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Health Status and PCBs in Blood of Workers Exposed to PCBs and of Their Children

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A follow-up study of capacitor manufacturing workers exposed to polychorinated biphenyls (PCBs) and their children was conducted since 1973. PCB levels in whole blood of workers as well as in breast milk of the exposed lactating mothers were approximately 10 to 100 times those of nonexposed Japanese. Blood PCB levels had a statistically significant correlation with the duration of PCB handling and breast milk PCB levels. The rate of decline of blood PCB levels, as well as the changes of the gas chromatograph of blood PCB over 7 years was found to vary with the kind of PCB handled. The levels of blood PCB tended to be higher in the children fed PCB-contaminated breast milk for a long period. The great majority of workers handling PCBs had dermatologic complaints. Discontinuance of contact with PCB led to gradual improvement of these lesions. Abnormal results in the blood chemistry of the workers were rare, while serum triglyceride concentration was significantly correlated with blood PCB levels in 1974.

In the questionnaire study, the number of complaints in children born from mothers who had handled PCBs, especially those fed breast milk for a long period, was conspicuously higher than that in control groups. Several children were found to have the same medical findings as in Yusho; however, they have not been diagnosed as PCB-poisoning, because these findings were neither so serious nor related to the blood PCB levels.

In Japan, the use of polychlorinated biphenyls (PCBs) for electric capacitors began in the early 1950s, and was discontinued in 1972 when the production and use of PCBs were administratively prohibited from a standpoint against global pollution of PCBs. In the initial period of PCB use in Japan, I had an opportunity to participate in the health supervision of PCB workers in a capacitor factory in Osaka (*1*). At that time, not much attention was paid to the toxicity of PCB. Workers had a certain exposure, especially those working at impregnation facilities, and among half of them chloracne was often observed.

The present paper reports on a survey of another capacitor factory in Shiga Prefecture, near Lake Biwa. At the factory studied, PCBs used were Kanechlor-500 (KC-500; chlorine content, 55%) and KC-300 (chlorine content, 43%). In March of 1972, very high PCB levels in the blood of workers at this factory were noted by the Ministry of Labour of Japan (*2*). In the same year, the use of PCBs was stopped. The next year, following this result, we started follow-up studies on the health status of the workers with the cooperation of medical and analytical teams.

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Table 1. Persons examined annually.

Year	Employee status		Families	Children
	Present	Retired		
1973	72	83	–	–
1974	94	24	–	–
1975	76	20	21	39
1976	60	15	20	29
1977	40	14	12	22
1978	58	15	7	13
1979	41	11	11	20

Those examined consisted of workers, retired workers and female workers, including those who gave birth to babies after exposure to PCBs. These children were also examined. The number of annual workers examined for PCB poisoning is shown in Table 1. Though the survey of the Ministry of Labour of Japan in 1972 sampled only 17 workers, we broadened our survey in 1973 to include all 155 workers who might have been exposed to PCBs in the plant. Thereafter the number of workers examined has gradually decreased. This was because workers with low blood PCBs were omitted from the follow-up. Table 2 shows the distribution of the duration of PCB handling. In the study population, the workers working on impregnation might have the highest exposure to PCBs, though the exposure levels were

Table 2. Duration of PCB exposure of 80 workers.

Duration, yr	Male occupation category		
	Impregnation	Others	Female
1– 4	15	13	8
5– 9	4	13	8
10–14	1	6	5
15–19	1	3	2
20–24	0	0	1
Total	21	35	24
Mean	4.1	6.6	8.0
SD	3.7	4.5	5.4

not determined. In the analysis of our results, jobs other than impregnation were classified as "others." Subjective complaints, inspection of the skin and blood PCB concentrations, the hematology and blood chemistry including triglyceride and liver function were studied. PCB levels in whole blood or breast milk were determined by gas chromatography (*3–5*).

Results and Discussion

Blood PCB Levels in the Workers

Table 3 lists the blood PCB levels of workers who handled PCBs at the plant until 1972. Though the blood PCB levels of workers exposed to KC-300 and KC-500 were found to be significantly higher than those of workers exposed to KC-300 alone, among both the KC-300-exposed workers and KC-300 and KC-500-exposed workers, there was no significant difference between workers employed at impregnation facilities and "others," currently employed and retired workers, or male and female.

A relationship between duration of the exposure to PCB and the blood PCB levels in 18 workers was shown (Fig. 1). These workers were engaged in impregnation of PCBs into capacitor till 1972, and the blood samples were collected in 1973. A significant correlation was observed, 0.83 (p <0.001).

Table 3. Blood PCB levels of the workers in relation to the job and PCB handling.

	Blood PCB level (mean ± SD), ng/g (ppb)			
	KC-300 handling		KC-300 and 500 handling	
	Impregnation	Other	Impregnation	Other
Male				
Currently employed	27.7±13.3 (N = 17)	30.1±14.5 (N = 14)	70.5±25.5 (N = 2)	
Retired	41.0±8.5 (N = 2)	35.8±17.5 (N = 6)		117.0 (N = 1)
Female				
Currently employed		21.5±11.1 (N = 20)		99.0±93.4 (N = 4)
Retired		18.7±7.5 (N = 3)		

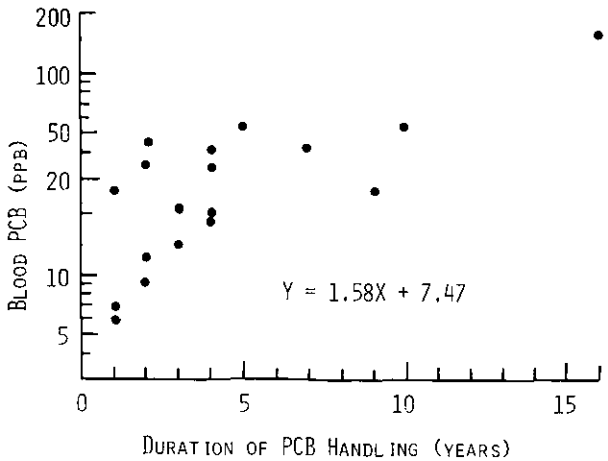

FIGURE 1. Relationship between blood PCB levels of the workers and the duration of PCB handling.

PCB levels in whole blood of the workers in 1973 (use of PCB was discontinued in 1972) were found to be about 10 to 100 times those of adults in the general population in Osaka Prefecture, Japan (ca. 3 ppb on the average, range < 0.5 ppb to 23 ppb) (*6*). Such high PCB levels in blood have been reported in many cases of other capacitor manufacturing plants (*7–13*).

There were no significantly different PCB levels in blood between two kinds of jobs in our study, although the degree of exposure to PCBs might have been different among the workers. These results may be due to differences in the duration of exposure (Table 2).

Decline of Blood PCB Levels in the Workers

The blood samples were again collected from 29 donors in 1980. These donors handled PCBs until 1972, and included workers exposed to both KC-300 and KC-500. In addition, the workers who were exposed to PCBs until 1971 were included. Table 4 compares their blood PCB levels in 1980 with those in 1973. The decrease in blood PCB levels in the workers exposed to both KC-300 and KC-500 was 27.5%, on the average, over a period of 7 years, inspite of being 61.1% in the workers handling only KC-300. This marked difference in the decline rates of blood PCB levels in the workers

Table 4. Blood PCB levels of male workers in 1973 and 1980.

	PCB handling until 1972		PCB handling until 1971
	KC-300	KC-300 and KC-500	KC-300 KC-500
Number	20	4	10
Blood PCB level (mean ±SD), ppb			
1973	28.8 ± 11.8	121.9 ± 76.1	68.2 ± 31.8
1980	11.2 ± 5.7	88.3 ± 64.1	64.7 ± 37.7
Ratio 1980/1973	38.9	72.4	94.9

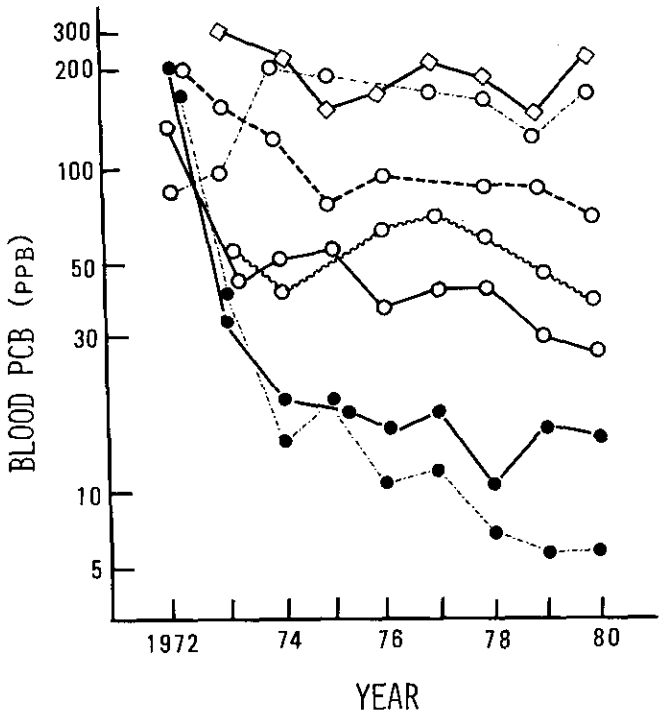

FIGURE 2. Decline of blood PCB levels of the workers. (●) male, handled KC-300; (○) male, handled KC-300 + 500; (◇) female, handled KC-300 + 500.

with the kind of PCBs handled led to the consideration that KC-500 might be eliminated less readily than KC-300 from the human body, as confirmed in animal experiments (*14*). Moreover, the rate of decrease of PCB levels in the workers exposed to both KC-300 and KC-500 up to 1971 was found to be only 5.1%. It was suggested that 10 to 20% of residual PCBs might have already been excreted in the sampling year 1973.

Figure 2 shows the annual change of individual blood PCB levels for seven typical workers. Differences in rate of decrease with the kind of PCBs handled can be observed. Especially, a marked decline was noticed from 1972 to 1973 in the case of KC-300-exposed persons. 1972 was the year when PCB handling was stopped at the plant. The 1972 blood PCB levels were assayed by Dr. Hasegawa et al., National Institute of Industrial Health, Japan (*2*).

Changes in Gas Chromatographic Pattern of Blood PCBs

Figure 3 compares the typical gas chromatographic patterns of the blood PCBs from a KC-300-exposed worker, a KC-500-exposed worker, and a worker exposed to both KC-300 and 500 from samples taken in 1973 and in 1980 with those of KC-300 and KC-500 standard. The column height shows relative chlorobiphenyl contents (CB%) of each peak as compared with peak 16. The chlorobiphenyl amount of peak 16 is fixed as 100% on the basis of the calculation for the OV-1 gas

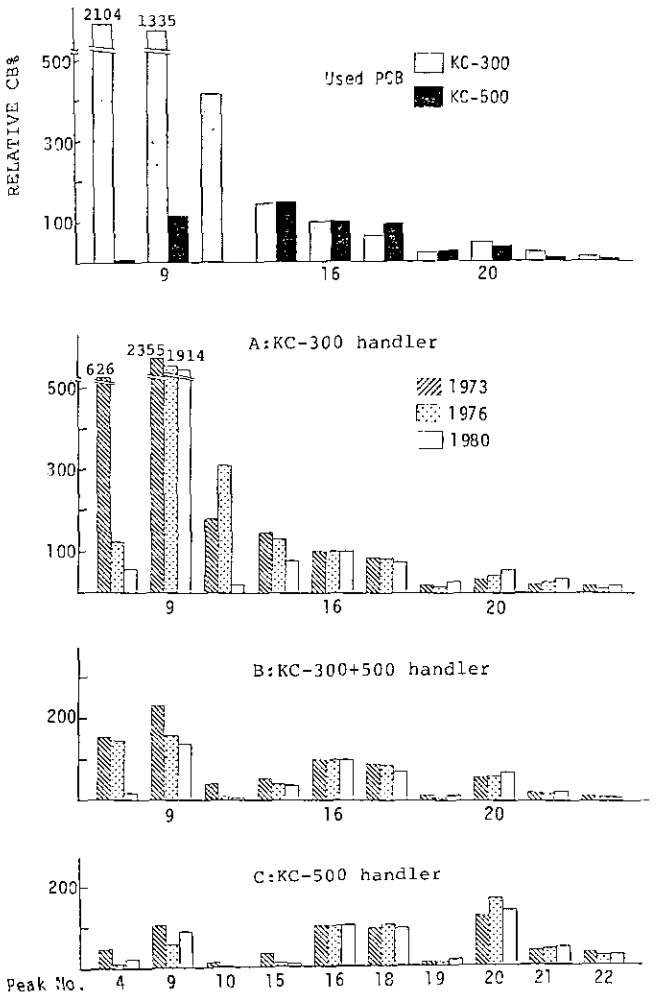

FIGURE 3. Gas chromatographic pattern of PCBs.

chromatography column of Ugawa et al. (*3*). The pattern obtained from KC-300-exposed workers and KC-500-exposed workers in 1973, one year after cessation of PCB handling, resembled the KC-300 and KC-500's standards, respectively. In the case of the KC-300-exposed worker, the relative CB% of peaks 4, 9, and 15 decreased by 100 to 1,000%, whereas in the case of the KC-500 or KC-300 plus KC-500-exposed workers, the decrease was only 10 to 100% in each peak.

Incidentally, polychlorinated quaterphenyls (PCQs) that were found especially in Yusho patients (*5*) were not detected in the blood of our capacitor workers.

Health Status of PCB Workers

During the time when PCBs were being handled, a great portion of the study population had dermatologic complaints: black comedones and acne, 40%; skin irritation and erythema, 13%. The frequency of skin symptoms of impregnation workers was higher than that of workers classified "others."

In 1973, when our follow-up study began, a mild

degree of black comedones and chloracne still remained in some of the workers who were exposed to PCBs up to 1972, and to 1980 these lesions of the skin decreased continuously.

Besides that, some workers complained of stomach upset, nausea and heartburn as the effect of PCBs, but after discontinuance of PCB handling, these characteristic subjective symptoms were no longer present,

The blood chemistry study (Table 5) showed rare abnormal results. Only serum triglyceride concentration in 1974 was significantly correlated with blood PCB levels ($p<0.05$).

It was noteworthy that, despite the very high blood PCB levels in these capacitor manufacturing workers, abnormal findings other than the dermatological lesions were very rare; we found dermatological changes such as comedones and acne to be the most prevalent abnormalities in other surveys of capacitor workers (*7,8,11*). Correlation between the blood PCB levels and serum triglycerides was found only in one instance of our eight years follow-up examinations, although elevation of serum triglyceride associated with elevated blood PCB levels was reported in a few studies of PCB workers (*9,13*). We did not find a high prevalence of liver or kidney lesions, similar to a few reports which found no effect of PCB on liver (*7,9*) or kidney function (*9*), although others reported abnormalities of liver function (*11,13*).

In the Yusho patients, dermatological symptoms, occular discharge and swelling of the upper eyelids, various nervous and general symptoms, hypertriglyceridemia, adrenocortial and ovarian dysfunction, bronchitis, hepatomegaly, hypobilirubinemia and low immunoglobulin levels were described as the most common clinical features (*15*). On comparing our results with Yusho patients, whose blood PCB levels were slightly higher than those of normal Japanese and were markedly lower than those of capacitor workers, the scarcity of abnormal findings was most impressive, as noted by Fishbein et al. (*8*).

Breast Milk PCB Level in Nursing Women

PCB levels in breast milk from exposed women who delivered children were found to be 10 to 100 times those in nonexposed women (Fig. 4). There is a good correlation between blood PCB level and breast milk PCB level of the women ($r = 0.98, p < 0.001, N = 8$), so it seems possible to predict a certain PCB level in the breast milk from analyses of blood PCB level.

Table 5. Result of blood biochemical tests of PCB workers in relation to blood PCB level.

Blood PCB level, ppb	N	Abnormality value, %			
		Triglyceride (>140)	GPT (>31)	Alkaline phosphatase (>13.6)	TTT (>4.1)
<10	28	21	0	7	4
11–30	46	26	2	15	4
31–50	14	29	0	14	0
51–100	8	63	0	0	0
>101	1	100	100	0	0
Total	97	29	2	11	3

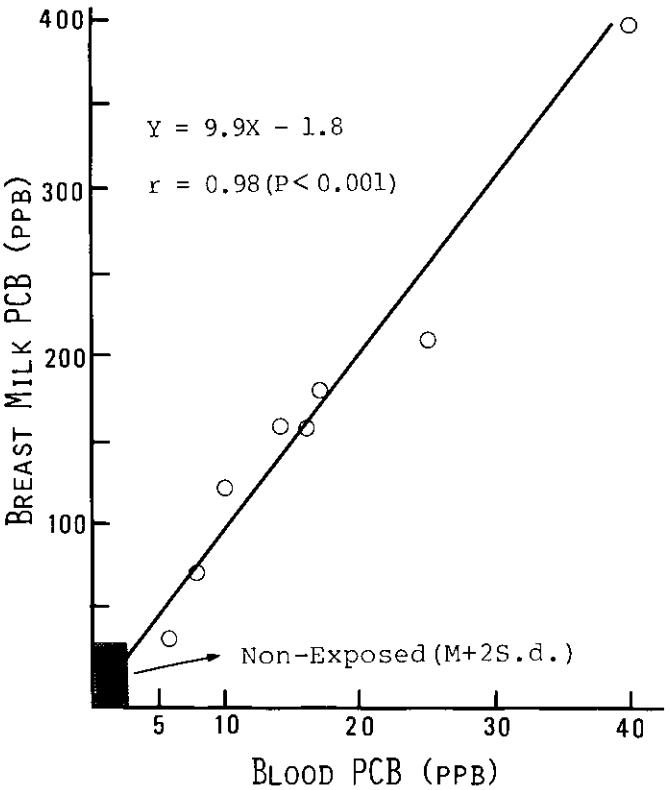

FIGURE 4. Relationship between blood PCB level and breast milk PCB level.

Questionnaire on Children

Appearance of such a high level of PCB in the breast milk suggests to us the need to survey effective health risks for children of exposed mothers.

A questionnaire study was carried out on the health status of the children of the workers at the factory. We divided them into three groups, A, B and C. Mothers in group A worked in the factory and handled PCBs; and mothers in groups B or C were shown in Table 6. No reports of "small for date" (SFD) or "Cola baby" were found, though these symptoms occurred in the Yusho babies. When the ratio of body height and weight of children to the standard ones for each sex and age were compared in three groups, the ratio of body weight of females of group A was smaller than that of groups B and C.

When the health status among three groups of children was compared with 37 specific items in the Yusho patients, the number of complaints was conspicuously higher in the children of group A than others, especially those who were fed breast milk for a long period (Table 6).

Table 6. Comparison of the complaints of three groups in relation to the duration of breast feeding.

Group	Work in this factory	Handling PCBs	Number *N*	Mean number of complaints			
				Total	Period of breast feeding		
					0	1 – 4 months	5 ≤ months
A	+	+	46	6.7	6.3	5.3	13.2
B	+	–	40	2.9	3.5	2.6	2.7
C	–	–	72	2.2	2.3	2.0	2.6

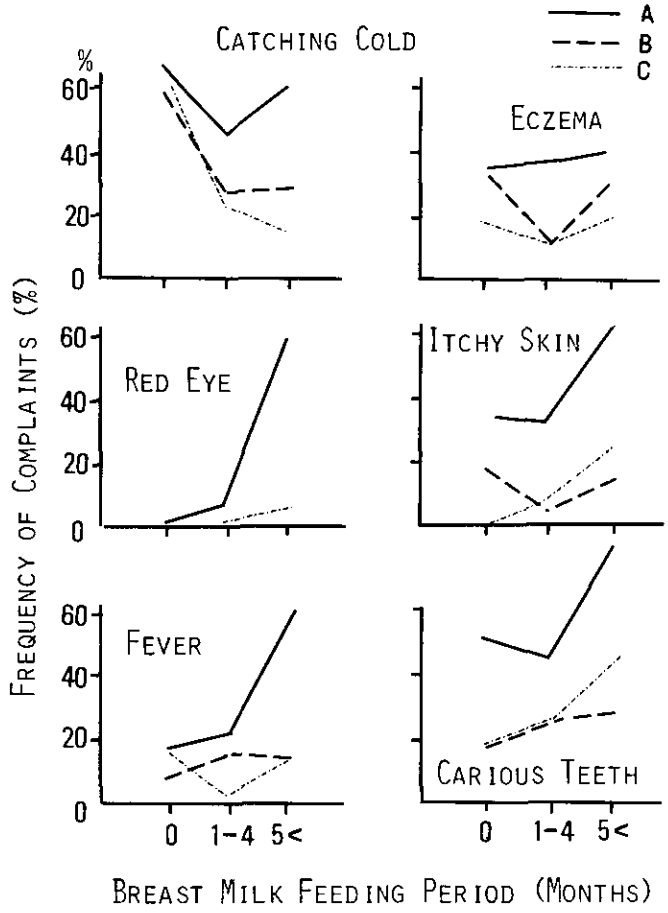

FIGURE 5. Frequency of complaints in relation to breast milk feeding period.

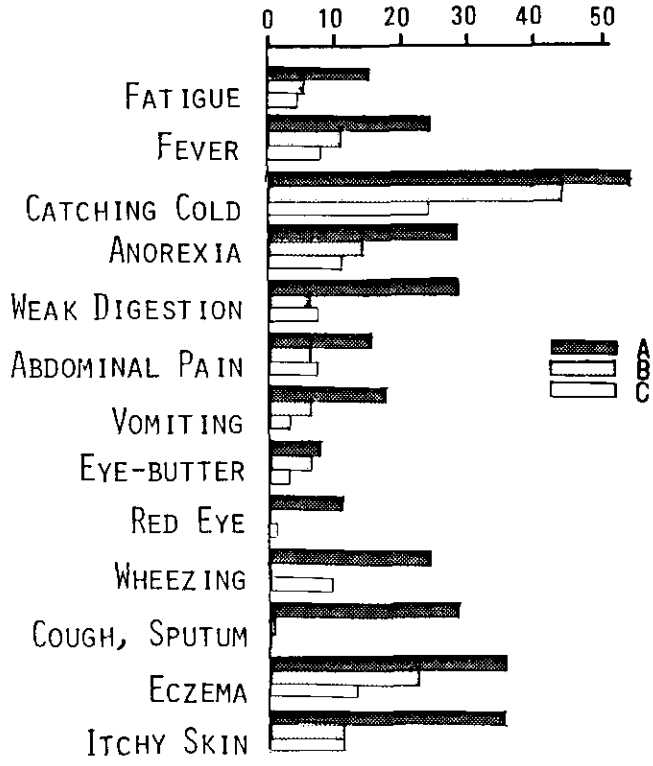

FIGURE 6. Comparison of complaints in three groups.

Moreover, Figure 5 shows that there are many complaints of fatigue, catching cold, weak digestion, coughing, expectoration, and itchy skin in group A. Figure 6 shows the relation between the breast feeding period and the frequency of complaints; the longer the period of breast feeding, the more frequent the complaints. These complaints include fever, red eyes, itchy skin and carious teeth.

Although this questionnaire method has some limitations, there seems to be some possibility of adverse effects of PCB on the children's health.

Health Status of the Children

Next, we introduce the results of the medical examiantion of about 40 children performed once a year over a five-year period. The result showed the level of PCB in blood was apt to become higher when the children were fed PCB-contaminated breast milk for a long period. (*16*). The children were examined in pediatric and dental surgery clinics as well as undergoing blood and urine tests. These children have not been diagnosed as having PCB poisoning. Some children were found to have decay of nails, gingival pigmentation, mottled enamel, and dental caries which were typical symptoms in Yusho, but not so serious. No relation of these changes or symptoms to the PCB levels was observed (Table 7).

Table 7. Result of health examination of children (1976).

	No. of children at each blood PCB level				
	< 3 ppb	3 – 4 ppb	5 – 9 ppb	> 10 ppb	Total
No. of examinees	12	7	4	4	27
Nail abnormality					
Deformity	2	3	1	0	6
Pigmentation	1	0	1	0	2
Dryness of skin	1	1	0	0	2
Gingival Pigmentation	4	2	3	2	11
Tooth abnormalities					
Mottled enamel	3	1	2	3	9
Carious teeth					
+ +	5	1	1	0	7
+	2	1	0	0	3

Conclusion

We found high blood PCB levels in the workers and their children exposed to PCB at a condenser factory or through breast milk. However, few signs and symptoms of PCB poisoning were discovered in this study. Three factors could contribute to the difference between our results and Yusho: first, the difference of absorption route might be not so important; second, the difference of exposure time length and the quantity involved might be significant because they lead to a difference in PCB distribution in the tissues, as shown in animal experiments (*17*); third, the difference of chemical components introduced, discussed in detail by our co-workers, Kunita et al. (*18*). Lest we overlook a latent disorder or dysfunction in these subjects, some new approaches, such as the immune function test and the test of induction of drug-metabolizing enzyme, have been carried out. We hope to continue our follow-up study as long as possible.

I am greatly indebted to all of our research group for this eager collaboration of many years. I also thank both the trade union and the company concerned for their support of this survey.

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