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Recent PCB Accidents in Finland

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Twenty-eight polychlorinated biphenyl (PCB) accidents were recorded during a 1-year period in Finland. They comprised leaks, fires or explosions of capacitors. Some of the explosions and fires gave rise to high concentrations of PCBs in air and of PCBs and tetrachlorodibenzofurans (TCDFs), including 2,3,7,8-TCDF, on surfaces. One large explosion is described in detail, and biomedical data and findings of this case are compared with those of smaller accidents in Finland.

Introduction

The annual consumption of polychlorinated biphenyls (PCBs) in Finland was 200 tons in 1969 (*1*). The open use of PCBs was voluntarily abandoned in the early 1970s, and their use in closed electrical systems was halted in 1979.

However, more than three million electrical devices containing various amounts of PCBs are still in use in Finland and the total amount of PCBs in these facilities exceeds 2000 tons (Table 1). Leaks, fires and explosions due to overloading are possible and also probable almost daily (*2*). The Institute of Occupational Health has studied 28 PCB accidents between August 1982 and August 1983. This number may even be an underestimate of the accidents that actually occurred in that 1-year period (Table 2). Especially small leaks and fires remain unreported despite the regulatory and informative action taken by the authorities. The cases reported comprise small leaks, limited explosions, large leaks, and large explosions, all of which require different actions and different decontamination procedures.

In the present paper, some of the PCB accidents recorded in Finland during a 1-year period (August 1982 to August 1983) are described, and the hygienic and biological data accumulated after one large capacitor explosion are reported and compared with data from other accidents.

Description of a Case

Just after midnight, on August 3, 1982, two strong explosions took place in the electricity room of a large paper mill in Imatra in southeastern Finland. Because of copious formation of smoke, it was not until 30 min later that the explosions could be localized in the capacitor bank behind the 10 kV contactor station (Fig. 1). Later it was realized that soot and gas had spread with the pressure wave through an open doorway to the 10 kV contactor station and the adjacent 3 kV contactor station and through cable holes to the storage space directly above the contactor stations and to the floor beneath to the instrument cross-connection room.

Each capacitor contained 20 L of Clophen A 30, i.e., a mixture of PCB with an average chlorine content of 42%. Immediately after the explosion it was not known that the damaged parts contained PCB, and thus respirators or other protection devices were not used. Fifteen people were thus exposed rather heavily and showed symptoms of acute irritation of the respiratory tract. Although the areas most heavily contaminated were therefore closed, an additional group of approximately 150 persons became exposed, albeit to a smaller degree, while moving around in the plant. In the afternoon of August 3, i. e., approximately 16 hr after the explosion, the first analyses showed the presence of polychlorinated dibenzofurans (PCDFs) in the soot. Thereafter, all possible precautions were undertaken in order to decrease or prevent exposure during the clean-up procedures.

Table 1. PCB-containing equipment in use in Finland (1983).

Equipment	Volume/unit, L	Number of units	Total amount of PCB, tons
Large and medium-sized capacitors	1–20	110,000	1500
Small capacitors	< 1	3,000,000	300
Transformers	50–1.000	250	250
Total		3,110,250	2050

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Table 2. PCB accidents in Finland in August 1982-August 1983.

Type of accident	N	Lost PCB, L	PCB in air, μg/m³[a]	PCB on surfaces, μg/m²[a]	TCDF on surfaces, ng/m²[a]	2,3,7,8-TCDF on surfaces, ng/m²[a]	Number of persons exposed
Large explosion	2	300	16,000	3.9×10^6	25,000	14,000	152
Limited explosion	16	< 16	50	300	12,000	4,000	113
Large leak	1	10	1,900	33,000	3,300[b]	—	?
Small leak	6	< 6	15	—	—	—	?
External fire	2	?	—	<10	<10	<10	open air
Electric fire	1	?	15	1,500	<10	<10	?
Total	28	<332					>265

[a]Highest concentration measured.
[b]Calculated on the basis that BCP in concern contained 0.01% of PCDF and PCDD.

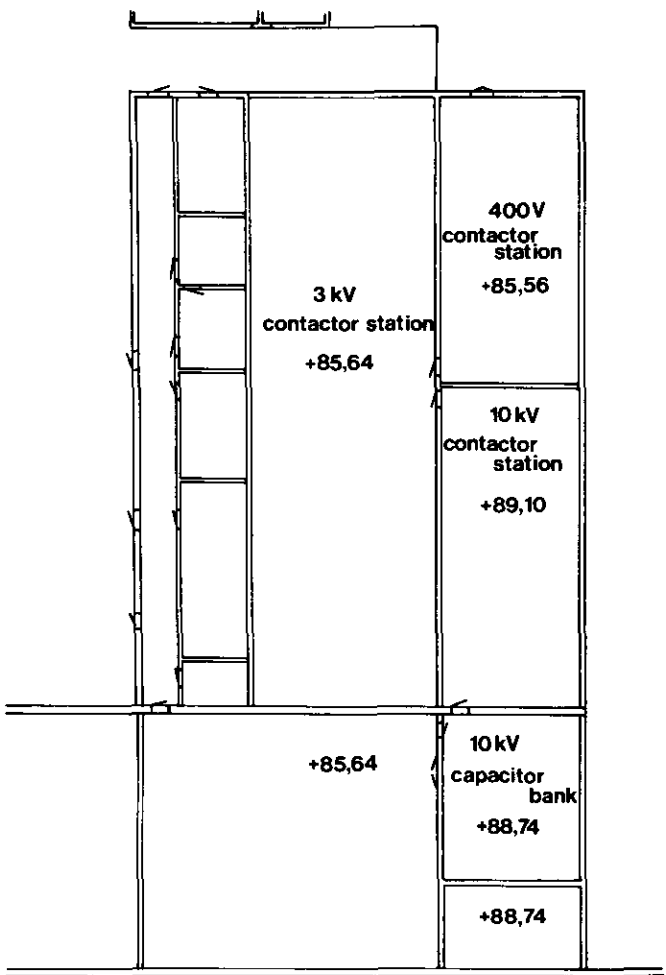

FIGURE 1. The floor plan at Imatra paper mill. The explosion took place in the capacitor bank room.

Clean-up Procedures

A combination of vacuum-cleaning (with vacuum cleaners equipped with microfilters), pressure washing, wiping with organic solvents, repainting, and removal of wall/floor surface were used in the clean-up, depending on the degree of contamination. The results of the clean-up procedures were followed by analyzing PCB and PCDF concentrations in wipe samples.

Table 3. Special equipment and supplies used in the clean-up process.

No./amt.	Item
3300	Respirators
4900	Overalls of nonwoven material
1200	Protective hoods
4100	Shoe covers
2800	Disposable gloves
40	Ordinary overalls
45 pairs	Rubber boots
35	Raincoats and hats
600	Glass jars
120 kg	Seaming foam
4000 kg	ABSOL absorption agent
93	VSS suits, in circulation (350 washes)
	Compressed air at 4 L × 200 bar
1,087 Units at 3.8–12.8	
1,195 Units at 13.8–18.1	
2000 L	Paint

The least contaminated area, the mill itself, was vacuum cleaned and washed with water two or three times. The control room and cross-connection room (on other floors) were wiped several times with methylene chloride and methanol, after several vacuum cleanings. In addition, the contactor station and adjacent rooms were high-pressure washed, the walls and the ceiling were painted twice with epoxide pitch and the floors received a coating with epoxide. In the room where the explosion occurred, the floor was pick dressed and the plaster was removed from the walls. The room was vacuum cleaned several times, and wiped with methanol. The floor and walls were reground. After moisture insulation, new concrete was laid on the floor, and it was epoxide painted. The walls and the ceiling were covered with epoxide pitch twice. Equipment used in the clean-up process has been listed in Table 3.

The clean-up procedure produced approximately 100 tons of PCB-containing waste.

Environmental Monitoring Data

Air Samples

The air samples for PCB analyses were absorbed into Amberlite XAD-2 sorbent. After desorption with *n*-hexane PCB was analyzed with gas chromatography using EC detection. The limit of detection (LD) was 0.1 μg/m³.

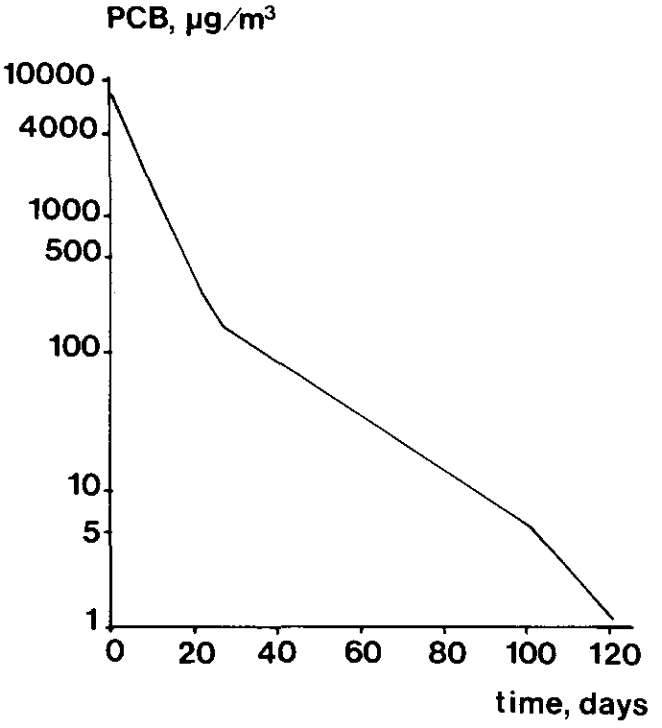

FIGURE 2. Concentration of PCB in μg/m (log scale) in the air of the room where the explosion took place, 0–120 days after the incident.

Figure 2 shows the concentration of PCB in the air of the room where the explosion took place. The determination of the first samples 3 hr after the explosion gave values of 8,000 to 16,000 μg PCB/m^3. Thereafter, due to effective decontamination procedure and the cleaning and covering of the surfaces, the levels declined to less than 1 μg/m^3 120 days after the explosion. The concentration of PCB in the 10 kV and 3 kV contactor rooms declined in 3 weeks from the level of 200 μg/m^3 to the level of 10 μg/m^3 and from about 80 μg/m^3 to less than 1 μg/m^3, respectively. The concentrations of PCB in the main work areas declined from original values of 100 μg/m^3 to below 1 μg/m^3 after 9 days of intensive decontamination efforts.

Surface Contamination

Surface contamination was followed up initially by analyses of the concentration of PCB and its pyrosynthetic derivatives in the soot. During the course of decontamination, the efficiency of the clean-up operations was followed by determinations of the concentrations of PCB, tetrachlorodibenzofurans TCDF, and 2,3,7,8-TCDF in surface samples taken by sweeping the surfaces with a cotton swab moistened with ethanol. The soot and wipe specimens were analyzed with modifications of published methods (*3–5*). The concentrations of various pyrosynthetic products in the soot are indicated in Table 4.

Table 4. Concentrations of pyrosynthetic products in a soot specimen.

Fraction	Number of isomers in the sample	Concentration, μg/g
PCDFs		
Monochloro	3	80
Dichloro	10	250
Trichloro	10	200
Tetrachloro	20	20
Pentachloro	5	1
Pyrene and biphenylenes		
Monochloropyrenes	3	10
Dichloropyrenes	5	2
Dichlorobiphenylenes	3	50

It should be borne in mind that, although the analyses of PCBs and their pyrosynthetic derivatives have reasonably good accuracy and precision, the surface sampling procedure is very problematic: the concentrations may be very different even in specimens collected from closely located areas. The figures on surface specimens are thus at best semiquantitative. The concentrations of total TCDF at the focal point were 11,000 to 26,000 ng/m^2 one week after the explosion. Three weeks after the explosion, analyses of surface samples from the room adjacent to the focal point yielded the results found in Table 4. Six weeks after the explosion and after intensive cleaning, no TCDF or 2,3,7,8-TCDF was detected in two of three samples; traces were found in the third sample. No chlorinated dioxins were found in either the soot or the surface samples at any time.

Biomedical Studies

Approximately 1.5 hr after the explosion, 15 persons participating in the cleaning measures experienced acute symptoms that included nausea, irritation of the eyes and respiratory tract, vertigo, smarting of the skin, intensive sweating and headache. Ten persons were admitted to a local hospital, where the symptoms disappeared without treatment. The health of these 15 most exposed persons was monitored for 7 months. No clearcut long-term effects could be delineated. No chloracne was seen, but acne vulgaris became worse in one individual, one person showed increased skin pigmentation, and two developed nail ridges. Nine out of the 15 had at least one upper respiratory infection during the 7 months after the accident. Whether this represents lowered resistance is debatable.

Concentrations of PCB and TCDF in Serum

The method for determining the concentration of PCB in serum has been described by Luotamo and co-workers (*6*). The highest concentrations of PCB in the serum were 30 μg/L at 3 days after exposure in the subjects with acute symptoms (Fig. 2). The values returned to control levels ($\leq$ 3 μg/L) in 4 weeks. Great variation in the absolute serum concentrations were

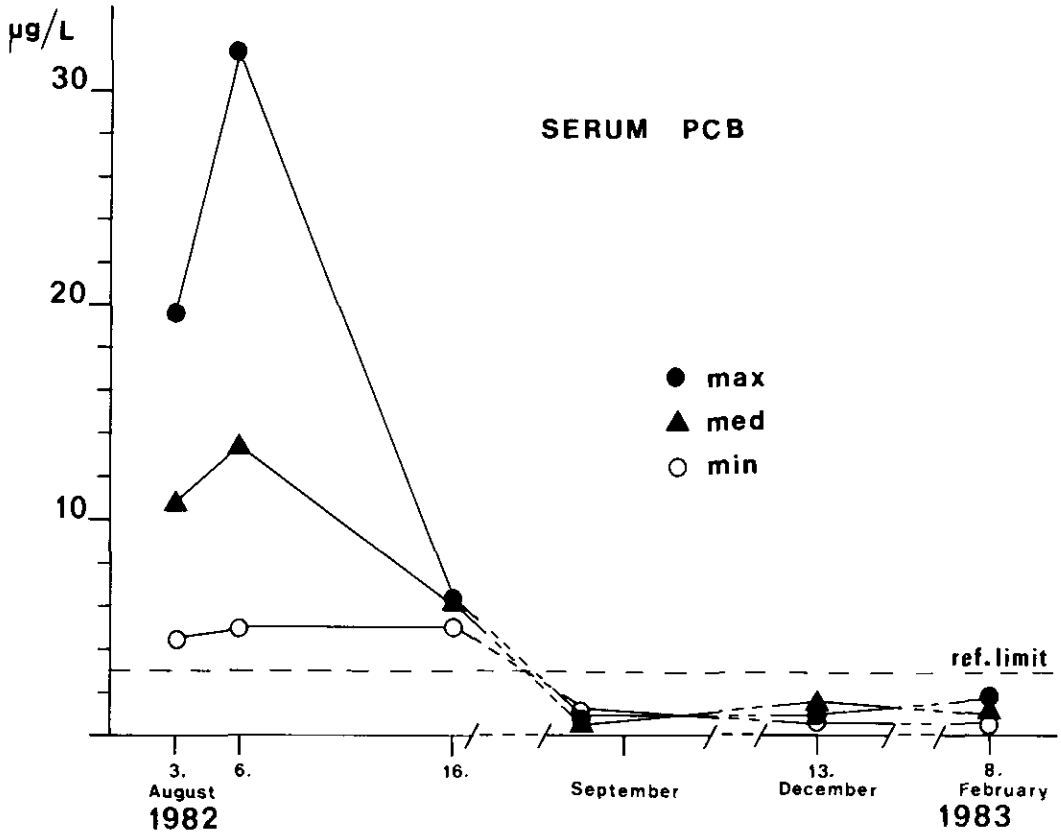

FIGURE 3. Blood PCB in µg/L (maximum, median and minimum) of the 15 most heavily exposed persons (n = 12–16, 0–189 days after the exposure). The variation in n depends on the differences availability of persons for specimen collection at various times of follow-up.

found, apparently due to differences in the exposure patterns and the biology of the subjects, e.g., the amount of the body fat. TCDF or TCDD values above the detection limit (0.15 µ/g) were not found in the blood of the exposed.

Clinical Chemical Studies

The serum activities of aspartate aminotransferase (S-ASAT = GOT), alanine aminotransferase (S-ALAT = GPT), glutamyltranspeptidase (gamma-GT), and alkaline phosphatase (S-AFOS) were determined. When compared to the same individuals' "basic" values (measured 36–64 days after the exposure), elevated activities were found for almost all exposed subjects, and the reference values of the Finnish population were exceeded for the serum activities of ASAT, ALAT, and gamma-GT in 8 of 16 persons. The increases in the serum activities of ASAT and ALAT were statistically significant ($2p < 0.05$ and $2p < 0.01$, respectively, with both Wilcoxon or the Student t-test). The rise in gamma-GT was not statistically significant ($2p < 0.1$). The use of alcohol could not explain all the detected effects (ALAT/ASAT ratio < 1 in six of eight cases with elevated enzyme activities). Thus it was concluded that the elevations were due at least in part to exposure to PCB and its derivatives.

Levels of serum cholesterol and triglycerides were determined 1 day and 1, 2, 4, 12, 19 and 27 weeks after the accident. Cholesterol showed a decrease at 1 to 2 weeks (26% in an average), whereas an increase was seen in the triglycerides (54% in average) at the same time. Both showed stable levels from the fourth week on.

Neurophysiological Findings

Maximal conduction velocities of the peripheral motor and sensory nerves were measured in the 15 acutely exposed subjects. The conduction velocities of the sensory fibers of *n. ulnaris* and *n. suralis*, and of the motoric fibers of *n. peroneus* were slightly and statistically significantly reduced. Six months later, the conduction velocities had recovered.

Immunologic Studies

No deviations were found in the immunoelectrophoresis of plasma proteins; the levels of complement components 3,4 and CI inhibitor were similarly normal. Cellular immune mechanisms were studied by determining the number of T-cells, and the T-helper/T-suppressor cell ratio; in addition, responses of T-cells to phytohemagglutinin, pokeweed mitogen and concanavalin A were studied.

The total number of T-cells was lowered in all

specimens studied 5 weeks after the incident; in four out of seven specimens, values were normal 7 weeks later. The T-helper/T-suppressor cell ratio was low (< 1.4) in six of seven specimens 5 weeks after the incident; in two persons it was not yet normal 6 months later. The response to phytohemagglutinin, concanavalin A and pokeweed mitogen was lowered in 4/10, 3/10 and 5/9 exposed persons 5 weeks after the explosion; at 6 months abnormal results were seen in 0/5, 1/5 and 0/5 persons.

Cytogenetic Studies

No statistically significant changes in the frequencies of chromosomal aberrations or sister chromatid exchanges (SCE) were found. A slight increase in the frequencies of SCE was found for smokers irrespective of exposure to PCB or its derivatives.

Other PCB Accidents in Finland

During the 1-year period from August 1982 to August 1983, the Institute of Occupational Health became aware of a total of 28 PCB accidents (Table 2). Two of them were explosions, one electric fire, and two external fires. The total number of persons potentially exposed was approximately 300. Two out of the 28 accidents were major explosions of capacitor banks. One of these was described more in detail above. In the other, PCB and 2,3,7,8-tetrachlorodibenzofuran were detected on three floors of a plating plant. In the ten primary specimens, the concentrations of 2,3,7,8-TCDF were 10, 12, 13, 20, 45, 80, 100, 3200, 3300 and 14000 ng/m^2. The highest concentrations were detected on the floors. The same tendency, high concentrations on the floors, seemed to hold true even for the concentrations of PCB. In this case, after one week's intensive clean-up, the concentration of 2,3,7,8-TCDF was less than 5 ng/m^2 in all 17 samples studied. No 2,3,7,8-TCDF was detected in three apples or four tree leaves collected in a nearby garden.

So far in Finland, no accident involving transformers has been seen; hence chlorodibenzodioxins have not been detected. The Ministry of Internal Affairs has located all major PCB-containing equipment in the country, and substitution has been started in locations deemed hazardous (plants manufacturing food, water treatment plants, hospitals). The fire brigades have been given information on ways of prevention, and management of PCB accidents.

The cytogenetic studies were performed in the Mutagenicity Laboratory (Dr. Marja Sorsa), the neurophysiological investigations in the Unit of Neurophysiology (Dr. A.-M. Seppäläinen), and the analyses of PCB in serum by Ms. Marita Luotamo, and in the air and surface specimens by Mr. L. Lindroos and Ms. P. Pfäffli of the Institute of Occupational Health. The analyses of chlorodibenzofurans and -dioxins were performed by Dr. S. Räisänen (Instrumentation Center of Chemistry, University of Helsinki), A. Hesso (Institute of Occupational Health), and Dr. C. Rappe of Umeå University, the cell-mediated immunology tests by Drs. E. Taskinen and R. Renkonen of the Transplantation Laboratory of the University of Helsinki. The Finnish Work Environment Fund has financially supported this study.

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