Use and Health Effects of Aroclor 1242, a Polychlorinated Biphenyl, in an Electrical Industry

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ABSTRACT

Aroclor 1242, a chlorinated biphenyl, is widely used as a dielectric medium in transformers and capacitors. In this survey, thirty-four occupationally exposed workers were examined. Complaints consisted of a burning sensation of the face and hands, nausea, and a persistent body odor. One had chloracne, and five suffered from an eczematous rash on the legs and hands. Although hepatic function tests were normal, the mean blood Aroclor level in the exposed group (approximately 400 ppb) was significantly higher than in the control group. A tentative value of 200 ppb is suggested for Aroclor 1242 as an acceptable level for occupationally exposed workers. The use of an efficient exhaust ventilation to maintain air concentrations below the threshold limit value, and the regular measurements of hepatic function and of blood Aroclor concentrations in exposed workers are recommended.

ALTHOUGH THE USE of polychlorinated biphenyls, or PCBs, began as early as 1881, their widespread application in industry did not begin until 1930.[1] Because of their chemical and thermal stability the PCBs are used in various countries as dielectric fluids in transformers and capacitors; as plasticers in paints, plastics, resins, inks, and adhesives; and as components of hydraulic fluids. In this study employees of an electrical industry were examined. A typical condenser as manufactured in the electrical industry is mainly for power factor correction in an electrical work and consists of a system of two conductors enclosed in a tin casing (80x60x30 cm).

The toxicology of PCBs in man is less well known than that of the chlorinated hydrocarbon pesticides, e. g., DDT. Industrial exposure has been reported to cause chloracne,[2-4] and Flinn et al. have described ten cases of fatal PCB or naphthalene poisonings, and, in all cases, found fatty degeneration, necrosis, and cirrhosis of the liver.[5]

Because of the potential adverse medical effects of Aroclor on the workers, the Division of Occupational Health and Radiation Control of the Health Commission in New South Wales conducted a survey in 1974 to determine the degree of absorption and the toxicologic effects of this substance.

Methods

Aroclor used in the industry was of electrical grade and did not contain any impurities. Aroclor concentrations in the air inside an industrial plant were measured and thirty-four workers who were occupationally exposed for varying periods to Aroclor were examined. In addition to the occupational and past histories (including amount of alcohol, drug intake, and previous history of hepatitis), blood samples were collected for Aroclor estimations and hepatic function tests. Bromsulphalein (BSP) excretion tests were also carried out on seven volunteers whose blood Aroclor contents were above 500 ppb. Glass syringes and containers wre used in blood collection, as plastic equipment may contain trace amounts of PCBs, which may cause erroneous analysis results.[6] The anticoagulant used in the containers was heparin. Thirty control volunteers from the Division of Analytical Laboratories of the Health Commission of New South Wales, were also interviewed and examined; none had an occupational history of exposure to PCBs.

The extraction of PCBs from blood samples, their separation from other pesticide residues, and their subsequent chromatographic analyses, were carried out by the Division of Analytical Laboratories. Each 1-gram sample of whole blood was shaken for 5 minutes in a

5 ml stoppered test tube with 2 ml of 2% sodium sulfate solution, and then shaken for a further 5 minutes with 2 ml of nanograde hexane. The mixture was then placed in an ultrasonic bath for 20 minutes and centrifuged for a further 5 minutes until there was clear separation of hexane and blood mixture. The hexane extract was dried over anhydrous sodium sulfate and injected directly into the gas chromatograph (Hewlett Packard 7610 Gas-Liquid Chromatograph) without any further clean up for identification and quantification. The column oven was equipped with a 5 foot long glass column packed with Varaport 30 coated with 3% silicone UCW98. The detector had a pulsed power supply with ^{63}Ni as the radioactive source for ionization. A mixture of methane 5% and argon 95% was used as a carrier gas. The temperatures of the injection block, column oven and detector were maintained respectively at 220° C, 205°C, and 280°C.

For the air analysis in industrial plants, the operators' breathing zones were sampled with a Greenburg-Smith Impinger at 30 l/m into 75 ml of isopropanol. The isopropanol used for sampling was rendered PCB-free by distillation. In most cases a sample volume of 1 m^3 of air was taken. The isopropanol was analysed for PCBs using a gas-liquid chromatograph with a tritium detector. Because several peaks were found, the seven principal peak heights were considered.

Since different PCB preparations give different peak heights and patterns, standards were prepared from the actual PCB in use. PCBs were analysed using Perkin Elmer F.11 gas chromatograph. The column was packed with gaschrome A 80-100 mesh with 5% $Q.F_1$. Nitrogen was used as a carrier gas. The temperatures of injection block, column, and detector were 210°C, 200°C, and 200°C respectively.

Table 2.–Blood Aroclor Levels and Abnormal Liver Function Test Results of Thirty-Four Exposed Workers

No.	Age, yr/Sex	Duration of Exposure, yr	Blood Aroclor Level (ppb) Retention Times Relative to Aldrin 1				Bilirubin, μmol/l	Alkaline Phosphatase, μmol/l	Total Protein, g/l
			0.69	1.31	1.47	1.96			
Impregnation Room Workers									
1	51/M	23	580	370	240				⊕
2	35/M	5	179	117	85				⊕
3	56/M	23	130	170					⊕
4	41/M	8	100	140		10			⊕
5	46/M	10	540	210	150				⊕
6	38/M	19	570	450	340				⊕
7	40/F	6	1,580	790	600	1,540			
8	54/M	12	240	150	120	270			⊕
9	50/M	2	650	320	340				
10	34/M	6	280	130		80			
11	36/M	3	1,470		620				⊕
12	46/M	3	440	194	230				
13	57/M	6	1,378	1,037	1,099				
14	51/M	6	550	290	160				
15	45/M	1/6	555		287				
16	44/F	2	170	91					
17	49/F	1	149	69					
18	41/F	1/12	181	79					
19	46/F	4	1,700	729	879				
Process Workers									
1	45/F	7	153	60	66				
2	47/F	7	115	Trace	425				
3	40/F	4	192	198	1,010				
4	33/F	1	102						
5	39/F	2	76	Trace	Trace				
6	47/F	2	33	Trace	Trace				
7	54/F	3	82	Trace	Trace				
8	50/F	2	198	Trace	837				
9	52/F	5	374		1,460			⊕	
10	54/F	6	215		Trace				
11	53/M	1½	172	76					●
12	47/F	6	80	Trace					
13	42/F	2	79	68					
14	33/F	3	93						
15	48/F	3	Trace						

⊕, ⊕⊕ –Slight and moderate increases from normal values, respectively.
● – Slight decrease from normal values.
*Bromsulphalein tests carried out in only seven workers.
†Dermatitis of the hands and/or legs; burning of the face, eyes, and skin.
+, +++ – Mild and severe lesions and complaints, respectively.
N –Normal values.

Blood Aroclor 1242 Levels of Exposed and Control Groups

	Blood Aroclor Level (ppb) Retention Times Relative to Aldrin 1			Mean ± SD
No. in Sample	0.69	1.31	1.47	1.96
34	394 ± 460	198 ± 258	415 ± 429	475 ± 718
30	N.D.*	N.D.	N.D.	N.D.

Results

Blood Aroclor Levels in the Exposed and Control Groups

The blood Aroclor 1242 contents among the control group, which consisted of twenty-three males and seven females with ages ranging from 21 to 50 years, were zero ($m = 30, \bar{X} = 0, SD = 0$). Similar statistics for the exposed group, which consisted of fifteen males and nineteen females with ages ranging from 33 to 55 years, are shown in Table 1. Comparison of the mean blood Aroclor levels of the exposed group with those of the control group demonstrates a statistically significant increase in blood levels among the former ($P < .01$).

Aroclor Levels and Liver Function Tests in Thirty-Four Workers

The thirty-four workers could also be divided into two groups according to the degree of exposure: one group of nineteen workers (fourteen males and five females) was employed in the impregnation room, so called because Aroclor was impregnated inside the capacitor casings. In the handling process, as the exposure to hot Aroclor (temp, 70°C) could be excessive, undue absorption of this

	α_1 Globulin, %	α_2 Globulin, %	β_1 Globulin, %	γ Globulin, %	GPT	BSP*	Signs and Symptoms†	
							Dermatitis	Burning & Irritation
		⊕				⊕		
						N		
					⊕⊕	⊕⊕		
			⊕			⊕⊕		
		⊕				N		
		⊕				N		
							+++	
						⊕⊕		
	●						+	
	●							
	●	⊕			⊕			
●							+	+
●				⊕			+	+
●	●				⊕⊕			+
				⊕				+
		⊕	⊕		⊕⊕		+	+
					⊕			+
	●			⊕				+
	●							+
		⊕						+
								+
								+
								+

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Table 3.—Comparison of Mean Blood Aroclor 1242 Levels and Hepatic Function Tests between the Exposed Workers Employed Inside and Outside an Impregnation Room

Group	Blood Aroclor Level (ppb), Mean ± SD — Retention Times Relative to Aldrin 1: 0.69	1.31	1.47	Hepatic Function Tests, Mean ± SD — Bilirubin, µmol/l (1.7-20.5)*	Alkaline Phosphatase, µmol/l (20-85)*	Total Protein, g/l (63-79)*	Albumin, % (62.5 ± 6.5)*	α_1 Globulin, % (4.2 ± 1.1)*	α_2 Globulin, % (7.9 ± 2.4)*	β Globulin, % (10.4 ± 3.6)*	γ Globulin, % (15.1 ± 4.6)*	GPT (5-35)*
Inside	602 ±527	313 ±283	391 ±313	5.7 ±2.9	60.7 ±12.3	76.8 ± 4.9	61.5 ± 5.1	3.6 ±0.6	9.4 ±1.8	11.9 ± 1.5	13.4 ± 2.9	21.4 ±17.8
Outside	140 ± 86†	100 ± 65‡	899 ±378†	6.1 ±1.8	62.8 ±17.4	72.1 ± 4.6	62.4 ± 2.7	3.6 ±0.5	9.3 ±1.1	10.6 ± 1.8	14.0 ± 2.1	28.6 ±18.1

* Normal values.

† Indicates a significant ($P < .01$) difference from value immediately above.

‡ Indicates a not significant ($P > .05$) difference from value immediately above.

substance can occur unless suitable impervious gloves are worn and an efficient exhaust ventilation is operating. The second group consisted of process workers (one male and fourteen females) who were employed outside an impregnation room and assembled Aroclor-dipped capacitor components. Here the main route of absorption was through the skin and, in general, exposure was not so great as in the first group. No job rotation was carried out between the two groups.

Table 2 shows the blood Aroclor levels and abnormal hepatic functions in these two groups of workers. The total periods of exposure to Aroclor 1242 and 42% chlorine containing PCBs are shown in column 3. As the pathway of Aroclor metabolism in humans has not been completely worked out, the chemical identification of the metabolites corresponding to the peaks in the gas chromatogram is at this stage not known. However, their sequence of appearance can be expressed as relative retention times using that of aldrin as 1. Thus a metabolite with a relative retention time of 0.69 appears before aldrin and those with relative retention times of 1.31, 1.47, and 1.96 appear after aldrin. The height of a peak indicates the concentration in blood.

Abnormal hepatic function tests are shown in full to indicate values higher (⊕) or lower (●) than the acceptable normal limits for the tests. These include measurements of serum bilirubin, alkaline phosphatase, total protein, GPT, and BSP retention. No history of excessive intake of alcohol or drugs, or of hepatitis was found in the thirty-four exposed workers. In the impregnation room group, for example, seven protein levels are high, and four α_1 globulin levels are low. Also three GPT and four BSP results are abnormal.

BSP tests were carried out on seven workers with relatively high blood Aroclor (i. e., above 500 ppb). Four our of seven results were above normal values of 5%, but because other conditions such as fever can also increase retention, the high BSP test results could not, by themselves, be taken as proof of hepatic damage. One case, who suffered from congestive cardiac failure and enlarged liver, had a normal liver function test.

Despite some individual abnormal results, however, the mean of each hepatic function test for the whole group is within normal limits (Table 3).

Aroclor Levels and Symptoms

Exposed workers tend to complain of burning of eye, face and skin. Aroclor "fume" is an eye irritant, has a pungent smell, and often causes persistent body odor. One worker suffered from chloracne without the systemic effects characterized by anorexia, nausea, edema of the face and hands and abdominal pain.[7] Five workers complained of eczematous rashes on the hands and legs. Although there does not seem to be a clear correlation between severity of dermatitis and/or burning or irritation of the skin, and blood Aroclor levels, the dermatological complaints occur more often among workers with higher blood Aroclor levels.

Table 3 shows the comparison of the mean blood Aroclor levels and hepatic function tests in the two

Table 4.—Correlation between BSP Retention Values, Blood Aroclor Levels, and Length of Exposure among Seven Impregnation Room Workers

Patient No.	Length of Exposure to Aroclor, yr	Blood Aroclor Level, ppb (Retention Time Relative to Aldrin 1 = 0.69)	BSP Retention, %
1	23	580	7.1
2	5	179	5.2
4	8	100	10.5
5	10	540	9.2
6	19	570	5.0
8	12	240	3.4
10	6	280	11.5

groups of exposed workers. It can be seen that the impregnation room workers tend to absorb more volatile compounds with low relative retention times, while the process workers outside the impregnation room tend to absorb 'heavier' compounds, as shown by the statistical differences in the two groups.

If the BSP test is used as an index of "hepatic" health of an exposed worker, poor correlations exist between the BSP retention values and blood Aroclor levels ($r = -0.1016$), and between the former and length of exposure ($r = -0.3639$), as shown in Table 4.

Aroclor Levels of the Workplace

Table 5 shows that the levels of Aroclor in the breathing zones of the operators exceeded the threshold limit value (TLV) of 1.0 mg/m^3. The Australian National Health and Medical Research Council publication, *Atmospheric Contaminants* (1970) recommended the TLVs for PCBs as follows: 42% chlorine (Aroclor 1242), 1.00 mg/m^3; 54% chlorine, 0.5 mg/m^3. In 1974 the American Conference of Governmental Industrial Hygienists recommended the same TLVs. When a more efficient exhaust ventilation was later installed, however, the air measurements were below 1.0 mg/m^3.

Two months following improvement of the exhaust ventilation system and the recommendation to wear suitable impervious gloves to lessen the absorption of Aroclor through the skin, further blood samples were taken to determine if there was any improvement in the blood Aroclor levels. Unfortunately only fifteen of the original thirty-four workers from inside and outside the impregnation room areas participated in the second test.

Although an efficient exhaust ventilation system had been installed and the concentrations in the air inside the plant were satisfactory (below 1.0 mg/m^3), the recommendation to wear suitable gloves to reduce skin absorption was not strictly followed. This could explain why, as shown in Table 6, there was no lowering of blood Aroclor levels in the "after" group. The failure to wear suitable gloves was due more to a lack of awareness of the toxicology of Aroclor than to the inconvenience of using them.

Discussion

It is interesting to find that no Aroclor was detected in the control group. In contrast, the PCB concentration

Table 5.—Aroclor 1242 Concentrations in the Air Inside the Plant Before and After Improvement of Exhaust Ventilation System

Area in Impregnation Room	Aroclor Concentration, mg/m^3	
	Before	After
Area in unloading tank in front of exhaust register from operator's breathing zone	1.44	0.75
Area in unloading tank not in front of exhaust register	2.22	0.7
General atmosphere near tank	1.08	0.18
Soldering area	0.32	0.08

(arithmetic mean) is 2.3 ppb among the nonexposed urban white volunteers in the U. S. A., and 3.1 ppb among volunteers from rural areas. Finklea[8] suggested that in the U. S. A., urban exposure to PCBs was by way of polluted air and contaminated water. In New South Wales, Australia, preliminary surveys were carried out to determine whether PCBs constituted a significant liquid pollution in general sewerage outfalls. Small and insignificant traces of PCBs were found in the liquid specimens tested. (Personal communication to the Sydney Metropolitan Water, Sewerage and Drainage Board.) Similarly, no PCBs were found in such food items as fish, eggs, and milk. This may explain why no detectable amount of PCBs was found in the control group.

Since some medical abnormalities were observed among the thirty-four in the exposed group, it is interesting to review the toxicology of PCBs, the understanding of which has increased since the unfortunate "Yusho" incident[7,9] in 1968, in which 644 people in Yusho, Japan were poisoned after ingestion of PCB-contaminated rice. The symptoms complained of included chloracne, blindness, nausea, vomiting with jaundice, edema and abdominal pain.[6] Further, it was reported that newborn babies of affected mothers had skin discoloration due to absorption of PCBs through the placenta. Gingival hyperplasia with pigmentation was reported in several cases.

Table 6.—Mean Blood Aroclor 1242 Levels Before and After Improvement of Exhaust Ventilation and the Recommendation to Use Suitable Gloves

Group	Mean Blood Aroclor Level (ppb)		
	Retention Times Relative to Aldrin 1		
	0.69	1.31	1.41
Before	281.6	135.1	58.41
After	477.2*	225.4*	524.7†

* Indicates a not significant ($P > .01$) difference from value immediately above.
† Indicates a significant ($P < .05$) difference from value immediately above.

The PCB which was responsible for the poisoning was the heat exchanger, Kana-chlor 400, a Japanese-manufactured PCB with 48% chlorine. The PCB level in the rice oil was estimated to be about 2,000 ppm. Exposure to the rice oil was estimated to be about 15,000 mg per day, with 3 mg as the lowest quantity producing minimal effects.

Although valuable data have been gained from animal experiments and from fatal poisoning cases, the exact dose-response relationship of PCBs (and in particular Aroclor 1242) in man is still to be determined, largely because of the complexity and heterogeneity of the materials themselves. At this stage, therefore, one cannot accurately set acceptable PCB blood levels that will produce no toxic episodes or long-term sequelae. However, it is reasonable to set 200 ppb as a tentative upper limit of acceptable blood Aroclor content for the occupationally exposed workers (in any of the relative retention times mentioned), as no significant effects on health were observed among the thirty-four exposed workers examined when their Aroclor levels were below 200 ppb. Furthermore, for pesticide workers this Division has set a tentative but acceptable upper limit of 200 ppb for blood DDT, which in animal experiments is about ten times more toxic than Aroclor 1242.[9] It must be emphasized, however, that the final safe level of blood Aroclor can be determined only by proper evaluation of hepatic function tests, adipose tissue levels, and long-term follow-up of exposed workers. Unfortunately, few blood PCB levels have been reported for occupationally exposed workers in Australia or overseas. It is easier to obtain blood samples than adipose tissues, although the latter show more accurate PCB residue levels. However, for screening PCB workers, the former is more convenient.

Studies to determine the effects of exposing animals to Aroclor vapor have been carried out. For example, Treon[10] et al. exposed laboratory animals to 0.83 ppm of Aroclor 1242 vapor (7-hour periods for 17 days) and found no signs of intoxication in a group of thirty-one animals. In the industrial setting, Elkins[11] reported atmospheric concentration levels of 5.8 and 4.5 mg/m^3 (average) in a condenser plant in Massachusetts and found no evidence of toxic effects among the exposed workers. However, in this survey, medical effects (e.g., eczema and skin burning) were observed even when the Aroclor concentration in the air was below the TLV of 1 mg/m^3. It is to be noted, however, that Aroclor "penetrates" the intact human skin[12,13] and careless contact may result in its absorption approaching or exceeding the dose inhaled.

The apparent excessive skin absorption has prevented us from agreeing on or recommending a new TLV for Aroclor 1242 in air. However, because of the potential adverse effects on health, use of an efficient exhaust ventilation system to maintain air concentrations below the TLV, and the regular estimations of hepatic function and blood level in exposed workers are recommended.

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