



Determinations of PCB within a project to develop cleanup methods for PCB-containing elastic sealant used in outdoor joints between concrete blocks in buildings†

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Determinations of PCB were carried out as part of a project aimed at developing cleanup methods for PCB-containing elastic sealant used in outdoor joints between concrete blocks. The goals of the project were to develop methods, which minimise the spread of PCB to the outdoor environment and to indoor air, and which keep the PCB levels as low as reasonably possible in the workplace environment whilst removing the elastic sealant. The following PCB determinations were carried out: (1) concentration in the elastic sealant; (2) concentration in the concrete close to the sealant; (3) concentration in soil; (4) concentration in the indoor air; and (5) concentration in the air in the workplace environment. The cleanup process consisted of a number of different steps: (1) cutting the elastic sealant with an oscillating knife; (2) grinding the concrete with a mechanical machine; (3) sawing the concrete with a mechanical saw and (4) cutting the concrete with a mechanical chisel. In all these different steps a high capacity vacuum cleaner connected to the machines was used. The elastic sealant contained 4.7 to 8.1% total PCB of a technical product with a composition most similar to Clophene A40. The concrete close to the sealant (first 2 mm) contained 0.12 and 1.7% total PCB at two different places. The pattern of the PCB in the concrete resembled that of the sealant. PCB concentrations in the soil from the ground close to the building were 0.1 and 0.3 ppm at two different places before the remedial action. The source of the PCB in the soil is most likely the sealant as the PCB pattern is similar for the two materials. The PCB levels in the workplace air at the beginning of the project, when the techniques were not fully developed, were generally above the occupational exposure limit of $10 \mu\text{g m}^{-3}$ (up to $120 \mu\text{g m}^{-3}$). Later when the techniques were optimised to better take care of dust and gases produced during the cutting and grinding *etc.*, the levels were below or close to $10 \mu\text{g m}^{-3}$. The pattern of the PCB in the workplace air was different from that of the sealant and contained higher levels of lighter components. The PCB concentrations in the indoor air were measured before and during the remedial process. The levels were around 600 ng m^{-3} and there was no significant increase during the removal of the sealant. The PCB level after the remedial action will be measured later. The pattern of the PCB in the indoor air was different from that of the sealant as well as from that of the workplace air. Higher levels of the lighter PCB were present indoors compared to the composition in both workplace air and in sealant. Extracts of PCB were analysed by GC-MS with a SIM method (selected ion monitoring). Standard procedures were used for extraction of solid materials. For the air samples an OVS tube was used with XAD-2 as adsorbent. The filter and adsorbent were extracted with toluene. This work shows that it is important to perform remedial action of PCB-containing elastic sealant as: (1) there is a spread of PCB to the indoor air giving high enough concentrations to make this the main PCB load on humans living in the apartments studied in this project; (2) large amounts are spread to the soil from these sealants; and (3) many of the PCB-containing elastic sealants used need to be changed from a functional perspective.

Introduction

PCB are persistent organic pollutants; their effects on the environment have been described in numerous papers. In this paper we refer to a single source with the aim of neither choosing the most extensive papers nor of selecting the first or most recent ones.¹ PCB is a collective name for 209 different chemical compounds, congeners, with biphenyl and chlorine as the common parts in the molecules. Several different PCB technical products have been produced; these include Clophene A40, A50, A60 and Arochlor 1242, 1248, 1254 and 1260. From 1956 to 1972 PCB were extensively used in Sweden as plasticizers in elastic sealants used in joints between concrete blocks in buildings. In particular, products based on thiokol,² a polysulfide, often contain PCB. In Sweden, the estimated

amount of PCB added in such sealants ranges from 100 to 500 tonne.³ It has been shown that PCB from sealants leak to the environment, into the surrounding ground⁴ as well as to indoor air.⁵ It is most likely that PCB from sealants have already spread to refuse dumps for used building materials, due to a previous lack of knowledge about the problem. Many of the sealants are getting old and need to be changed from a functional perspective and it is far more expensive to take care of PCB when it is diluted with other garbage on a refuse dump than to take care of it at source. Thus, there is a need for efficient methods for exchanging these sealants with new PCB free materials, which minimise the spread of PCB to the environment, to indoor air and to the workplace environment. In this paper results are presented mainly from chemical measurements from a project to develop cleanup methods for PCB-containing elastic sealants. Technical descriptions of the cleanup process, where relevant, are given as background information.⁶

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Methods and background information

Taking away the sealant

The cleanup process consisted of different steps: (1) cutting the elastic sealant with an oscillating knife; (2) grinding the concrete with a mechanical machine; (3) sawing the concrete with a mechanical saw; and (4) cutting the concrete with a mechanical chisel. In all these different steps a high capacity vacuum cleaner connected to the machines was used. The vacuum cleaner had a capacity of $425 \text{ m}^3 \text{ h}^{-1}$ (maximum flow). The dust was separated in three steps with cyclone, fine filter and micro filter.

Description of the building

The building was eight storeys high and was located in Bergsjön, Göteborg, Sweden. Wall structures were constructed of concrete blocks and the joints were filled with a PCB-containing elastic sealant which was in bad condition and had to be replaced. The length of the sealants was about 4000 m which corresponds to about 1500 kg sealant; with an average content of 6% PCB this corresponds to about 90 kg of PCB.

Extraction and sampling of PCB

To determine the PCB concentration in the sealant an extraction with heptane was performed. Sealant (100 mg) was immersed in heptane (3 ml) and extracted in an ultrasonic bath (1 h). The extraction procedure was repeated twice. The extracts were collected and washed with concentrated sulfuric acid (1 ml) and then diluted with heptane (100 ml final volume). 1,2,3,4-Tetrachloronaphthalene (100 μl with concentration $10 \text{ ng } \mu\text{l}^{-1}$ to 10 ml extract) was added as an internal standard. The internal standard was added after the extraction procedure. The extraction efficiency was not determined, but the repeated procedure most likely gives efficiencies greater than 90% (by comparison with similar compounds in similar matrices).

To determine the PCB concentration in soil an extraction with heptane was performed. Larger stones were taken away and soil (1–3 g) was mixed with heptane (3 ml) and extracted in an ultrasonic bath (1 h). The extraction procedure was repeated three times. The extracts were collected and washed (50 ml 0.2 M NaCl in 0.1 M H_3PO_4). The water phase was extracted with heptane. The collected heptane phase was evaporated (*ca.* 3 ml) and washed with concentrated sulfuric acid (1 ml) and then diluted (5 ml). 1,2,3,4-Tetrachloronaphthalene (50 μl with concentration $10 \text{ ng } \mu\text{l}^{-1}$ to 5 ml extract) was added as an internal standard. The internal standard was added after the extraction procedure. The extraction efficiency was not determined, but the repeated procedure most likely gives efficiencies greater than 90%. To determine the dry weight (dw) of the soil sample, soil was dried (24 h, 105°C) and weighed before and after drying.

To determine the PCB concentration in concrete, ground concrete was collected and the powder was extracted with heptane. Ground concrete (0.3 g) was mixed with heptane (3 ml), extracted in an ultrasonic bath (1 h) and the sediment was then allowed to settle. The extraction procedure was repeated twice. The extracts were collected and washed with concentrated sulfuric acid (1 ml) and then diluted with heptane (100 ml final volume).

1,2,3,4-Tetrachloronaphthalene (100 μl with concentration $10 \text{ ng } \mu\text{l}^{-1}$ to 10 ml extract) was added as an internal standard. The internal standard was added after the extraction procedure. The extraction efficiency was not determined, but the repeated procedure most likely gives efficiencies greater than 90%.

To determine the PCB concentration in air an OVS tube with XAD-2 as an adsorbent was used. An air sampling pump, SKC aircheck sampler model 224-PCXR7, was used and depending on whether the air was from indoor or from the workplace environment the air volumes sampled were around 60 l and around 1500 l, respectively at a flow rate of around

1 l min^{-1} . The flow rate was checked using a calibrated flow meter. The filter and first section of the adsorbent were extracted together and the backup section of the adsorbent was extracted separately. The materials were mixed with toluene (5 ml) with 1,2,3,4-tetrachloronaphthalene (50 μl with concentration $10 \text{ ng } \mu\text{l}^{-1}$) added and extracted in an ultrasonic bath for 0.5 h. The method is partly validated by OSHA. Extraction efficiencies were greater than 93%. Breakthrough was not detected, for 125 l air, and the average recoveries were 95%. The breakthrough in all our measurements was less than 2%. Blank tubes were also extracted and no PCB could be detected.

Analysis of PCB extracts

All extracts were analysed by a gas chromatography mass spectrometry selected ion monitoring (GC-MS-SIM) method. The instrument used was an HP 5890 GC with an MSD 5970. The column used for the GC separation was a BPX 25 $\text{m} \times 0.25 \text{ mm}$. The parameters used were as follows: 70 ml min^{-1} split flow, 300°C injector temperature splitless injection, 100°C for 1 min then 5°C min^{-1} to 300°C . MSD parameters: SIM detection 3- and 4-Cl congeners starting at 6 min, Cl m/z 256.0, 258.0, 254.0, 220.0 and 292.0; 4-Cl congener starting at 23.4 min, m/z 292.0, 290.0 and 288.0; internal standard starting at 24.3 min, m/z 263.9, 265.9 and 194.0; 5-Cl starting at 25.5 min, m/z 326.0, 324.0 and 322.0; 6-Cl congener starting at 30.4 min, m/z 360.0, 362.0 and 356.0; 7-Cl congener starting at 33.0 min, m/z 393.9, 395.9 and 390.0. To secure the identification, retention times and relative peak heights of the SIM masses were used. The PCB congeners 28, 52, 101, 118, 138, 153 and 180 were quantified by this method and the sum of these is denoted by $\Sigma 7\text{PCB}$. To determine the total PCB content the results were compared with the PCB contents in the technical products and then $\Sigma 7\text{PCB}$ was multiplied by the appropriate correction factor.⁷ For air samples which do not have the same composition as any technical product a conversion factor of 6 was used to obtain the total PCB concentration from $\Sigma 4\text{PCB}$.⁵ $\Sigma 4\text{PCB}$ is the sum of the congeners 28, 52, 101 and 138.

Quantification and detection limits and accuracy and precision in the measurements

The quantification limit of a single congener was $4 \text{ pg } \mu\text{l}^{-1}$ and the detection limit was $1 \text{ pg } \mu\text{l}^{-1}$. The total accuracy for the different measurements was estimated to be better than $\pm 21\%$. The accuracy was estimated by adding an estimated accuracy for the sampling-extraction step of $\pm 15\%$ and for the analytical step of $\pm 15\%$. To obtain a value of the combined repeatability in the analysis and extraction step, 18 sealants were extracted and analysed twice. The results gave at 95% confidence level a spread of $\pm 12\%$.

Results and discussion

Elastic sealant

The elastic sealant contained from 4.7 to 8.1% PCB of a technical product similar to Clophene A40 (Table 1). Most likely, the original PCB content in the sealant was higher as PCB certainly was added from a functional perspective to plasticize the sealant. The sealant is 30 years old and PCB have leaked to the surrounding ground and to indoor air as is shown below.

Soil

The soil from the ground was contaminated by PCB. The results are summarised in Table 2. A 2 cm portion was taken from the top layer of the soil from a $0.5 \times 0.5 \text{ m}$ surface. The

Table 1 Partial content (normalised to highest) of the 7 selected PCB congeners in sealant and the technical product Clophene A40 and sum concentrations of PCB. For Clophene A40 the conversion factor from $\Sigma 7\text{PCB}$ to total PCB concentration is 5.3. The results reported in the same row are results obtained for the same sample but with separate extractions and analyses, thus giving an indication of the repeatability

Partial content of the respective PCB in sample and product content									
PCB Congener	28	52	101	118	138	153	180	Content $\Sigma 7\text{PCB}$	Total content
Clophene A40	0.19	0.39	0.14	0.13	0.05	0.06	0.01		
Sealant	0.17	0.30	0.29	0.17	0.05	0.03	0.01	9.4 and 8.8 g kg	5.1 and 4.7%
Sealant	0.19	0.38	0.24	0.15	0.04	0.02	0.01	14 and 15 g kg	7.4 and 8.1%

Table 2 Results obtained for soil samples taken from the ground before and after the refinishing process. The results reported in the same row are results obtained for the same sample but with separate extractions and analyses, thus giving an indication of the repeatability

	$\Sigma 7\text{PCB}$ (mg kg ⁻¹ dw), before	$\Sigma 7\text{PCB}$ (mg kg ⁻¹ dw), after
Soil 1 1–1.5 m from building	0.013 and 0.028 ^a	0.080 and 0.088
Soil 2 1–1.5 m from building	0.048 and 0.062	
Soil 3 10–10.5 m from building	Below detection limit	0.026 and 0.025 ^a

^aThese values are below the quantification limit, at this dw, $\Sigma 7\text{PCB}$ 0.04 mg kg⁻¹ dw. The detection limit is, at this dw, $\Sigma 7\text{PCB}$ 0.01 mg kg⁻¹ dw.

results obtained indicate that the soil was contaminated during the work involved in removing the sealant. See below for an estimate of the amount of PCB that was spread during the remedial process.

Concrete

The concrete close to the sealant was contaminated by PCB but the concentrations drop quickly with the distance from the joint. The results are summarised in Fig. 1. The first layer from which the sealant was cut has a high PCB concentration which shows the need for grinding the concrete surface to get rid of the PCB in this layer. It is reasonable from a practical point of view to grind a few millimetres of the concrete but not much more.

Indoor air

The results are summarised in Table 3. The quantification limit with the used air sampling volumes was $\approx 50 \text{ ng m}^{-3}$ with an operating range up to $\approx 2000 \text{ ng m}^{-3}$. Rather high levels of PCB were found in the indoor air in the building. This can most likely be coupled to the PCB present in the sealant. Previous investigations of buildings in Germany showed that PCB from sealants can leak to indoor air and particularly when lower chlorinated technical products are used as sealants higher concentrations are found indoors.⁸ There is also a correlation between PCB concentration in indoor air and outdoor temperature.⁵ At higher temperatures the concentration indoors gets higher. We have not attempted to study this correlation further in this project due to limited resources.

Cut surface	Cut surface	Cut surface	Cut surface	
Ground layer	Ground layer	0,11 %	1,7 %	Ca 1-2 mm
		0,11 %	1,8 %	
330 ppm	410 ppm			Ca 2 mm
270 ppm	450 ppm			
15 ppm	86 ppm			Ca 2 mm
12 ppm	83 ppm			

Fig. 1 Total PCB concentration in different layers of concrete close to the surface where the sealant was cut away. The results reported in the same column at the same depth are results obtained for the same sample, but with separate extractions and analyses, thereby giving an indication of repeatability. The different columns represent results obtained for samples taken from different locations.

We conclude that no significant increase of the PCB levels indoors occurs during the remedial process. The PCB sample of indoor air taken after the remedial action was taken shortly after the process was finished and we believe that the concentration will drop considerably within the next half year.

Workplace air

The results are summarised in Table 4. The air was sampled in the breathing zone of the worker. The quantification limit of PCB in used air was $\approx 2 \mu\text{g m}^{-3}$ with an operating range of up to $\approx 80 \mu\text{g m}^{-3}$. An important conclusion drawn from the measurements is that workers should use some kind of breathing protection due to the levels of PCB present in workplace air. Furthermore, small mistakes in the remedial procedure can result in high PCB concentrations; therefore it is important to be careful during all the steps involved in the procedure. Measurements of the PCB concentration in the air located after the vacuum cleaner at the vent were also carried out and the total PCB concentrations were found to be 15 and $17 \mu\text{g m}^{-3}$ in the new and used filter, respectively.

Comparison of the PCB pattern in different samples

The relative contents of the 7 indicator congeners are different for different types of samples taken in the project reported in this paper (Table 5). Some important conclusions can be drawn. The concentration of the PCB with low chlorine content is important for the level of the concentrations in air as the PCB found in air is dominated by lighter more volatile PCB. The PCB found in soil and concrete most likely originate from the sealant as there is a similarity between the PCB pattern found for these three materials. The different air measurements that is, workplace environment, air located after the vacuum cleaner and indoor air, show different patterns. Looking at the 7 indicator congeners, indoor air is dominated by PCB 28 and 52, air after the vacuum cleaner is dominated by 28, 52 and 101 and workplace environment is dominated by PCB 28, 52, 101 and 118. It is also important that there is no significant difference between the PCB pattern of the indoor air before and during the remedial action which indicates that the remedial action does not affect the PCB level indoors.

Estimation of the PCB spread during the remedial action

The estimations are rough but give a feeling of the magnitude of the PCB spread and the amount of PCB left in the building after remedial action had been taken.

Table 3 PCB concentrations in indoor air before, during and after remedial action

	Total PCB concentration in indoor air before remedial action	Total PCB concentration in indoor air during remedial action	Total PCB concentration in indoor air after remedial action	Outdoor temperature before, during and after remedial action
Apartment a, uninhabited	530 ng m ⁻³	910 ng m ⁻³		11 °C, 12.5 °C, —
Apartment b, inhabited	610 ng m ⁻³	570 and 660 ng m ⁻³	810 ng m ⁻³	15.5 °C, 7–8 °C, 0–5 °C
Apartment in building without PCB-containing sealant	< 50 ng m ⁻³			7–10 °C, —, —
Long term target level in Germany ⁹	30 ng m ⁻³			
Guideline level in Germany ⁹	300 ng m ⁻³			
Level of concern in Germany ⁹	3000 ng m ⁻³			

Table 4 PCB concentrations in workplace air. The results in the same row were not obtained during the same period, thus giving an indication of the variation in the concentrations during the work

Working operation	Vacuum cleaner	Total PCB concentration in breathing zone	Comments
Cutting with an oscillating knife	Not connected	14 and 49 µg m ⁻³	Not optimised method, beginning of the project
Grinding with a mechanical machine	Connected		
Cutting with a mechanical chisel	Not connected		
Cutting with an oscillating knife	Connected	5.6 and 9.4 µg m ⁻³	Optimised method
Grinding with a mechanical machine	Connected	11.0 and 5.5 µg m ⁻³	Optimised method
Threshold limit value for workplace environment in Sweden		10 µg m ⁻³	
Cutting with an oscillating knife	Connected	42 and 30 µg m ⁻³	Vacuum cleaner tubing got loose
Sawing with a mechanical saw	Connected	34 µg m ⁻³	Vacuum cleaner tubing got loose
Cutting with a mechanical chisel	Connected		
Grinding with a mechanical machine	Connected	120 µg m ^{-3 a}	Vacuum cleaner tubing got loose
Grinding with a mechanical machine	Connected	80 µg m ⁻³	Sampling during all the time of the two measurements above
Sawing with a mechanical saw	Connected		
Cutting with a mechanical chisel	connected		

^aConcentrations of individual PCB congeners in samples higher than those in the highest standard might give a higher uncertainty in the value compared to other values.

The amount of PCB spread to the air during the remedial action should mainly be that located in the air after the vacuum cleaner. The sealants in the entire building took 120 d to cleanup and change. In a normal day, two vacuum cleaners were run 4 h each. A flow of 300 m³ h⁻¹ per machine at a concentration of 16 µg m⁻³ gave a total amount spread to the air of $120 \times 2 \times 4 \times 300 \times 16 \times 10^{-6} = 5$ g PCB during the entire cleanup process. It is reasonable to assume that the PCB spread to the air during the remedial action mainly goes this way as the flow is so high through the vacuum cleaner. This can be compared to the amount that is off-gassed to the indoor environment during one year: Volume of the house \times air exchange rate (not measured, 0.5 per hour is a usual value for mechanical ventilated apartments) \times hours in 1 year \times PCB concentration indoors (representative value for the measurements 600 ng m⁻³) = $77 \times 13 \times 22 \times 0.5 \times 24 \times 365 \times 600 \times 10^{-9} = 60$ g PCB spread to the indoor air during one year.

We estimate the increase in the PCB concentration in the soil as being an average of 0.05 ppm in the first 4 cm, no increase deeper into the soil, and in the first 20 m from the house. The soil samples were taken at 0–2 cm depth, and 1 and 10 m from the house. The house was 77 m long \times 13 m wide. The amount of soil contaminated by 0.05 ppm is equivalent to $[(77 + 20 + 20) \times (13 + 20 + 20) - (77 \times 13)] \times 0.04 = 208$ m³ \times 1000 kg m⁻³ \times 0.05 \times 10⁻⁶ \times 5.3 (from Σ 7PCB to total concentration) = 55 g PCB.

We estimate the amount left in the concrete to be as follows: first 2 mm ground away; then, 2 mm \times 2 (number of edges) \times 3 cm (width of ground surface) \times 4000 m \times 2300 kg m⁻³ (density of concrete) = 1104 kg concrete, 2 to 4 mm contains 400 ppm, 4 to 6 mm contains 90 ppm and deeper no PCB, giving $1104 \times (400 + 90) \times 10^{-6} = 0.54$ kg PCB. The 2 mm grinding of the concrete is a minimum value, in most cases more than 2 mm are ground. Therefore 0.54 kg is probably too large an estimate.

Table 5 The relative contents of the 7 indicator PCB for different samples

	PCB28/31 ^a	PCB52	PCB101	PCB118	PCB138	PCB153	PCB180
Concrete	0.67	1	0.99	0.60	0.12	0.063	0.010
Concrete	0.49	0.85	1	0.60	0.19	0.13	0
Concrete	0.80	1	0.79	0.49	0.11	0.055	0.007
Concrete	1	0.83	0.98	0.63	0.14	0.069	0.008
Concrete	0.44	0.84	1	0.56	0.20	0.11	0.036
Soil	0.47	0.76	1	0.56	0.88	0.81	0.53
Soil	0.52	1	0.90	0.56	0	0	0
Soil	0.64	1	0.68	0.34	0.17	0	0
Soil	0.66	1	0.95	0.51	0.18	0.14	0
Vacuum cleaner	1	0.63	0.19	0	0	0	0
Vacuum cleaner	1	0.49	0.15	0.040	0	0	0
Sealant	0.53	1	0.96	0.56	0.14	0.091	0.027
Indoor air before work	1	0.44	0	0	0	0	0
Indoor air before work	1	0.50	0.042	0	0	0	0
Indoor air during work	1	0.52	0.048	0.012	0	0	0
Indoor air during work	1	0.42	0.033	0	0	0	0
Workplace environment	1	0.94	0.49	0.22	0	0	0
Workplace environment	1	0.88	0.37	0.19	0.037	0.016	0
Workplace environment	1	0.90	0.36	0.14	0.051	0	0
Workplace environment	1	0.90	0.35	0.13	0	0	0
Workplace environment	1	0.82	0.35	0.16	0	0	0
Workplace environment	1	0.88	0.40	0.17	0.054	0.022	0
Workplace environment	1	0.89	0.40	0.17	0.045	0.022	0

^aIn this table the sum of PCB28 and 31 are used for the comparison, since there is a poor chromatographic separation between these two congeners.

To summarise 540 g + 55 g + 5 g = 0.6 kg PCB is either spread or left in the building compared to the 90 kg PCB taken away. Thus more than 99% of the PCB are removed, which must be considered a good result.

Conclusions

It is important to remove PCB-containing elastic sealant in order to reduce the spread of PCB to indoor air and to the outdoor environment. Some kind of breathing protection should be used by workers during the work involved in removing the sealant. There is no significant increase in PCB levels indoors during the remedial process. A few millimetres of the concrete should be taken away as the concentration in the concrete closest to the sealant is high.

It is possible to remove PCB-containing elastic sealant with minor spread of PCB to the environment. A rough estimate suggests that more than 99% of the PCB is removed.

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References

- 1 C. Bernes, in *Monitor 16, Persistent Organic Pollutants, A Swedish View of an International Problem*, Swedish Environment Protection Agency, Stockholm.
- 2 Thiokol is a polysulfide which often has PCB added as a plasticizer.
- 3 T. Hammar, *PCB i fogmassor, Länsstyrelsen i Kalmar informerar* (The County Government Board in Kalmar, Sweden informs), 1992, 10.
- 4 B. Jansson, J. Sandberg, N. Johansson and A. Åstebro, *PCB i fogmassor—Stort eller litet problem?* Swedish Environmental Protection Agency, Stockholm.
- 5 C. Bente, B. Heinzow, H. Hessen, S. Mohr and W. Rotard, *Chemosphere*, 1992, **25**, 1481.
- 6 E. Sikander, M. Sundahl, M. Tornevall, B. Ek-Olausson, A. Hjorthage, L. Rosell and P.-O. Johnnesson, *Utveckling och utvärdering av metoder för PCB-haltiga fogmassor*, SP Swedish National Testing and Research Institute, Borås, Sweden, 1999, 07.
- 7 D. E. Schultz, G. Petrick and J. C. Dulnkner, *Environ. Sci. Technol.*, 1989, **23**, 852.
- 8 E. Balfanz, J. Fuchs and H. Kieper, presented at Dioxin '93, 13th International Symposium on Chlorinated Dioxins and Related Compounds, Organohalogen Compounds 1993.
- 9 Internet address: <http://www.mtm.de/pcbnrw.htm>

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