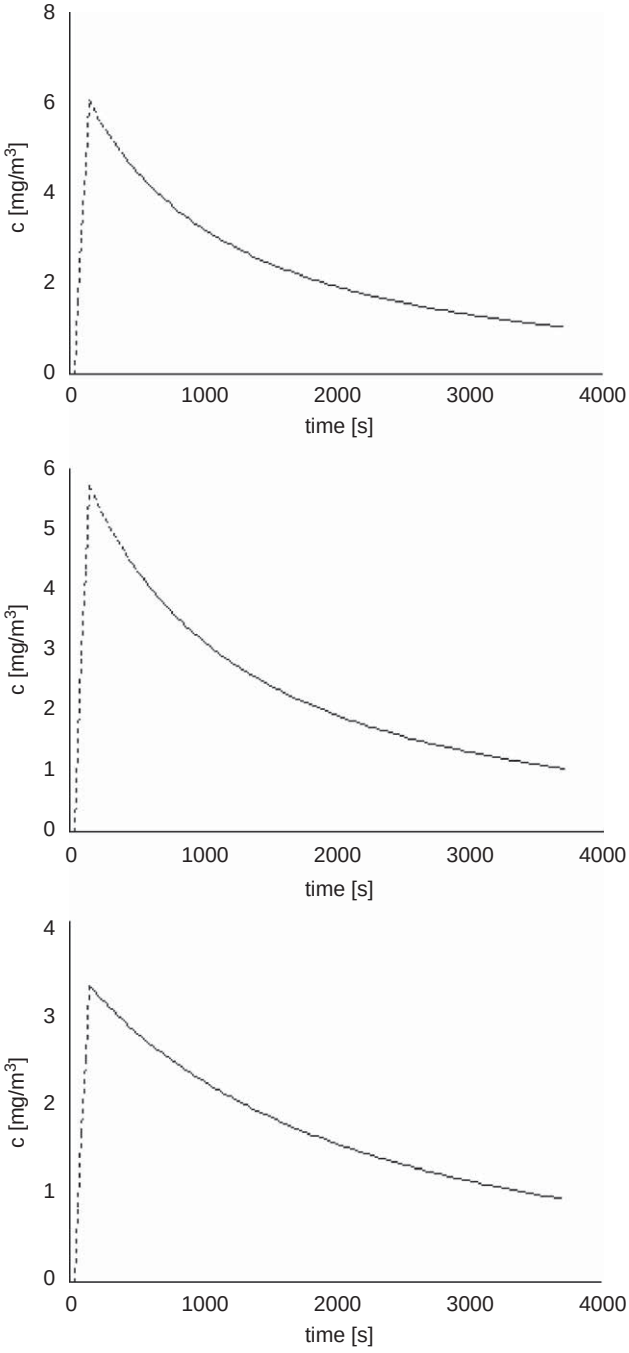

Fig. 7. Concentration curves of the respirable, thoracic, and inhalable fractions of the active substances released during worst-case use of the "Blattanex fly spray" (new), as calculated in the model based on the measured spray droplet distribution and the release rate.

With regard to inhalation exposure, there are only a few reports in the literature about indoor air concentrations after using aerosol sprays. For instance, spraying of two different aerosol sprays for 10–15 seconds in a 50-m^3 room led to average indoor air concentrations (during spraying and within the following 15 minutes) of 300 $\mu g/m^3$ for tetramethrin, 90 $\mu g/m^3$ for cyfluthrin,

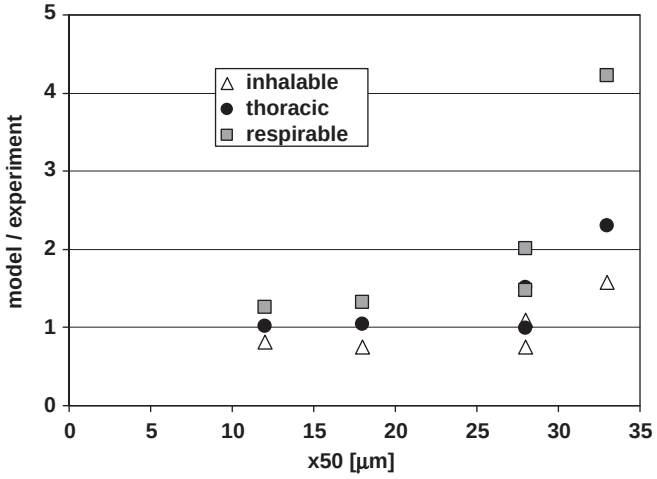

Fig. 8. *Ab initio* model prediction and measurement results for the concentration of respirable, thoracic, and inhalable aerosol fractions during the correct use of insect sprays. X50 is the median particle diameter of the spray droplet distribution.

125 µg/m^3 for pyrethrins, and 55 µg/m^3 for tetramethrin (Class and Kintrup, 1991a). The authors calculated an inhalation intake of, for instance, 70 µg for tetramethrin within the first hour of spraying. Some studies about the use of aerosols in indoor areas are also available from Matoba. The use of biocidal room sprays (10 seconds) in a room (23 m^3) led to average concentrations (20 minutes including spraying) in the air of 148 µg/m^3 and 20.5 µg/m^3 for d-tetramethrin and d-resmethrin, respectively (Matoba et al., 1998a). When using an aerosol spray for surface treatment (2.5 minutes spraying) average indoor concentrations of 752 µg/m^3 for d-phenothrin and 1040 µg/m^3 for d-tetramethrin were determined (Matoba et al., 1998b). Further data were reported, e.g., when using the insectides chlorpyrifos and permethrin in various pump sprays for surface flea control in a private area (Koehler and Moye, 1995). Average indoor air concentrations measured (during spray application and up to 2 hours thereafter) in the apartments were 21–52 µg/m^3 for chlorpyrifos and 32–54 µg/m^3 for permethrin.

During spraying various aerosols in an aircraft cabin for the purpose of disinsection (Berger-Preiß et al., 2006), concentrations of d-phenothrin (average concentrations during spraying and in the next 20 minutes) were reported to be 234–1313 µg/m^3 (no air exchange in the passenger cabin) and 116–348 µg/m^3 (air conditioning operating, air exchange (1/h): approximately 22). Inhalable doses of d-phenothrin relevant for e.g. the spray user were calculated to be between 29–235 µg (when using 100 g spray). The use of a spray with pyrethrum and PBO for aircraft disinsection when the air conditioning was operating (Berger-Preiß et al., 2004) led to inhalable doses of 3–12 µg pyrethrins and 25–69 µg PBO for the spray user who spent 20 minutes in the passenger cabin (calculations based on the use of 100 g spray).

In conclusion, our data on biocide concentrations and inhalation exposure after applying household insecticide sprays are well comparable with those which have been reported by other authors after using insecticidal sprays indoors. The exposure concentrations determined for spraying according to the manufacturers' instructions during the period of the actual spraying and shortly thereafter (2–3 minutes) are also on the same scale like e.g. the concentrations (average values over 20 minutes) obtained for sprays used for aircraft disinsection (air conditioning switched on). As expected, by simulating worst-case conditions the concentrations of biocidal substances in the indoor air are far higher.

Furthermore concentrations of active substances in the air are strongly dependent by the level of active substances in the different spray formulations.

In the private sector electro-vaporizers are frequently applied for controlling flying insects. After operating electro-vaporizers, other authors have reported indoor air concentrations of 2–5 µg/m^3 for allethrin (Class, 1991b) and approximately 4 µg/m^3 in conjunction with the staging of simulation experiments (Matoba et al., 1994). The indoor air concentrations reported by the authors during operation of the "Nexa Lotte" and the "Paral" plug-in mosquito killer were in the same range. In case of the "Paral" vaporizer the concentration ratio of pyrethrins and PBO in the air was similar as expected from the active substance composition of the pad. In contrast for the "Nexa Lotte" vaporizer the PBO level was lower than the d-allethrin level. It seems that PBO was not completely vaporized during the operating process. Summarizing the results obtained for electro-vaporizers, one can conclude that the active substance concentrations in the air are far lower than during biocide spraying. For this reason, measurements carried out to determine inhalation exposure by using

the Respicon aerosol monitoring system, could not be reliably evaluated.

Only a very few publications have presented results on the potential dermal exposure during application of aerosol sprays. Some studies were performed by our group. When using different biocidal aerosol sprays and methods for aircraft disinsection, values of 1700–4100 µg for d-phenothrin, 200–830 µg for pyrethrins, and 2140–8840 µg for PBO could be determined for the potential total dermal dose of the spraying person (using 100 g of the product) (Berger-Preiß et al., 2004, 2006).

Other available information on dermal exposure during spray use by consumers are based on tracer experiments and model estimates (Popendorf and Selim, 1995; Thompson and Roff, 1996; Roff and Baldwin, 1997). Any comparison with the results reported in our study is however difficult.

From our data it can be concluded that the concentrations of the active substances, which vary considerably in the various spray formulations, have a decisive impact on the level of dermal contamination. As expected, worst-case applications of sprays lead to far higher dermal exposure levels. Dermal exposure levels after normal use of the sprays are comparable with those after application of electro-vaporizers, if a prolonged stay in the room is assumed.

With regard to human biomonitoring we have focused our investigations on chrysanthemum dicarboxylic acid (CDCA), which is a metabolite of pyrethrins, tetramethrin, phenothrin, and allethrin. Also in the literature some data on this metabolite have been reported. Exposure of a pest controller to (S)-bioallethrin led to a CDCA concentration in the urine of 204 µg/l (Leng et al., 1999). After spraying a d-phenothrin-containing aerosol spray for aircraft disinsection, CDCA concentrations of 0.6 and 1.2 µg/l were found in the urine of persons who had entered the aircraft cabins immediately after spraying (Berger-Preiß et al., 2006).

In another study (E)-trans-CDCA concentrations in the range of <0.05 up to 54 µg/l (mean: 1.1 µg/l $\pm$ 4.35 µg/l, 95th percentile: 9.95 µg/l) were reported in 30 individuals after they had used sprays containing pyrethrum (Leng et al., 2006). E-cis-CDCA could not be detected in any case. At the same time, the metabolite concentrations in the urine of 45 test persons without any known biocide exposure were determined, demonstrating background concentrations with (E)-trans-CDCA values of <0.05 µg/l up to a maximum 0.82 µg/l. Furthermore, metabolite concentrations were determined in the urine of test persons after operating electro-vaporizers containing d-allethrin and pyrethrum (Elflein et al., 2003). (E)-trans-CDCA concentrations ranged from 1.0 µg/l to 6.2 µg/l, depending on the time period spent in the room (1–3 hours). Values for metabolites of pyrethroid insecticides in urine are also reported by Heudorf (Heudorf et al., 2006).

Comparison of the results obtained in our study with data in the literature shows that the (E)-trans-CDCA concentrations found in urine after correct use of four different consumer sprays were on the same scale as the values reported in the literature after spraying or using electro-vaporizers.

Conclusions

A characterization of the exposure scenarios during self-use of biocidal consumer products like aerosol sprays and electro-vaporizers in indoor areas was undertaken. Products were applied according to the manufacturers' instructions and in a worst-case scenario simulating foreseeable or unforeseeable misuse. Different active substances were determined: various pyrethroids and pyrethrins as well as chlorpyrifos and the synergist PBO. Breathable air and dermal concentrations were measured, and inhalable and dermal doses for the sprayers were quantified. In addition, biomonitoring was performed by determining urine metabolites of the sprayers and bystanders. The data presented allow a better understanding and assessment of the potential exposure levels for occupants of a room in which biocides are sprayed or vaporized. Based on the calculated exposure levels a realistic risk assessment should be able to be performed with regard to normal and worst-case exposure conditions.

In addition, the time-dependent air concentrations of the active substances after spraying were simulated by a deterministic model (SprayExpo). The model calculations mainly led to an acceptable correlation with the experimental data.

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References

Barr, D.B., Leng, G., Berger-Preiß, E., Hoppe, H.W., Weerasekera, G., Gries, W., Gerling, S., Perez, J., Smith, K., Needham, L.L., Angerer, J., 2007. Cross validation of multiple methods for measuring pyrethroid and pyrethrum insecticide metabolites in human urine. Anal. Bioanal. Chem. 389, 811–818.

Berger-Preiß, E., Preiß, A., Sielaff, K., Raabe, M., Ilgen, B., Levsen, K., 1997. The behaviour of pyrethroids indoors: a model study. Indoor Air 7, 248–261.

Berger-Preiß, E., Koch, W., Behnke, W., Gerling, S., Kock, H., Elflein, L., Appel, K.E., 2004. In-flight spraying in aircrafts: determination of the exposure scenario. Int. J. Hyg. Environ. Health 207, 419–430.

Berger-Preiß, E., Koch, W., Gerling, S., Kock, H., Klasen, J., Hoffmann, G., Appel, K.E., 2006. Aircraft disinsection: exposure assessment and evaluation of a new pre-embarkation method. Int. J. Hyg. Environ. Health 209, 41–56.

CEN, 1992. Workplace Atmospheres, Size Fraction Definitions for Measurement of Airborne Particles in the Workplace. Comité Européen de Normalisation (CEN).

CEN, 1993. EN 481: Specifications for Conventions for Measurement of Suspended Matter in Work Places. Beuth Verlag, Berlin.

Class, T.J., Kintrup, J., 1991a. Pyrethroids as household insecticides: analysis, indoor exposure and persistence. Fresenius J. Anal. Chem. 340, 446–453.

Class, T.J., 1991b. Determination of pyrethroids and their degradation products in indoor air and on surfaces by HRGC-ECD and HRGC-MS(NCI). J. High Resolution Chromatogr. 14, 446–450.

DIN CEN, 2006. Exposition am Arbeitsplatz-Messung der Hautbelastung-Grundsätze und Verfahren; Deutsche Fassung CEN/TS 15279, pp. 1–42.

ECB, 1998. Assessment of human exposures to biocides. Report to DG XI from the Biocides Steering Group. Project 97/505/3040/DEB/E2. European Chemicals Bureau, Ispra.

Elflein, L., Berger-Preiß, E., Preiß, A., Elend, M., Levsen, K., Wünsch, G., 2003. Human biomonitoring of pyrethrum and pyrethroid insecticides used indoors: determination of the metabolites E-cis/trans-chrysanthemumdicarboxylic acid in human urine by gas chromatography-mass spectrometry with negative chemical ionization. J. Chromatogr. B 795, 195–207.

Heudorf, U., Butte, W., Schulz, C., Angerer, J., 2006. Reference values for metabolites of pyrethroid and organophosphorous insecticides in urine for human biomonitoring in environmental medicine. Int. J. Hyg. Environ. Health 209, 293–299.

Koch, W., Dunkhorst, W., Lödding, H., 1999. Design and performance of a new personal aerosol monitor. Aerosol Sci. Technol. 31, 231–246. http://www.baua.de/nn_8514/sid_10332B0486A46C197D6-FA71879F0A6BF/de/Publikationen/Fachbeitraege/Gd35.html__nnn = true.

Koehler, P.G., Moye, H.A., 1995. Airborne insecticide residues after broadcast application for cat flea (Siphonaptera: Pulicidae) control. J. Econ. Entomol. 66, 1684–1689.

Leng, G., Kühn, K.-H., Wieseler, B., Idel, H., 1999. Metabolism of (S)-bioallethrin and related compounds in humans. Toxicol. Lett. 107, 109–121.

Leng, G., Gries, W., Selim, S., 2006. Biomarker of pyrethrum exposure. Toxicol. Lett. 162, 195–201.

Matoba, Y., Hirota, T., Ohnishi, J., Murai, N., Matsuo, M., 1994. An indoor simulation of the behavior of insecticides supplied by an electric vaporizer. Chemosphere 28, 435–451.

Matoba, Y., Takimoto, Y., Kato, T., 1998a. Indoor behavior and risk assessment following space spraying of d-phenothrin and d-tetramethrin. Am. Ind. Hyg. Assoc. J. 59, 181–190.

Matoba, Y., Takimoto, Y., Kato, T., 1998b. Indoor behavior and risk assessment following residual spraying of d-phenothrin and d-tetramethrin. Am. Ind. Hyg. Assoc. J. 59, 191–199.

OECD, 1997. Guidance document for the conduct of occupational exposure to pesticides during agricultural application. OECD Environmental and Safety Publications, Series on testing and assessment no. 9, OECD/GD (97) 148, Paris, France.

Popendorf, W., Selim, M., 1995. Exposures while applying commercial disinfectants. Am. Ind. Hyg. Assoc. J. 56, 1111–1120.

Roff, M., Baldwin, P., 1997. Dermal exposures of amateur users to pesticide products: trigger sprays, dusting powders and dilution of liquids. Sheffield, UK, Health and Safety Laboratory, Report, Report no. IR/L/A/97/11.

Thompson, J., Roff, M., 1996. Dermal exposure of occasional users of pesticide products: flea-spray in aerosol cans. Sheffield, UK, Health and Safety Laboratory, Report, Report no. IR/A/96/10.