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Polychlorinated Biphenyls in Indoor Air

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Polychlorinated biphenyls (PCBs) have been recognized as environmental contaminants since the mid-1960s. Until recently, however, little work has been done on identifying levels of PCBs in the indoor air. This paper describes a method for the analysis of PCBs utilizing low-volume indoor air sampling. The method uses polyurethane foam as a collector and has a limit of detection of ~0.01 μg/m³. This study shows that indoor air, whether in commercial, industrial, or residential buildings, contains levels of PCBs at least 1 order of magnitude higher than outdoor levels. Defective fluorescent light ballasts are also shown to emit PCBs and to be an important source of indoor atmospheric contamination.

Polychlorinated biphenyls (PCBs), which were commercially available for almost 50 yr in the United States, were in great demand because of their nonflammability, electrical-insulating properties and their chemical and thermal stabilities. From 1957 to 1974 over 300 million kg were manufactured by Monsanto Corp. and used in this country (*1*).

Starting in 1966, PCBs were discovered to be environmental contaminants present in such diverse media as Antarctic snow (*2*), human mothers milk (*3*), and Icelandic plants and animals (*4*). In 1971, Monsanto voluntarily cut back production and ceased making all PCBs in October 1977, but the problem of universal contamination is still present. For example, atmospheric concentrations in the ng/m³ range have been reported recently from such widely distributed places as Rhode Island (*5*), Bermuda (*6*), and Southern California (*7*).

Even with the present interest in documenting PCB levels in the atmosphere, most of the work has been done on ambient air, and very little is known about PCB concentrations found indoors. However, many of the products containing PCBs were for indoor use: textile dyes, printing inks, paints, carbonless copy paper, fireproofing agents, small electrical capacitors, and fluorescent light ballasts. Previous researchers have reported on PCB emissions for fluorescent lighting fixtures in offices (*8*), but there have been no surveys published of PCB levels in private homes.

Until recently, the method most often used for the collection of PCBs from air was to draw the air through ethylene glycol-filled impingers (*9*). The hygroscopic nature of the ethylene glycol made sampling difficult and limited sampling time under all but the most arid conditions (*10*). These difficulties were eliminated with the introduction of polyurethane foam as a collection medium (*5*). Foam plugs are light weight and much easier to transport than the liquid ethylene glycol in impingers. Background levels of PCB using precleaned foam plugs give much cleaner gas–liquid chromatography (GLC) chromatograms than that associated with ethylene glycol reagent blanks. The PCB detection limits when using ethylene glycol in midget impingers are in the range of 0.5 μg/m³ for a 5-h sample (*5*). When foam plugs are used as described in this method, the detection limit for a 4-h sample is ~0.01 μg/m³. This higher sensitivity permits a more accurate assessment of air levels, which is especially important in light of the proposed National Institute for Occupational Safety and Health (NIOSH) criterion for a safe workplace atmosphere of 1.0 μg/m³ over an 8- to 10-h workday and a 40-h workweek (*11*).

In this study, we took air samples in laboratories, offices, and homes. All of the laboratories and offices had fluorescent light and forced air heating and air conditioning. Of the nine houses, four contained fluorescent lighting in their kitchens, all but two of the homes had forced air heating, and all but one had air conditioning. There was also an opportunity to monitor contamination resulting from the burnout of a PCB-containing fluorescent light ballast.

Experimental Section

Apparatus. Two types of air samplers were used in this study. The first type, which utilized a Rendix Hurricane pump, collected large amounts of air (100–300 L/min) but was unsuited for indoor sampling. This sampler was used for the outdoor comparisons and to collect samples in the laboratories and offices when they were unoccupied. The smaller, low-volume pumps analyzed were the Mine Safety Appliance (*MSA*) portable pump Model *S* and the Du Pont constant-flow sampling pump Model P4000A. These personal samplers were much better suited to indoor monitoring because they were quiet and unobtrusive, although they sampled at only 2.5–4.0 L/min.

The sampling cartridges used with the low-volume samplers were made from glass tubes 2 cm in diameter and 7.5 cm long with 8-mm diameter × 3-cm long connectors. They were attached to the pumps with PVC tubing. The cartridge used with the Rendix pumps consisted of the 10-cm round filter holder that is standard equipment modified by upsizing a cylindrical metal chamber 5-cm i.d. × 25 cm long behind the filter holder. This was then attached to the pump by 7.6 m of flexible hose.

The sorbent used in both sampling cartridges was polyether-type polyurethane foam (density 0.022 g/cm³). The plugs (5.5-cm diameter × 5 cm long for the large samplers and 2-cm diameter × 4 cm long for the small ones) were cut from sheets of polyurethane upholstery material and shaped to fit into the cartridges under slight compression to ensure that all of the air sampled would be pulled through the foam.

All analyses were carried out with a Tracor 222 gas chromatograph equipped with ^{63}Ni electron capture detectors. The columns used included 3% OV-225 on Supelcoport 80/100 mesh, 3% OV-1 on Chromosorb WHP 80/100 mesh, and 4% SE-30/6% OV-210 on Gas-Chrom Q 100/120 mesh. All columns were 6-mm i.d. and 1.8 m long.

Reagents. Aroclor standards were obtained from the Pesticide Repository, U.S. Environmental Protection Agency, Health Effects Research Laboratory, Research Triangle Park, N.C. The standard solutions were made by dissolving the Aroclor in pesticide-grade benzene and diluting with hexane. Stock solutions were stored at −20 °C, and working standards were remade periodically from these.

The benzene and hexane used throughout were from Burdick and Jackson Laboratories. Analytical reagent-grade diethyl ether containing 2% ethanol was obtained from Mallinckrodt.

Basic alumina (80 mesh) was from Alfa Products, and the silicic acid used was Mallinckrodt AR, 100 mesh.

Procedure. Before use the foam plugs were extracted twice in Soxhlet extractors for at least 7 h each time with 5% diethyl ether in hexane. The solvent from the second extraction was concentrated, passed through a deactivated alumina column (see below), and analyzed by GLC to determine background

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Table I. Airborne PCB Levels in Workplaces

site	period of sampling	no. samples	av concn, [a] ng/m³	% RSD
	Industrial Research Facility			
laboratory A	6 months	11	200	27
laboratory B	2.5 months	6	240	36
office A	1 week	2	110	20
office B	2 days	2	80	24
outdoors [b]	1 week		18	
	Academic Facility			
laboratory	2 days	2	210	10
outdoors	2 days	2	4	11
	Shopping Complex			
office	2 days	2	44 [c]	35

[a] Concentrations are calculated as Aroclor 1242 and Aroclor 1254. [b] Unpublished data from A. Brown and M. Jackson, Analytical Chemistry Branch, Health Effects Research Laboratory, U.S. Environmental Protection Agency. [c] No Aroclor 1254 was present.

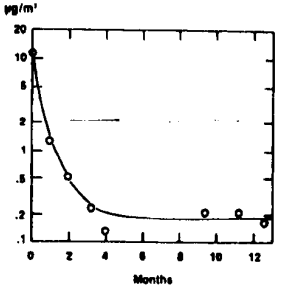

Figure 1. Levels of PCB in the air after a fluorescent light ballast burnout.

levels of of PCBs present. The plugs were then wrapped in hexane-rinsed aluminum foil for storage. When needed for sampling, the plugs were loaded into the cartridges by using forceps and rewrapped for transport to and from the sampling site.

The efficiency of the extraction and cleanup process was tested by carrying plugs spiked with 100 ng each of Archlor 1242 and Aroclor 1254 through the same procedure as that for the exposed plugs. The retention efficiency of the foams was tested by spiking a plug with a standard solution and then drawing air through both the fortified plug and then a second plug at 4 L/min for 4 h. The collection efficiency of the low-volume samplers was tested by placing a hexane solution containing 500 ng each of Aroclor 1242 and Aroclor 1254 into the bottom of midget impingers and drawing air through the impingers and then through foam plugs. Four samplers were run side by side to determine the actual variation of the method in a sampling situation.

The facilities sampled were placed into four categories: (1) an industrial research facility, (2) an academic laboratory building, (3) a shopping complex, and (4) private residences. The focus of the study was to determine "normal" levels of PCBs that people come in contact with during everyday activities (categories 3 and 4) and compare those to laboratory situations (categories 1 and 2). The ambient air outside two of the buildings and one home was also sampled for an indoor/outdoor comparison. The sampling was carried out at various times of the year, but the heating and air conditioning systems assured that all indoor samples were collected at temperatures of 20 ± 6 °C. The outdoor samples were collected in March (house) and September (industrial research facility and academic building) when the ambient temperatures approximated those found indoors.

The sampling periods were usually either 8 or 16 h so that a total sample equivalent to 1–4 m³ of air was collected. The air intake during sampling was positioned 1–2 m above the floor and oriented downward or horizontally.

A fluorescent light ballast burnout which occurred in an office during this study presented the opportunity to examine the persistence of PCB in the air. The ballast was replaced almost immediately after burnout and was placed in another room overnight while the first air sample was collected. The ballast was removed and disposed of the next morning, and sampling was continued in the affected room intermittently for over a period of ~1 yr.

After sampling, the plugs were Soxhlet extracted with hexane for at least 40 cycles. The extracts were concentrated to ~5 mL with a rotary evaporator and then to less than 1 mL under a gentle stream of nitrogen at ambient temperature.

Table II. Airborne PCB Levels in Homes

site	month sampled	no. samples	av concn, [a] ng/m³	% RSD	fluorescent lighting	forced air heat, air conditioning [b]
kitchen A	June	1	460			1, 2
kitchen B		1	180			1, 2
kitchen C	June, Nov	2	250	28	yes	1, 2
kitchen D	Apr	2	210	21	yes	2
kitchen E	July, Dec	3	240	32		
kitchen F	June, July, Oct, Nov	5	150	27		1, 2
kitchen G	July, Sept	2	580	36	yes	1, 2
kitchen H	Mar, Apr, Nov	3	260	24		1, 2
kitchen I	Mar, Apr	5	500	29	yes	1, 2
living room D	Apr	1	39			2
bedroom E	July, Dec	3	170	23		
basement E	July, Dec	3	120	28		
garage F	June, July, Oct	4	84	30		1, 2
library I	Mar, Apr	3	400	28		1, 2
outdoors I	Mar	1	4			

[a] Concentrations are calculated as Aroclor 1252 and Aroclor 1254. [b] Forced air heat = 1, forced air conditioning = 2.

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Column Chromatography. The alumina was weighed into a flask, distilled water equal to 6% by weight of the alumina was added, and the flask was stoppered and shaken well. The adsorbent was then allowed to stand for at least 15 h before use. A plug of preextracted glass wool was placed in the bottom of a 7-mm i.d. × 22-cm long glass column and washed with 10 mL of hexane. The column was then packed to a depth of 17 cm with the deactivated alumina. The sample was added to the column and eluted with 15 mL of hexane, and the volume of eluate was adjusted for GLC analysis.

The method used to characterize the PCBs found in the sample has been previously described (*12*).

When it was necessary to separate the PCBs from interfering chlorinated pesticides, especially residues of technical chlordane, the sample extracts were fractionated by silicic acid column chromatography (*13*).

Results and Discussion

The results indicate that the foam plugs collect PCBs nearly quantitatively compared to a collection efficiency of ~80% for ethylene glycol (6). The extraction and cleanup of four fortified plugs gave 100 ± 3% recovery for Aroclor 1242 and 99 ± 5% for Aroclor 1254. The retention of PCBs by foam was at least 97% when two plugs were used in series. In the worst case (Aroclor 1242 on only the first plug) the retention was 87 ± 7%. The collection efficiency was 96 ± 15% for Aroclor 1242 and 96 ± 7% for Aroclor 1254. The efficiency of the foam plug sampling system was studied by using a minimum of five replicates for each experiment.

When four samplers were run side by side in the same laboratory and the samples were taken through the analytical procedure at the same time, the results showed that the overall method had a relative standard deviation of 17%.

The percent relative standard deviations for the actual sampling in the field varied from 10 to 36%. This larger variation is due, at least in part, to the fact that sampling at a given location was spread over as much as several months with some of the samples taken when the forced air heating or cooling systems were in use and others taken when the house air was more or less stagnant.

The average level of PCBs, calculated as Aroclor 1242 plus Aroclor 1254, found outside the industrial research building was less than 0.02 $\mu g/m^3$ while the level inside the offices was 5 times higher, 0.10 $\mu g/m^3$. Inside the laboratories the level was 10 times higher than ambient, averaging 0.21 $\mu g/m^3$ (Table I). The air outside one home contained 0.004 $\mu g/m^3$ of PCB while the average level inside that house on the same day was 0.31 $\mu g/m^3$. While these data indicate that indoor air contains much higher levels of PCBs than the surrounding outdoor air contains, the amounts found are still well below the NIOSH proposed criterion.

In the room containing the burned-out light ballast, air levels of PCBs on the day of burnout were found to be over 50 times higher than normal (11.6 vs. 0.2 $\mu g/m^3$) for that room, and levels remained elevated for 3–4 months afterward (Figure 1). In another study of a ballast burnout where ethylene glycol in impingers or on nylon screens was used as the collection medium, the levels had reached the detection limit of the method (0.5 $\mu g/m^3$) "within weeks" (8). Comparison of these studies illustrates the benefits of the foam collection system's lower limit of detection when following trends caused by PCB spills or contamination.

Of the nine houses tested, four had pre-1972 fluorescent lighting fixtures in their kitchens. Besides the nine kitchens, a total of six other rooms also were tested. As can be seen in Table II, in every case the levels of PCB found were higher in the kitchen than the other rooms tested, but there was little or no correlation between PCB concentration and the type of lighting used. However, other electrical appliances typically found in kitchens may emit PCBs to account for the observed effect. It is interesting to note that the levels found in laboratories were no higher than those found in the houses.

It is apparent from this work that the "normal" levels of PCBs found in indoor air are at least 1 order of magnitude higher than those in the surrounding outdoor atmosphere. The relatively high levels of PCBs that have been reported in urban air may be the result of PCBs leaking from the many buildings present rather than from one or two sources of high PCB contamination. More work needs to be carried out to pinpoint the sources of indoor PCB emissions and to determine to what degree the levels are dependent on air circulation in a given residence.

Acknowledgment

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