DEVELOPMENT OF A JOB EXPOSURE MATRIX (JEM) FOR FORMER WORKERS IN CAPACITOR MANUFACTURING

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Introduction

Polychlorinated biphenyls (PCBs) were used as a dielectric fluid in the manufacture of capacitors from the early 1930s until they were banned in the US in 1978. Capacitor manufacturing began with winding bales of foil, paper, or plastic film in a clean, dust-free room. The bales were placed in a metal capacitor box (pre-assembly), and trays of these pre-fabricated capacitors were placed in a vacuum chamber for impregnation (flood-filling) with the dielectric fluid (PCB). Excess PCB was drained after the filling-cycle, and wet capacitors were transported to a sealing station where ports were soldered shut. Large capacitors, requiring several gallons of dielectric fluid, were filled manually through ports on the top of the capacitor and then loaded into an oven. Finally, the capacitors were degreased, leak tested, and painted. Commercial PCB brands were mixtures, using about 100 to 150 of the 209 possible congeners. The potential for adverse human health effects from PCB exposure has been examined in epidemiological studies but the results are inconsistent.[1-4] One potential explanation is the lack of detailed exposure assessments. A job exposure matrix (JEM) categorizes groups of workers who share common exposures and accounts for differences in exposure across jobs.[5-13] The carcinogenicity of PCBs is being investigated in several National Institute for Occupational Safety and Health (NIOSH) cohort studies. The purpose of this work was to develop a period-specific JEM for a cohort of capacitor manufacturing workers (n=3600) who worked with PCBs from 1957 until 1977.

Methods and Materials

The JEM resulted from a detailed exposure assessment for this plant and was based on a number of exposure determinants in addition to proximity to the impregnation ovens. For this study, records were reviewed for factors such as proximity to PCB sources, particularly impregnation and repair of faulty capacitors with PCB oil; the intensity, frequency and duration of exposures by job; and the potential for exposures via dermal uptake and inhalation. Records providing the layout of the plant and location of each job were used to estimate distances from PCB sources. Detailed information about the capacitor manufacturing process at the plant, including process temperatures, which affect volatility, and the composition of the PCB mixtures in use at the plant, was available and incorporated into the JEM. Detailed job descriptions for each of the hourly job titles were used to assess PCB exposure intensity for both inhalation and dermal uptake for each job. In addition, the job descriptions provided frequencies of some tasks and activities and sources of other chemical exposures, such as degreasing with trichloroethylene. In developing exposure categories these additional exposures were also considered, in addition to known industrial hygiene changes that were made during the plant's production period (1957 – 1977). Also, a change in PCB mixture occurred during this time period. These factors; proximity, exposure intensity, frequency, duration, exposure routes, additional chemical exposures, and PCB composition contributed to the development of the JEM.

The JEM was developed in four steps: (1) all job codes (n=884) were assessed for exposure determinants such as activities, mobility, and plant location, (2) jobs with similar exposure determinants were categorized together, resulting in 19 categories, (3) for each category, exposure intensity (high-medium-low-background) and frequency (continuous-intermittent) were qualitatively rated separately for inhalation and dermal exposure, and (4) for each category, the product of intensity (assigned based on the air sampling data) and frequency (fraction of day exposed) was calculated. The JEM was then modified for two eras of stable PCB type exposure conditions.

Results and Discussion

Qualitative PCB exposure intensity levels for each of the 19 categories were assigned using several exposure determinants (Table 1).

Table 1 Quantitative job exposure matrix for employment at a U.S. electrical capacitor manufacturing plant (1957 – 1977)

Job category		Inhalation (μg/m^3)				Dermal (*unitless*)				Total exposure
		FREQ[A]	INT[B] 1°	INT[B] 2°	EXP[C]	FREQ	INT 1°	INT 2°	EXP	
1	Salvage and repair	I	H	M	185	C	H		230	415
2	Fill, solder, and impregnate	C	H		230	C	H		230	460
3	Leak tester	I	H	M	185	C	H		230	415
4	Maintenance	I	L	B	27.5	I	M	L	95	122.5
5	Recloser	C	L		50	C	L		50	100
6	Research and development	I	L	B	27.5	I	M	L	95	122.5
7	Checker/receiving/packer/shipping/stock	I	L	B	27.5	I	M	L	95	122.5
8	Material handler/driver/process control	I	M	L	95	C	M		140	235
9	Inspectors and testers	C	L		50	C	L		50	100
10	Pre-assembly	C	L		50	C	L		50	100
11	Arresters	C	L		50	C	L		50	100
12	Welding, braze and solder	C	L		50	C	L		50	100
13	Boiler	C	B		25	C	B		25	50
14	Set-up and/or operate wet machines	C	L		50	C	L		50	100
15	Set-up and/or operate dry machines	C	L		50	C	L		50	100
16	Electroplating, metal oxide processing	C	L		50	C	L		50	100
17	Film, winding	C	L		50	C	L		50	100
18	Post-assembly	C	L		50	C	M		140	190
19	Salary	C	B		25	C	B		25	50

[A] FREQuency of exposure (I = intermittent, C = continuous);

[B] INTensity of exposure (1° = primary, 2° = secondary; H = high, M = medium, L = low, B = background).

[C] EXPosure level was calculated using weights of 230 for high, 140 for medium, 50 for low, and 25 for background. For continuous exposure, the full workday was assigned to the primary intensity level. For intermittent exposures, half of the workday was assigned to the primary intensity level and the remaining half was assigned to the secondary intensity level. For example, for category 1, inhalation exposure was rated as 'intermittent – high', so the inhalation exposure level was assigned 0.5×230 + 0.5×140 = 185 μg/m^3; similarly, dermal exposure was rated as 'continuous – high', so the dermal exposure level was assigned 1×230 = 230 units. Exposure levels for employment in the first half of the production period (October, 1957 – December, 1967) were estimated to be 20% higher.

First, the extent of exposure due to source output strength and worker proximity to the source was determined. Second, the likelihood of exposure to PCB vapors (e.g. definitely/possibly) was assessed based on known ventilation considerations. Third, the exposure could be to different physical states of PCB (e.g. vapor / liquid / contaminated dust). These exposure determinants defined the intensity of exposure for each category. The scale used to rate intensity was high, medium, low or background exposure level. The frequencies or the patterns of exposure were assigned as continuous or intermittent. The available air concentration measurements were associated with the 19 job categories. Available PCB air concentration measurements, both personal and area, were used in conjunction with knowledge of the exposure patterns of the categories assignments, resulting in 50, 140, 230 μg/m^3 for low, medium, high respectively, and a background level of 25. These concentrations were used for the cumulative exposure calculations.

Since the ratio between inhalation and dermal uptake of PCBs cannot be assessed, we set the ratio to 1, e.g. non-differential weight between the two exposure pathways. For both inhalation and dermal exposure intensity was multiplied by frequency and summed. Cumulative exposure calculations based on work histories first multiplied the number of days worked multiplied by the appropriate category exposure level, and exposure summed across all jobs in the work history. The Pearson correlation coefficients between the cumulative exposure estimates and duration of employment at the plant as a proxy for exposure were r=0.68 for inhalation, r=0.71 for dermal, and r=0.70 for combined inhalation and dermal exposure (Figure 1).

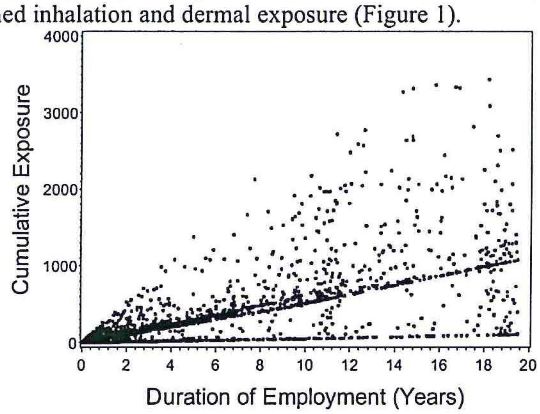

Figure 1 Scatterplot of cumulative exposure (unit year) for the combined exposure (inhalation : dermal, 1:1) versus duration of employment (years).

Duration of employment is often used as a proxy for exposure in epidemiologic studies, although it is often an inadequate surrogate for exposure and a likely source of exposure misclassification bias leading to underestimation of any associated health effects and a distortion of the exposure-response relationship.[14] Insufficient industrial hygiene data, a common problem in retrospective studies, was also a problem for this assessment, since industrial hygiene data was only available from 1975 and 1977, at the end of the time period during which PCBs were used at the plant.[15-17] The most important restricting factors in retrospective exposure assessment are the availability and quality of data on exposure levels and work histories. Even when direct data on exposure are incomplete, it is often possible to infer the existence and/or the level of exposure on the basis of available data. The major limitation of this JEM is that manufacture of PCB-filled capacitors no longer exists and validation measurements could not be made. Possible misclassifications cannot be ruled out when categorizing 884 different jobs into 19 categories. The quality of the exposure estimates are expected to improve with this JEM because it includes clear contrasts of exposure (e.g., heavy exposure vs. definite non exposure) [18] and also provides semi-quantitative exposure estimates for all jobs.

Conclusion

The JEM will be linked with work histories to develop individual cumulative PCB exposure estimates for use in assessing risk of cancer mortality and incidence in this cohort. These exposure estimates, derived from a more systematic and rigorous use of the exposure determinant data, should lead to improved accuracy of the risk estimates.

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