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Quantitative risk assessment in relation to occupational exposure to polychlorinated biphenyls in the removal of old sealants from buildings

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Quantitative risk assessment in relation to occupational exposure to polychlorinated biphenyls in the removal of old sealants from buildings

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Objectives The objectives of the study were to assess exposure to polychlorinated biphenyls (PCB) among workers involved in the removal of old sealants containing PCB and to evaluate the related long-term health risks by means of quantitative risk assessment.

Methods Workers' exposure via different exposure routes was estimated from air and material samples and exposure calculations. The health risks were evaluated using unit risks and a reference dose based on animal tests and evaluations made by the Environmental Protection Agency in the United States.

Results The estimated exposure of the workers was higher than that of the general population. It was about 10-fold higher than the reference dose and average dietary intake (both 0.02 µg/kg-day). The calculated point estimate of excess cancer risk was 4.6×10^{-4} cancer cases per lifetime.

Conclusions The estimated excess cancer risk among workers was low, although the PCB exposure of these workers was higher than the dietary intake of the general population. This quantitative risk assessment method can be used to evaluate the health risk of groups of workers by occupational health professionals.

Key terms cancer.

Polychlorinated biphenyls (PCB) are persistent organic compounds with known detrimental health and environmental effects. They are carcinogenic in humans (1), and they can negatively affect the human reproductive and immune systems (2–4). PCB probably cause liver cancer and non-Hodgkin's lymphoma in humans (1–3). The acute toxicity of PCB compounds is, however, generally low. Some nonortho and mono-ortho PCB congeners (coplanar PCB) have dioxin-like effects, and toxic equivalency factors (TEF) have been set for 12 PCB congeners (5). Food, especially fatty fish, is still the major source of PCB in the general population (2, 3, 6). In Finland, the average dietary daily intake of PCB was estimated to be about 1.5 µg/day in the 1990s (7), and in Sweden it has been estimated to be about 3 µg/day (8).

Elastic polysulfide sealants containing PCB were commonly used in Finnish prefabricated residential buildings between 1959 and 1975 (9). PCB were used as plasticizers, and their content in sealants was normally between 5 and 20 weight-%. A large building can contain up to 100 kg of PCB (9, 10). It has been estimated that 220 tonnes of PCB were used in prefabricated buildings in Finland in 1959–1975 (9). The PCB used in these sealants were mainly 54% or 60% chlorinated PCB (10–12), like Aroclor 1254 and 1260. They contain mainly tri-, tetra-, penta-, hexa- and hepta-chlorinated PCB congeners, and their content of coplanar (dioxin-like) PCB is low. The possible PCB exposure originating from these sealants was first noted in Germany as an indoor air problem, and guidelines were issued to control the exposure of residents in the buildings in question (13, 14). In Finland, however, PCB sealants were used almost exclusively in outdoor seams between element blocks, where they can cause both environmental pollution and occupational exposure to remediation workers. This problem did not become general knowledge in Finland until 1997–1998.

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PCB plasticizers were replaced by chlorinated paraffins in the mid-1970s, and later in the 1980s polysulfide sealants were replaced by one-component polyurethane sealants (PU foam). During the removal of old sealants, workers can be exposed to PCB via inhalation, the skin, and hand-to mouth transferral. Remediation work normally includes the following four phases: (i) the removal of old sealant by a knife or other tool, (ii) the grinding of the old seam with a hand grinder, (iii) the application of a primer to the ground surfaces, and (iv) the installation of new PU-foam sealant. Workers are exposed to PCB-containing dust especially while grinding the old PCB-contaminated seam. The dust contains approximately 0.4% PCB (11). Inhalation is generally considered the main exposure pathway. Because of this potential exposure, workers normally wear personal protective equipment (filtering and motorized respirators, gloves, helmet) and protective clothing (overalls).

It has been estimated by the Finnish union of facade entrepreneurs that about 150–300 workers are involved annually in the removal and replacement of concrete element sealants. In Finland this work is carried out normally between April and November due to the cold winter conditions. Little information is available on the occupational exposure of these workers, and so far only one published study has dealt with occupational PCB exposure among remediation workers (11).

Quantitative risk assessment has been commonly applied to assess the health risks of residents in contaminated areas and buildings. The Environmental Protection Agency (EPA) in the United States and other organizations (15–18) have issued detailed instructions for risk assessments in such cases. These methods are based on exposure assessments and unit risks or reference doses (15–18). All exposure routes and scenarios are normally evaluated and the lifetime average daily dose (LADD) is calculated. Risk is obtained by multiplying the LADD by unit risk (slope factor). A linearized multistage model is the most common approach although other models can also be used. Unit risks are calculated on the basis of animal tests or epidemiologic studies. Quantitative risk assessment is generally suitable for the evaluation of long-term chemical exposures and risks. This study is one example of the application of such assessment to long-term chemical exposure and a group of workers. Occupational health professionals can benefit from risk calculations because they give quantitative estimates of the magnitude of chemical risks.

The main objectives of this study were (i) to determine and calculate workers' PCB exposure during the removal of old PCB-containing sealants and (ii) to quantify the long-term health risks of workers as a result of this PCB exposure.

Material and methods

Studied worksites

Measurements were carried out at nine renovation sites. Personal samples were taken from the breathing zone of 14 workers. Grinding normally covered 1–4 hours of worktime daily.

About half of the surveyed workers used Tyvek™ or other disposable overalls. Most of the workers used air-filtering respirators with P2 or P3 filters or powered air respirators (Proflow or Autoflow, Scott Health & Safety Ltd, Vaasa, Finland). The workers used mainly leather or textile gloves during the work. The grinding wheels were equipped with local exhaust units.

Sampling and analytical methods

Twenty-seven elastic sealant samples were taken from nine buildings and analyzed for their PCB content. The total PCB and 10 individual PCB congeners were determined. The congeners were PCB 28, 52, 77, 101, 118, 126,138, 153, 169, and 180. The most toxic PCB include the following nonortho congeners: PCB 126 (TEF 0.1), PCB 169 (TEF 0.01) and PCB 77 (TEF 0.0001). Total PCB was calculated by comparing the sample with corresponding Aroclor 1260 or 1254 mixtures.

The sampling and analytical procedure were as follows: PCB was sampled from the breathing zone of the workers (outside their masks) using OVS-2 sampling tubes (SKC cat no 226–30–16, Eighty Four, PA, USA) and personal sampling pumps (SKC Inc, Eighty Four, PA, USA) with a flow rate of about 2 l/min. The OVS-2 sampler contains both a glass fiber filter and a XAD-2 resin section, and it collects both particulate and gaseous PCB. The OVS-2 sampler is recommended for PCB by the Occupational Safety and Health Administration (OSHA) in the United States (19). The sampling time varied from 15 to 350 minutes and covered the removal of old sealant and the grinding of old seams to remove traces of old sealant-containing PCB.

PCB were extracted with hexane in an ultrasonic bath. The PCB concentration was determined using a gas chromatograph connected to electron capture or mass selective detectors (12, 13, 19).

Exposure and risk calculations

The LADD is the average daily dose (by all exposure routes) per kilogram of body weight during a 70-year lifetime. LADD was calculated using the following formulas:

inhalation exposure
$LADD_{inh} = CA \times BR \times ABS \times FW \times EF \times ED / (BW \times LF)$;

dermal exposure
$LADD_{dermal} = CS \times SA \times AF \times ABS \times EF \times ED \times CF / (BW \times LF)$;

ingestion:
$LADD_{ing} = CS \times IR \times ABS \times EF \times ED / (BW \times LF)$,

where LADD = lifetime average daily dose (mg/kg-day), CA = concentration of PCB in air (mg/m^3), BR = inhalation volume (normally 10 m^3/8-hour workday), ABS = absorption factor (unitless), FW = fraction of workday (8 hours) with exposure, EF = exposure frequency (fraction of year), ED = exposure duration (years), BW = body weight (kg), LF = lifetime (years), CS= concentration in dust or soil (mg/kg), SA = skin area available for contact (cm^2/event), CF = conversion factor (10^{-6} kg ->mg), AF = soil-to-skin adherence factor (mg/cm^2), and IR= ingestion intake rate (mg/day).

The carcinogenic risk was calculated using the following basic equation

$Risk = LADD \times CSF$,

where CSF = slope factor (per mg/kg-day).

The preceding equation is based on a linearized multistage model, and the slope factor for the carcinogenic risk was obtained from the IRIS database (4).

Noncarcinogenic risks normally have a threshold dose or concentration. They are normally evaluated by comparing the calculated exposure to a given reference dose or acceptable daily intake. This ratio is called the hazard quotient (18). If the hazard quotient exceeds 1, some risk possibly exists.

Results

Materials and sealant samples

The PCB profile of the studied samples closely resembled that of Aroclor 1260 in most cases. For two of nine buildings, the profile was closer to that of Aroclor 1254. The major congeners found in the samples were PCB 101, 138, 153, 180 (Aroclor 1260 type) and PCB 52,101, 138, 118, 153 (Aroclor 1254 type). The congener distribution and concentrations and total PCB levels are given in the table 1.

PCB spread as dust particles rather than as a vapor, and the congener pattern was similar to that determined for the equivalent sealant.

In addition to the PCB, the polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran (PCDD/F) content of the samples was determined. PCDD/F are present in PCB as impurities from the manufacturing process. The four studied sealant samples mainly contained penta-, hexa- and heptachlorinated furans. The total PCDD/F content of the sealant samples was between 0.7–4.3 mg/kg and 10–350 µg /kg in I-TEQ units.

The PCB levels measured in the breathing zone of the workers is given in table 2, as are the total inhalable dust levels.

Exposure routes

Inhalation has been considered a major exposure route of PCB in occupational environments, especially if respiratory protection is not used. Dermal exposure is also possible if PCB-containing dust or sealant surfaces come in contact with skin. We estimated that, during the work, one such contact occurs daily. The cleaning of the vacuum cleaner connected to the grinding wheel involves the risk of both inhalation and dermal exposure. The significance of dust ingestion (hands-to-mouth access and dust settled in upper airways) is difficult to evaluate. It is probably small, but not zero.

Exposure and risk calculations

The used exposure parameters and their origins are presented in table 3.

The inhalation exposure (without a mask) was calculated as $LADD_{inh} = 0.026\ mg/m^3 \times 1 \times 10\ m^3/8\ hours \times (4/8\ hours) \times (100/365\ days\ in\ year) \times 15\ years/(70\ kg \times 70\ years) = 1.1 \times 10^{-4}\ mg/kg\text{-}day = 0.11\ \mu g/kg\text{-}day = 7.6\ \mu g/day$.

The dermal exposure was determined to be $LADD_{dermal} = 4000\ mg/kg \times 10^{-6}\ kg/mg \times 360\ cm^2/event \times 0.52\ mg/cm^2 \times 0.06 \times 1/day \times (100/365) \times 15\ years/70\ kg \times 70\ years = 3.7 \times 10–5\ mg/kg\text{-}day = 0.037\ \mu g/kg/day = 2.6\ \mu g/day$.

Table 1. Total polychlorinated biphenyl (PCB) and selected congener concentrations of the studied 27 sealant samples.

Determined compound	Mean (mg/kg)	Standard deviation (mg/kg)	Range (mg/kg)
PCB 28	82	106	<1–239
PCB 52	3 030	3 907	230–10 400
PCB 77 (coplanar)	37	77	<2–262
PCB 101	10 325	7 096	2400–24 100
PCB 118	6 145	7 325	590–17 100
PCB 126 (coplanar)	42	71	<1–190
PCB 138	11 765	3 209	4 900–15 600
PCB 153	11 185	4 676	3 560–23 200
PCB 169 (coplanar)	32	66	<1–170
PCB 180	7 254	3 581	1 510–14 000
Total PCB	163 150	70 365	60 000–300 000

Table 2. Total dust and polychlorinated biphenyl (PCB) concentrations measured in the breathing zone of the workers during the removal and grinding of old sealants.

Measurement	Number of measurements	Median (mg/m^3)	Range (mg/m^3)
Total dust	16	6.4	<0.1–309
Total PCB [a]	16	0.026	0.006–0.803

[a] Calculated as Aroclor 1260 or Aroclor 1254.

Table 3. Used calculation parameters. [PCB = polychlorinated biphenyls, CS =concentration in dust or soil (mg/kg), CA = concentration of PCB in air (mg/m^3), FW = fraction of workday (8 hours) with exposure, EF = exposure frequency (fraction of year), ED = exposure duration (years), SA = skin area available for contact (cm^2/event), AF = soil-to-skin adherence factor (mg/cm^2), ABS = absorption factor (unitless), IR= ingestion intake rate (mg/day), US EPA = United States Environmental Protection Agency]

Parameter	Used point estimate	Range	Reference
PCB concentration of dust (CS)	4000 mg/kg	100–11000 mg/kg	Sundahl et al, 1999 (11); Rantio et al, 2001 (12)
PCB concentration in air during grinding (CA)	0.026 mg/m^3	0.0005–0.803 mg/m^3	Rantio et al, 2001 (12)
Exposure duration			Observation/this study
Fraction of day (FW)	4/8 hours	1–8 hours	
Days/year (EF)	110/365 days	10–180 days	
Work years (ED)	15 years	1–45 years	
Exposed palm area / event (SA)	360 cm^2		US EPA, 1992 (21)
Adherence to skin (AF)	0.52 mg/cm^2		Finlay et al, 1994 (20)
Absorption factor / skin (ABS)	0.06	0.01–0.06	US EPA, 1992 (21)
Absorption factor (ABS) / ingestion of dust, inhalation	1		Worst case assumption
Ingestion of soil or dust (IR)	50 mg/day (adult)		US EPA, 1997 (16)

Table 4. Comparison of exposure with reference dose (RfD) given for Aroclor 1254 by the United States Environmental Protection Agency.

Exposure route	Exposure (µg/kg-day)	Hazard quotient [a]
Inhalation without mask or respirator	0.076	3.6
Inhalation with mask (estimated protection factor 10)	0.008	0.4
Dermal	0.037	1.9
Ingestion	0.084	4.2
All routes (sum)	0.230	11

[a] Exposure/reference dose.

Exposure through ingestion was $LADD_{ing}$ = 4000 mg / kg × 10–6 kg / mg × 50 mg / day × 0.5 × 100 / 365 × 15 years / 70 kg × 70 years = 8.4×10^{-5} mg / kg-day = 0.084 µg / kg / day = 5.6 µg / day.

The used exposure factors and their sources are presented in table 3.

The sum of the exposure estimates was 2.3×10^{-4} mg/kg-day = 0.23 µg / kg-day. The estimated current dietary exposure to PCB was estimated to be about 1.5 µg / day = 0.021 µg / kg-day. Thus this occupational exposure estimate exceeded the dietary intake by about tenfold.

When the EPA cancer slope factor (2 kg-day / mg) was applied, the risk estimate was determined to be 2 × $2.30 \times 10^{-4} = 4.60 \times 10^{-4}$ cancer cases / lifetime. Although the risk was clearly higher than that of the general population, it was, nevertheless, so low that no liver cancer cases would probably be noted among a group of 150–300 workers.

Noncancer effects

Other effects cannot be especially attributed to dioxin-like PCB. We compared the occupational exposure with the reference dose (RfD) presented by the EPA for Aroclor 1254 (22), the RfD being based on a lowest observed adverse effect level (LOAEL) of 5 µg / kg-day (immunological effects in monkeys) and a safety factor of 300. The results are given as hazard quotients (quotients calculated from RfD = 0.02 µg / kg-day) in table 4.

Discussion

Uncertainties of the exposure assessment

The inhalation of PCB-containing dust, together with its ingestion, is generally considered the main route of exposure to PCB, and also in our calculations it was the most important exposure route, if respirators are not used. It is very difficult to estimate the possible ingestion of PCB-containing grinding dust. The most important estimate found by us was the EPA estimate of 50 mg/day for industrial or commercial environments. This value has, however, been considered to be an overestimate, although also higher estimates for this parameter have been suggested (23).

All the air samples were taken from the breathing zone outside the mask of the workers. Inhalation exposure is, however, reduced by at least a factor of 10 when respirators are worn appropriately during dusty work operations (European standards EN 141–143). Thus our risk calculations probably overestimated the exposure and risk. The calculated hazard quotient was less than one only for the inhalation route when respiratory protection was used during the removal of old sealant.

Very little is known about the bioavailability of PCB from concrete dust. We have used the worst case estimate and assumed the intake to be 100% due to the lack of better information. Our dermal absorption factor of 0.06 was based on the findings of a study with a single PCB compound (2, 21).

Calculation of the carcinogenic risk

There are major problems with risk calculations based on the results of animal carcinogenicity tests, for example, the interspecies variation in metabolism, sensitivity and the like, and the needed extrapolation from the high doses used in animal tests to low doses in actual situations. In the case of PCB, which is probably a promoter rather than a direct carcinogen, a threshold limit possibly exists, and linear extrapolation is not necessarily justified. However, linear extrapolation is used by most risk assessors and governmental bodies.

Acceptability of risk

In general, risks of 10^{-5} to 10^{-6} are accepted in public health contexts. However, in work environments, much higher risks are generally accepted, and a smaller uncertainty factor is normally applied. If the old Finnish occupational exposure limit for PCB inhalation, namely, 0.5 mg PCB/m^3, is accepted for daily inhalation exposure for 45 years (inhalation 10 m^3/day), it indicates cancer risk of about 5×10^{-2}, which is considered very high. The Occupational Safety and Health Administration in the United States has used a risk level of 10^{-3} as acceptable for carcinogens (24).

The estimated occupational exposure of our study exceeded the reference dose given for Aroclor 1254 type PCB. The used reference dose was calculated with the use of a safety factor of 300. The estimated exposure of the workers did not, however, exceed the original LOAEL of 0.05 mg/kg-day obtained from animal tests on monkeys (22).

Comparison with dietary intake

The average dietary intake of PCB in Finland is estimated to be about 1.5 µg/day, which is about 0,02 µg/kg-day (7). Fatty food, and especially fish (salmon, Baltic herring) from the Baltic Sea, are considered to be the main sources. If the average daily intake is expressed in micrograms per kilogram, it is roughly on the same level as the reference dose of 0.02 µg/kg-day issued by the EPA for Aroclor 1254 (22). The calculated lifetime average daily dose of 0.23 µg/kg-day (all routes) exceeds the average dietary intake by about tenfold. This finding is consistent with that of the biomonitoring study of the same workers (serum PCB), which showed 3–4 times higher PCB levels for the workers than for the general population (12).

Concluding remarks

The following conclusions can be drawn from our study. The PCB exposure of remediation workers exceeds that of the general population by about tenfold. The calculated excess cancer risk (lifetime excess cancer risk of 4.6×10^{-4}) is, however, considered "acceptable" in occupational exposure contexts even though it is not accepted for public health purposes. The PCB exposure of the workers in our study exceeded the EPA reference dose for Aroclor 1254 by about tenfold. The PCB exposure was also higher than the average dietary intake of the Finnish population in the 1990s. Quantitative risk assessment enables the estimation of small risk levels that are difficult to obtain with epidemiologic methods. Risk calculations are cheap when compared with the costs of epidemiologic studies, but, at the same time, they should not be considered alternatives. The quantification of risks helps safety personnel, occupational health professionals and workers deal with exposure to hazardous substances.

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