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Industrial hygiene summary report for workers exposed to polychlorinated biphenyls (PCBs) in a capacitor manufacturing plant (plant 3; 1958-1977)

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Abstract

This industrial hygiene summary report summarizes available information about workers who manufactured polychlorinated biphenyl (PCB) filled capacitors at plant 3. Production started in October 1957 and ended in March 1977. Complete work history records for 3,603 workers were microfilmed in March 1977 and 40 personal and 16 area air samples were collected for the evaluation of PCB exposures (NIOSH survey 1977). 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 with the dielectric fluid (PCB). 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. Impregnation involved placing the capacitor trays in the oven under vacuum to remove moisture, flood-filling the ovens with PCBs, and then heating the PCB oil to a less viscous state. After this soaking cycle the excess PCB was drained and pressure was re-instated before the warm, wet capacitors were transported to a sealing station. Here the ports were soldered shut (post- or final assembly) and the capacitors were degreased before they were sent off to be leak tested and painted. Changes in the physical plant layout were minor enough to assume little effect on exposure scenarios throughout the PCB operation years. Use of industrial PCB mixtures changed within the time period PCBs were used at this plant. A commercial PCB mixture such as Aroclor 1242 was used from 1957 through 1971 and Aroclor 1016 from 1971 until the dielectric fluid was replaced in 1977. The two mixtures differed in distribution of the chlorination of the congeners, although the average chlorination for Aroclor 1242 and Aroclor 1016 was 41-42%. PCBs vaporized due to the heat from the ovens, and either condensed and settled on surfaces or the vapors adsorbed directly to surfaces within the facility, providing exposure opportunity to workers in the plant whose job tasks did not involve direct contact with liquid PCBs. Other sources of PCB exposure during manufacture of the capacitors were in the leak testing, repair and salvage, and degreasing areas. Dermal exposure intensities were assigned based on opportunity for contact with PCB liquids, job

location, total usage, and other task activities. Local exhaust ventilation was provided for soldering and welding operations and dilution ventilation operated throughout the plant. Overall there were 884 known job codes: 331 salaried and 553 hourly. Detailed job descriptions for all 553 hourly job codes were obtained. The job descriptions included information on how tasks were performed, and what chemicals were used. These jobs were categorized into 19 similar exposure groups. The categories were ordinally ranked on inhalation and dermal exposure separately. The values for the inhalation exposures were derived from the air concentrations measured at the plant in 1977. There was a potential for significant dermal exposure for some jobs. Dermal exposures were rated separately for each job and each category. Dermal exposures were rated in the same general magnitude as inhalation exposures. Both inhalation and dermal exposure estimates were used to develop a combination JEM.

Chapter 1 Westinghouse

Westinghouse Electric Corporation in Bloomington Indiana (the largest town in Monroe County) manufactured polychlorinated biphenyl-filled capacitors beginning in 1958. The brands of polychlorinated biphenyls (PCB) used were predominantly Aroclor 1242 and Aroclor 1016 (42% and 41% chlorine by weight, respectively). The plant had been in existence since 1957, but began operation in 1958 as part of the Distribution Apparatus Division. Prior to 1958 [1934-1958], the operations were located in East Pittsburgh, Pennsylvania (NIOSH Survey, 1976). The main products of the Bloomington plant were shunt capacitors, series capacitors, lightning arresters, reclosers and breakers, switches, potential devices and line traps. (NIOSH Survey, 1977). Two new areas were added to the original facility in 1968. Both areas, the Engineering Lab and the Materials Lab were non-production areas. In 1977 there were 720 workers employed at the Indiana plant (NIOSH, 1977). Only the capacitor manufacturing operation used PCBs. They were used as a dielectric fluid from the opening of the facility until late in 1977 (Smith et al. 1982; Sinks et al., 1992).

Capacitors not meeting quality control specifications were disposed of in three landfills in Monroe County. Since draining the dielectric fluid from these capacitors was very labor intensive they were discarded without being drained (ATSDR, 1992).

After the manufacture and commercial distribution of PCBs were banned by the U. S. Environmental Protection Agency (EPA) in 1978, the manufacturer began using isopropyl biphenyl as the dielectric insulating fluid.

The rationale making a specialized JEM for Westinghouse

In earlier NIOSH PCB studies duration of employment was used as a proxy of exposure dose (Brown and Jones, 1981, Brown, 1987); others have used the distance from the ovens as a proxy of exposure dose (Sinks *et al.*, 1992). We believe that if exposure determinants such as opportunity for direct exposure with liquid PCBs, air sampling measurements for specific job titles, and degree of chlorination of PCB (which is known by era) could be incorporated into the estimation of exposure dose then this would give a better exposure estimate for the workers. In addition, the exposure estimated for specific job titles by era would be combined with individual work histories and serum concentrations, where available, to estimate individual exposures.

Background for this study

Sinks *et al.*(1992) is the most recent retrospective cohort study among workers in a capacitor manufacturing plant who were potentially exposed to Aroclor 1242 and Aroclor 1016. Mortality through June 30, 1986 was studied among 3588 individuals (2742 males and 846 females) who worked at the Bloomington, Indiana plant for a minimum of one day between January 1, 1957 and March 31, 1977 (Sinks *et al*, 1992). When exposure status was not considered, there was an increased risk for mortality due to melanoma and brain cancer, but these deaths did not have a clear relationship with latency or duration of employment. One potential problem with this study is that the exposure weighting scheme was rudimentary and have introduced misclassification. The primary purpose of this study is to investigate whether mortality increased risks for brain cancer and malignant melanoma previously observed among workers with occupational exposure to polychlorinated biphenyls (PCBs) will remain elevated with an additional 12 years of follow-up data (Sinks, 1992). This study also will examine the effects of PCBs on all cause mortality, especially all neoplasms, rectal cancer and liver, biliary tract, and gall bladder cancers, conditions for which some previous cohort studies indicated increased risks (Brown, 1987; Brown and Jones, 1981). Cancer incidence studies using both registry data (all cancers) and worker interview data (breast cancer) are also under way.

Table 1 Study design of PCB mortality studies among electrical capacitor manufacturers

First Author	Brown1 (1981)	Brown2 (1987)	Taylor (1988)	Sinks**(1992)
No. Subjects	2,567	2,588	6,292	3,588
Male	1,258	1,270	3,601	2,742
Female	1,309	1,318	2,691	846
No. Deaths	163	295	510	192
Male	83	141	355	?
Female	80	154	155	?
Person Years	39,018	55,543	122,783	72,010
Male	17,054	25,053	68,505	
Female	21,964	30,492	54,278	n/a
Min. Period Employment	3 months	3 months	3 months	1 day

Employment Period	1940 to 1976	1940 to 1977	1946 to 1975	1957 to 4-1-77
Study Period	1940 to 1-1-76	1940 to 1-1-83	1946 to 1980	1957 to 7-1-86
Workers selected for study	Highly Exposed	Highly Exposed	All ranges	all ranges

Table 2 Relative* Risks of Mortality in PCB Studies among Electrical Capacitor and Transformer Manufacturers

Cause of Death	**Brown and Jones**	**Brown**	**Taylor Male**	**Taylor Female**	**Sinks**
All Cause	89 76-104	93	83 74-92	84 71-98	70 60-80
All Cancers	89 63-122	76	83 64-105	110 85-140	80 60-110
Rectum	336 92-860	211	173 47-444	235 47-666	80 0-450
Liver, Biliary Tract, Gall Bladder	280 58-820	263	133 15-480	90 1-500	110 0-640
Skin			98 11-355	100	410 180-800
Brain			30 0-165	0	180 60-420
Lymphomas	46	68	0	0	100 40-200
Urinary Bladder, Kidney		143	0 184	--- ---	
Prostate			110 30-281		

*Relative to the general population (adjusted for gender, race, age, and calendar era)

The method of exposure assessment used in the original relative mortality risk study performed by Sinks *et al.* (1992) was based on duration of employment in specific jobs which were judged to include direct exposure to PCBs. These jobs included impregnation, sealing and testing capacitors. The classification of these jobs as high exposure was supported by personal and area air sampling.

Published Westinghouse industrial hygiene articles by other authors

In addition to Sinks (1992), there are several NIOSH reports

1975. A survey was conducted in 1975 (NIOSH, 1975) in the Large Rotating Apparatus Division (LRA), section D-12; construction of the generator. This construction process involved the use of epoxy resins, and soldering. Workers had reported skin problems. This report is for the East Pittsburgh Westinghouse plant.

1976. Another survey was done (NIOSH, 1976) after workers complained about skin dermatitis in the Muncie, Indiana, Westinghouse plant in the oil filling areas. The following toxic substances were checked; nuisance dust, oil mist, benzene, petroleum distillates, xylene, and ethyl alcohol.

1977. NIOSH issued a health hazard evaluation (NIOSH, 1977) report in April 1977 for Westinghouse in Bloomington, Indiana. The HHE report is based on investigations June 1-3, 1976, and September 9, 1976, for the purpose of evaluating exposures to PCBs. Blood was drawn from 230 workers to analyze PCB in serum.

1984. A follow-up to the 1977 cross-sectional medical survey was done of approximately 230 employees of the Westinghouse, Bloomington, Indiana plant, exposed to polychlorinated biphenyls (NIOSH, 1990). The sixty 1977 participants who had the highest and the lowest serum PCB levels workers were followed up in 1985 with a number of medical tests, including serum PCB levels. The serum PCB levels in 1985 were determined to be elevated for participants who also had the highest serum PCB levels in 1977. There were possible on-going exposures to PCB at the plant due to residual contamination even though the plant ceased use of Aroclors in 1977. Smith *et al.* (1982) published the results from the environmental and medical findings including PCB serum levels, from the 1975-1977 surveys.

1989. Another report (NIOSH, 1991) was published with the findings of excess risk of malignant melanoma, subsequent published in Sinks *et al.* (1992). Phillips *et al.* (1989) used the PCB serum levels from the 1977 NIOSH study and 1985 ISBH-NIOSH study to calculate half-lives of HPCBs and LPCBs.

1992. The Agency for Toxic Substances and Disease Registry (ATSDR, 1992) issued a report on community exposure to polychlorinated biphenyls in Indiana written by Indiana State Board of Health, Bureau of Disease Intervention Division of Chronic Disease Indianapolis, Indiana. No associations were identified between the liver function parameters studied and serum PCB levels.

Reference:

ATSDR (1992) Atlanta, GA: Community Exposure to Polychlorinated Biphenyls Bloomington Indiana by Indiana State Board of Health, Bureau of Disease Intervention Division of Chronic Disease Indianapolis, Indiana June 1992, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, Agency for Toxic Substances and Disease Registry DHHS (ATSDR)

NIOSH (1975) Health Hazard Evaluation Determination Report: Westinghouse Electric Corporation Bloomington IN. Cincinnati, OH: U.S. Department of Health, Education, and Welfare Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) No. 75-147-318

NIOSH (1976) Health Hazard Evaluation Determination Report: Westinghouse Electric Corporation Bloomington IN. Cincinnati, OH: U.S. Department of Health, Education, and Welfare Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) No. 76-94-406

NIOSH (1977) Health Hazard Evaluation Determination Report: Westinghouse Electric Corporation Bloomington IN. Cincinnati, OH: U.S. Department of Health, Education, and Welfare Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) No. 76-52-386

NIOSH (1990) Health Hazard Evaluation Report: Westinghouse Electric Corporation Bloomington IN. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) No. 84-339-2054

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NIOSH survey report (1976) December 4, 1975 by Jones, M., Brown, D., Murthy, L., Young, C., Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH)

NIOSH survey report (1977) April 1977 by Jones, M., Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH)

Phillips, D.L., Smith, A.B., Burse, V.W., Steele, G.K., Needham, L.L., Hannon, W.H. (1989) Half-life of polychlorinated biphenyls in occupationally exposed workers. Archives of Environmental Health. 44 (6):351-354

Sinks T. Steele G. Smith AB. Watkins K. Shults RA. Mortality among workers exposed to polychlorinated biphenyls. American Journal of Epidemiology. 136(4):389-98, 1992.

Smith AB. Schloemer J. Lowry LK. Smallwood AW. Ligo RN. Tanaka S. Stringer W. Jones M. Hervin R. Glueck CJ. Metabolic and health consequences of occupational exposure to polychlorinated biphenyls. British Journal of Industrial Medicine. 39(4):361-9, 1982.

Taylor, P.R. (1988) The Health Effects of Polychlorinated biphenyls. ScD thesis, Harvard School of Public Health Of June 1988.

Chapter 2 Background

NIOSH conducted a walk-through survey of the plant in December 4th 1975.

NIOSH issued a health hazard evaluation (HHE) report in April 1977 for Westinghouse in Bloomington Indiana (NIOSH, 1977). The HHE report was based on an investigation made June 1-3 1976 and September 9 1976 for the purpose of evaluating exposures to PCBs. A meeting was held with company representatives on January 21, 1977. A medical study was conducted by NIOSH during March 1977.

Manufacturing of capacitors at Westinghouse

Capacitor production began by winding bales of foil, paper, or plastic film in a dust-free room (and therefore having minimal exposure to PCBs). The exact size of the bale was determined by the size of the capacitor being made. A predetermined number of bales was placed in a metal capacitor box and the top of the capacitor was put in place. A group of capacitors then was banded together and placed in a vacuum chamber for impregnation with the dielectric fluid. Impregnation involved heating the chamber, placing it under a vacuum to remove all moisture from the capacitor, and adding the dielectric fluid. Large capacitors, those requiring several gallons of dielectric fluid, were filled manually through ports on the top of the capacitor. This procedure was reported to result in spillage and extensive dermal contact with the dielectric fluid. Following impregnation, the warm, wet capacitors were transported to a sealing station where the ports were soldered shut. They then were taken to a washing station to remove any dielectric fluid from the outside of the capacitor.

PCB Composition over time

Two types of PCB-containing dielectric fluids were used at this facility, Aroclor 1242 and Aroclor 1016. Aroclor 1242 was used between 1958 and 1971 and Aroclor 1016 from 1971 until 1977 at which time PCB use ceased (NIOSH Survey, 1977).

Changes in the plant

Not known

Changes in the production process

Not known

Production rate

Not known

Production volume

Not known, but EPA estimated that 50 million pounds PCBs were purchased from 1958 through 1977.

Ventilation

Many operations used local exhaust ventilation. A letter from the Westinghouse industrial hygiene engineer was sent to the Westinghouse safety personnel with recommendations for improvements of the plant ventilation. According to the NIOSH survey of 1977: "The plant does a good job in keeping most work areas clean." (NIOSH Survey, 1977).

In the NIOSH survey report of 1977 the recommendations among others were as follows:

"During soldering operations the local exhaust systems that are present should always be used. Many times during our visit they were not used. The system utilized in the soldering operation located where the capacitors come out of the impregnation chambers would be more efficient if a larger duct opening was used to increase the area of capture. The degreasers in the welding and plating areas should be checked for leaks since high concentrations of trichloroethylene were found around the area of the degreaser. The tanks should be covered when not in use and if necessary an appropriate ventilation system used." (NIOSH Survey, 1977).

In a June 7th 1977, letter from M. Jones, Industrial Hygienist, NIOSH to supervisor of personal relations at Westinghouse Electric Corporation these recommendations are made (Jones, 1977):

"The ventilation system on the degreaser in area F-30 is not designed for maximum efficiency as it is only activated when the side doors are completely open thereby allowing vapors to escape. It should come on as soon as the doors start to open."

"The ventilation system at the repair station in area F-30 is inadequate. Even if it did work properly, the vapors would have to flow past the worker's breathing zone to be collected by the exhaust system. Some form of flanged slot local exhaust ventilation would be more efficient."

"The hood above the oven in the engineering lab draws the air through the worker's breathing zone. One way to reduce the worker's exposure would be to put the oven under a vacuum prior to opening the door. The exhaust ventilation system connected to the oven should turn on as soon as the door is opened.

Any exhaust duct located near a window should be properly constructed to prevent re-entry of exhaust vapors into the building.

The side doors on the painting booth in area A-35 should be kept closed when painting is being done

As was evident during our visit, one of the biggest problems is for workers to properly use the safety equipment which is provided (i.e. use of portable exhaust ducts while soldering and proper use of paintingbooths) Management and union representatives both need to make sure that workers know how to use the safety equipment provided and then follow up to make sure they are using it." (NIOSH Survey, 1977).

In a summary report dated August 31, 1977, the Westinghouse's industrial hygiene engineer wrote about hygienic measures needed in the plant (Comp. Comm., 1977). These are condensed below. The recommendations pertaining to PCB exposure are in italics.

Flexible local exhaust systems are available but unused in some areas, e.g. bench welding station in A-35. Other areas have existing exhausts, but no means of supporting the collector hood at the proper location, e.g. welding booth in F-18.

A-40 Solder Pot – The exhaust on this pot must be extended to exit the building. Although it probably provides adequate dilution for lead fume it is not acceptable because of the highly irritating flux used.

E-[illegible] Solder Station – The capture hood should be reconstructed so that the irritating flux fume is also captured from beneath the work piece. The existing system only collects the fume from above.

F-50 Plating Tanks - The exhaust system is in a very poor state of disrepair. It is particularly important to repair and clean the system at the cyanide tank. One of the hoods is missing completely, the other is installed upside down and is clogged. No less than 100 linear feet per minute is required at the middle of the tank. Accidental addition of acid to the cyanide tank could cause a fatality in the observed condition. All unused ports should be blanked off so that the exhaust functions at maximum where it is needed. Slot-type collection hoods should be installed at the chromic acid tank. The hot water rinse tank does not need ventilation except perhaps for comfort control during hot, humid weather.

F-30 Degreaser – The exhaust fan should be programmed to turn on when the doors are partly open, as well as when they are fully open. For conservation purposes, the fan could be wired to operate at half capacity when the doors are half open and full capacity when they are fully open.

F-30 Fill and solder station – The present exhaust system is of marginal capacity. In order to take advantage of what you have, the flexible exhaust tube should be replaced with one which (1) has a smoother inside surface to reduce drag; and (2) has an inside diameter no smaller than the inlet fitting to the fan. Also, the collection end of the flexible tube should be fitted with a sheet metal collector hood which is either flanged or cone-shaped.

F-30 Vacuum pump on #1 impregnating oven (east end) – this pump appeared to have a broken oil seal which leaked large quantities of oil mist each time it started up.

F-40 Capacitor repair station – this hood has no exhaust at all. The system requires redesign.

Engineering lab oven exhaust – this system should be fitted with an outside stack which carries the fume above the roofline to prevent re-circulation through adjacent open windows. Also, the eye-bolt on the oven door should be removed so the existing canopy hood can be properly positioned.

Inerteen[1] incineration exhaust system – all duct joints on the exhaust (higher pressure) side of the fan should be soldered to prevent leaks. The fan installation should be modified to eliminate the 90° elbow which is located immediately after the outlet of the fan.

Boiler room fire box fan – a bushing should be installed on the "closed side" of the fan to eliminate leakage of the fumes being collected for incineration.

Industrial Hygiene

Due to volatilization, condensation, dripping and spillage in the capacitor impregnation and sealing work areas, significant portions of exposed surfaces in these areas apparently were wet with PCB-containing dielectric fluid, resulting in the saturation of air in the immediate vicinity with PCB vapors. Individuals working in these areas were reported to have considerable opportunity for both dermal and respiratory uptake of PCBs.

There was no industrial hygienist at the plant but a corporate industrial hygienist was available to the plant when needed. The company collected approximately 40 air samples for evaluation for PCBs, but no regular monitoring was done. Personal protection programs enforced at the plant in 1977 were safety glasses, safety shoes, respirators and protective clothing (gloves and aprons) (NIOSH Survey, 1977).

PPE. In the summary report by Westinghouse's industrial Hygiene engineer (Comp. Comm., 1977) it was stated that: "A statement is needed to the effect that the safety supervisor shall designate in writing, with a copy to the plant nurse and responsible foreman, those occupations which require the use of a respirator, and specifically what type of respirators shall be used (e.g. dust, organic vapor, acid gas, etc.)." "Many

[1] Inerteen was Aroclor 1242 or Aroclor 1016. See chapter 3 for more details.

deficiencies were found during the evaluation any one of which could be the basis for a citation for failure to comply. Examples included storage in an unsanitary condition, wrong type of cartridge, depleted (use-up) cartridge, no cartridge at all, no respirator available where needed, inadequate employee training on fitting and use (in some cases, no training at all) and faulty operation (respirator in need of repair)."

Housekeeping

Plant maintenance workers spent a considerable amount of time in the impregnation, sealing and washing areas of the plant and therefore, they were reported to have opportunity for direct exposure to PCBs. Part of the housekeeping was keeping surface contamination low by cleaning the contaminated surfaces and not allowing for PCB buildup over time.

Building and layout

All operations were under one roof with limited partitions between operations. The administrative offices and a few specific processes were isolated by walls.

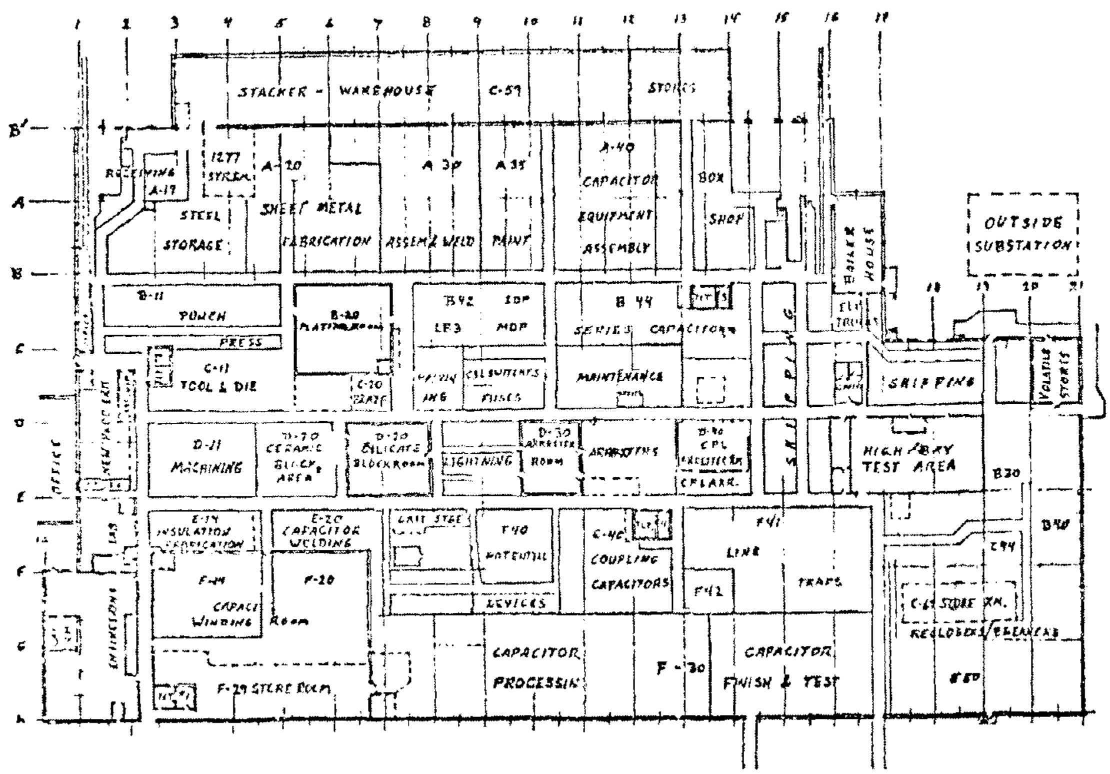


Figure 1 A layout of the plant 1970-77.

In general the alpha code started at the north side of the plant with the letter A and progressed to the south ending with the letter F. Numerically, the numbers began on the west side of the building and increased to the east. All of the "G" codes were for workers in maintenance. There were two maintenance locations, the one shown on the map (at C11-12), and a second location between F-20 and F-30.

Chemicals

Other chemical exposures at this Westinghouse plant were toluene, xylene, methyl ethyl ketone (MEK), trichloroethylene, and 1,1,1-trichloroethane.

Reference:

Company Comm. (1977) Internal Westinghouse Electrical Corporation Letter of August 31, 1977 from John F. Adams, Industrial Hygiene Engineer, Westinghouse Industrial Hygiene Laboratories to R. Dyer, Safety Supervisor, Bloomington Works.

Jones, M. (1977) Letter of June 7, 1977 from Mark Jones, Industrial Hygienist, NIOSH, to Robert Dyer, Supervisor, Personal Relations, Westinghouse Electrical Corporation, Bloomington IN. Cincinnati, OH: U.S. Department of Health, Education, and Welfare Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH)

NIOSH (1977) Health Hazard Evaluation Determination Report: Westinghouse Electric Corporation Bloomington IN. Cincinnati, OH: U.S. Department of Health, Education, and Welfare Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) No. 76-52-386

NIOSH survey report (1977) April 1977 by Jones, M., Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH).

Chapter 3 Use of PCB

Commercial production of PCBs in the USA began in 1929 at the Swan Chemical Company; in 1935 this company was purchased by Monsanto Industrial Chemicals Company. A series of chlorinated biphenyl mixtures was produced under the name of Aroclor. The initial production was mainly applied as dielectric fluids in transformers. After World War II, utilization in capacitors and open systems increased steadily, and somewhat later the use in heat-transfer systems began (Voogt and Brinkman 1989). More than 95% of all power capacitors contained PCBs. Among their applications were: use on electric utility lines, in air conditioners, and in the ballast of fluorescent lamp fixtures. PCBs were employed for safety, reliability, and long life, as well as to achieve size compatibility with equipment and installation requirements. However, non-PCB power capacitors were being manufactured in 1975 (e.g., General Electric's Econol line and Sprague's Eccol line) which may serve as alternatives (Personal communication 1975). ‡

Beginning in 1971, Monsanto voluntarily restricted its domestic sales of PCBs to closed system dielectric applications in capacitors and transformers (Monsanto 1974). Current domestic applications of PCBs include use in investment casting processes, as heat exchange fluids, and as hydraulic fluids. Imports of PCBs have been estimated to exceed 375,000 pounds for 1974. Reclaimed PCBs also are reported to be available (Schweitzer 1975).

Chemical composition

Polychlorinated biphenyls (PCBs) are synthetic chlorinated organic compounds having the following formula: $C_{12}H_{10-n}Cl_n$ with n=1-10.

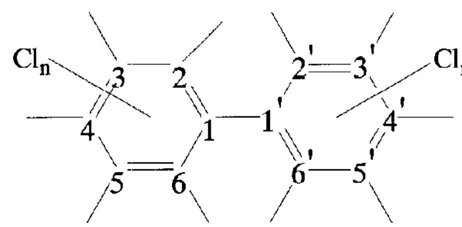


Figure 1. The chemical formula of PCB presented as $C_{12}H_{10-n}Cl_n$, where n, the number of chlorine atoms in the molecule can range from 1 to 10

Synthesis of PCB

PCBs are generally prepared industrially by chlorination of biphenyl with anhydrous chlorine in the presence of iron filings or a ferric chloride catalyst. Trace quantities of chlorinated naphthalenes and chlorinated dibenzofurans have been reported in some commercial samples of PCBs and it has been suggested that the presence of these impurities may be of toxicological significance (Hutzinger *et al.* (1974), Bowes *et al.* 1975, Curley *et al.* 1975). Commercial PCBs are generally mixtures of many different chlorinated biphenyls, as shown in Table 2, manufactured to meet operational specifications (such as dielectric constant, flash point, fire point, density, percent chlorine, and color); these commercial mixtures may vary chemically from batch to batch.

Biphenylrings

Unlike dioxins or dibenzofuranes, the phenyl rings of a PCB are not constrained through ring fusions and have relatively unconstrained rotational freedom. Chlorines at the *ortho* (2,2',6,6') positions introduce constraints on rotational freedom that can hinder coplanarity of the phenyl rings. The preferred conformation for all PCBs, including those without *ortho*-substituents, is non-coplanar. PCBs without *ortho*-substitution are often referred to in the biological literature as the planar (or coplanar) PCBs and all others as the nonplanar (or noncoplanar) PCBs. There are 209 possible different chlorinated biphenyls and they are collectively referred to as PCBs although many are not actually polychlorinated. Approximately half of these compounds have been synthesized and characterized.

Physical and chemical properties

Mixtures of polychlorinated biphenyls are very resistant to degradation, are thermally stable, and are resistant to oxidation, acids, bases, and other chemical agents. They are soluble in most of the common organic solvents and lipids, but only slightly soluble in water, glycerol, and glycols. PCBs are good electrical insulators. Although most individual polychlorinated biphenyls are solids at room temperatures, the mixtures vary in consistency from mobile oils to viscous liquids or sticky resins.

PCB Vapor pressures calculated from the product of solubility (mol/m^3) and HLC (atm.m^3/mol) data, generally decreased with relative molecular mass and increased with increasing degree of *ortho*-chlorine substitution.

Table 1 Physical and chemical properties of a number of Aroclors

Aroclor	Vapor pressure	Density	Appearance	Bp. 1atm 20°C
1016	4.0*10-4	1.33	Clear, mobile oil	325-356
1242	4.1*10-3	1.35	Clear, mobile oil	325-366
1254	7.7*10-5	1.50	Light yellow viscous oil	365-390

Depending on the reaction conditions, the degree of chlorination can vary between 21 and 68% (w/w). Only about 130 of the 209 congeners are likely to occur in commercial products or mixtures of such compounds (Safe, 1990).

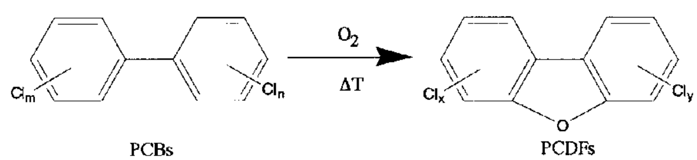
Commercial PCBs are generally mixtures of many different chlorinated biphenyls, manufactured to meet operational specifications (such as dielectric constant, flash point, fire point, density, percent chlorine, and color); these commercial mixtures may vary chemically from batch to batch.

Conversion factors (ATSDR 2000)

Aroclor 1016	1	mg/m^3	=	0.095	ppm
Aroclor 1242	1	mg/m^3	=	0.092	ppm
Aroclor 1254	1	mg/m^3	=	0.075	ppm

Decomposition of PCB

Individual pure PCB congeners are colorless, often crystalline compounds, but commercial PCBs are mixtures of these congeners with a clear (Aroclor 1242 and 1016) or yellow (Aroclor 1254) color. They form vapors heavier than air, but do not form any explosive mixtures with air. They possess very low electrical conductivity and an extremely high resistance to thermal breakdown, and it is on the basis of these properties that they are used as cooling liquids in electrical equipment. According to laboratory tests, they stay chemically unchanged, even at high temperatures (up to 170 °C).



The PCB isomers can be transformed to PCDFs via intramolecular cyclizations.

PCBs are known for their chemical stability. Brown *et al.* (1988) found that the electrical use of PCB dielectric fluids in capacitors did not increase the PCDFs content significantly.

In commercially prepared PCB mixtures, the weight-percent of chlorine has varied from 21 to 68%. In some preparations, there has also been some degree of contamination by PCDFs (Hutzinger *et al.,* 1974, Brown and Jones, 1981). The primary use of PCBs has been as a liquid insulating material in electrical capacitors and transformers; therefore, the greatest potential for occupational exposure has been in the manufacture and repair of these components.

PCBs have found wide use in industry and were manufactured in the United States from 1929. The major domestic manufacturer (the sole U.S. producer of PCBs (Kimbrough, 1995)), Monsanto Chemical Company, produced PCBs at Sauget, Illinois, and Anniston, Alabama. They reported to have manufactured 40 million pounds of PCBs in the United States during 1974 (down from 85 million pounds in 1970).

Monsanto voluntarily stopped open-ended uses of PCBs in 1971. Subsequently, the lower chlorinated biphenyls, Aroclor 1016, 1242, and some 1254 were produced. Prior to 1971, other more highly chlorinated biphenyl mixtures such as Aroclor 1248, 1254, and 1260 were also marketed. In 1977 Monsanto Chemical Company ceased production of PCBs entirely (Kimbrough, 1995). Monsanto's domestic production and sales of PCBs by grade and category from 1957 through the first quarter of 1975 are shown in Table 2 (Monsanto, 1975).

Since 1971, PCBs were sold in the United States only for use in closed systems. According to the Toxic Substances Control Act of 1976, rules and regulations were promulgated to limit the manufacture and use of PCBs. This Act stipulated that all U.S. production of PCBs end January 1, 1979, and that all U.S. sale and distribution of PCBs end July 1, 1979 (Brown and Jones, 1981).

Table 2 PCB Manufacture and Sales Monsanto Industrial Chemicals Company 1957 Through 1964(Thousands of Pounds) (Monsanto, 1975)

	1957	1958	1959	1960	1961	1962	1963	1964
U.S. Production				37919	36515	38353	44734	50833
Domestic Sales	32299	26061	31310	35214	37538	38043	38132	44869
Domestic Sales by Category								
Transformer	12955	5719	5984	7921	6281	7984	7290	7997
Capacitor	17028	14099	16499	16967	15935	15382	15606	19540
Domestic Sales by PCB Grade								
Aroclor 1221	23	16	254	103	94	140	361	596
Aroclor 1232	196	113	240	155	241	224	13	13
Aroclor 1242	18222	10444	13598	18196	19827	20654	18510	23571
Aroclor 1248	1779	2559	3384	2827	4023	3463	5013	5238
Aroclor 1254	4461	6691	6754	6088	6294	6325	5911	6280
Aroclor 1260	7587	5982	6619	7330	6540	6595	7626	8535
Aroclor 1262	31	184	359	326	361	432	414	446
Aroclor 1268	--	72	102	189	158	210	284	190
Aroclor 1016	--	--	--	--	--	--	--	--

Source: Monsanto Industrial Chemicals Company, St. Louis, Missouri, September, 1975.

Table 3 (Monsanto, 1975) PCB Manufacture and Sales Monsanto Industrial Chemicals Company 1965 Through 1970 (Thousands of Pounds)

	1965	1966	1967	1968	1969	1970
U.S. Production	60480	65849	75309	82854	76389	85054
Domestic Sales	51796	59078	62466	65116	67194	73061
Domestic Sales by Category						
Transformer	8657	8910	11071	11585	12105	13828
Capacitor	23749	28884	29703	29550	25022	26708
Domestic Sales by PCB Grade						
Aroclor 1221	369	528	442	136	507	1476
Aroclor 1232	7	16	25	90	273	260

Aroclor 1242	31533	39557	43055	44853	45491	48588
Aroclor 1248	5565	5015	4704	4894	5650	4073
Aroclor 1254	7737	7035	6696	8891	9822	12421
Aroclor 1260	5831	5875	6417	5252	4439	4890
Aroclor 1262	558	768	840	720	712	1023
Aroclor 1268	196	284	287	280	300	330
Aroclor 1016	0	0	0	0	0	0

Table 4 (Monsanto, 1975) PCB Manufacture and Sales Monsanto Industrial Chemicals Company 1971 Through 1975 (Thousands of Pounds)

	1971	**1972**	**1973**	**1974**	**(1st quarter) 1975**
U.S. Production	34994	38600	42178	40466	8532
Domestic Sales	34301	26408	37742	34406	7986
Domestic Sales by Category					
Transformer	11134	>25656	37742	34406	7986
Capacitor	14141				
Domestic Sales by PCB Grade					
Aroclor 1221	2215	171	35	57	10*
Aroclor 1232	171	0	0	0	0
Aroclor 1242	21981	728	6200	6207	2201**
Aroclor 1248	213	807	0	0	0
Aroclor 1254	4661	3495	7979	6185	2115**
Aroclor 1260	1725	305	0	0	0
Aroclor 1262	1	0	0	0	0
Aroclor 1268	0	0	0	0	0
Aroclor 1016	3334	20902	23531	21955	3660*

* Used Primarily in capacitors
** Used Primarily in transformers

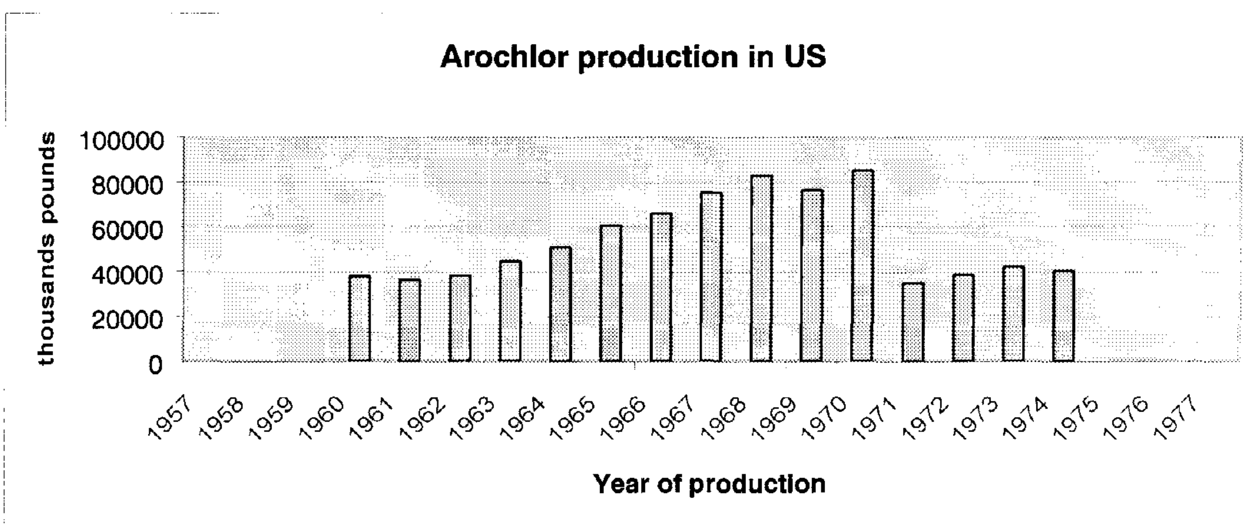


Figure 1 Aroclor production in the US. Production data before 1960 not available.

Table 5 (Monsanto, 1975) Aroclor type and use category over the years 1957-1975

Year	Aroclor						Use Category	
	1016	1242	1248	1254	1260	Others	Closed systems	Other uses
1957	0	18.2	1.8	4.5	7.6	0.3	30.0	2.3

1958	0	10.4	2.6	6.7	6.0	0.4	19.8	6.2
1959	0	13.6	3.4	6.8	6.6	1.0	22.4	8.9
1960	0	18.2	2.8	6.1	7.3	0.8	24.9	10.3
1961	0	19.8	4.0	6.3	6.5	0.9	22.2	15.3
1962	0	20.7	3.5	6.3	6.6	1.0	23.3	14.7
1963	0	18.5	5.0	5.9	7.6	1.1	22.9	15.2
1964	0	23.6	5.2	6.3	8.5	1.2	27.5	17.4
1965	0	31.5	5.6	7.7	5.8	1.1	32.4	19.4
1966	0	39.6	5.0	7.0	5.9	1.6	37.8	21.3
1967	0	43.1	4.7	6.7	6.4	1.6	40.8	21.7
1968	0	44.9	4.9	8.9	5.3	1.2	41.1	24.0
1969	0	45.5	5.7	9.8	4.4	1.8	37.1	30.1
1970	0	48.6	4.1	12.4	4.9	3.1	40.5	32.6
1971	3.3	22.0	0.2	4.7	1.7	2.4	25.2	9.1
1972	20.9	0.7	0.8	3.5	0.3	0.2	25.7	0.7
1973	23.5	6.2	0	8.0	0	<0.1	37.7	0
1974	22.0	6.2	0	6.2	0	<0.1	34.4	0
1975	14.6	8.8	0	8.5	0	<0.1	31.9	0

Table 6 de Voogt and Brinkman (1989) numbers for U.S. sales (in 10^6 lbs of PCBs) by Aroclor grade and use category.

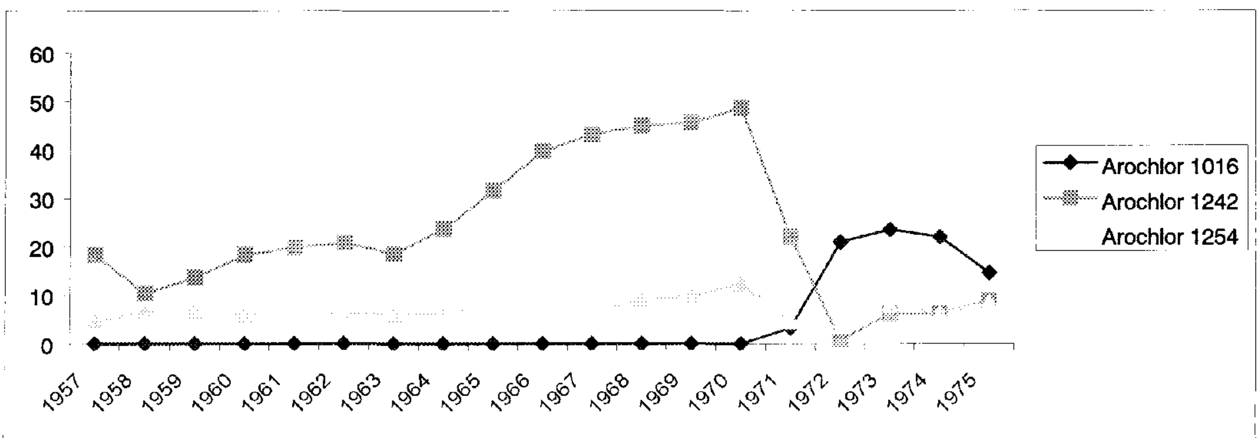


Figure 2 Overview of Aroclors used over time

Impurities with synthesis

Trace quantities of chlorinated naphthalenes and chlorinated dibenzofurans have been reported in some commercial samples of PCBs and it has been suggested that the presence of these impurities may be of toxicological significance (Hutzinger *et al.,* 1974, Bowes *et al.* 1975, Curley *et al.* 1975). In the commercial mixtures of PCBs produced by Monsanto Chemical Company, polychlorinated dibenzofurans (PCDFs) only occurred in trace amounts or were not detected at all (Kimbrough, 1995).

Additives

According to Westinghouse there were no additives used in Aroclor 1242 and Aroclor 1016, known as Inerteen.

Commercial use of PCB

Mixtures of polychlorinated biphenyls are important industrial products. The most common trade names for these mixtures are Aroclor, Inerteen, Kanechlor, and Pyranol. See table below. Production of PCBs in the U.S. began in 1929 and 85 million pounds were produced under the trade name Arochlor in 1970. After 1970 production decreased considerably; in 1976, annual production was around 40 million pounds (Jones 1986). PCB production in the US ended in 1977. Monsanto was the sole producer of PCB during this time (de Voogt and Brinkman).

PCBs were employed in capacitors and transformers because they combine: dielectric properties with chemical stability and fire resistance. Approximately twice as many pounds of PCBs were used in the manufacture of capacitors as in the manufacture of transformers. PCB-containing dielectrics (electrical insulators) were generally referred to as "askarels" in the electrical industry.

Table 7 Trade names for Known PCB Containing Products.

Trade name	Trade name Owner
Aroclor	Monsanto Company St. Louis, MO
Chlorextol	Allis-Chalmers Milwaukee, WI
Clophen	Farbenfabricken Bayer GmbH Germany
Dykanol	Federal Pacific Electric Co. Newark, NJ
Fenclor	Caffaro S.P.A. Italy
Inerteen	Westinghouse Electric Corp. Pittsburgh, PA
Kanechlor	Kanegafuchi Chemical Industry Co., Ltd. Japan
Noflamol	Wagner Electric Corporation Newark, NJ
Phenoclor	Prodelec France
Pyralene	Prodelec France
Pyranol	General Electric Co. Schenectady, NY
Santotherm	Mitsubishi-Monsanto Japan
Therminol*	Monsanto Co. St. Louis, MO

PCBs are employed in transformers at locations where their proximity to people and/or property demand a fire resistant dielectric. Approximately 5% of transformers are PCB filled and each of the transformers so filled contains between 40 and 500 gallons of PCBs (about 235 gallons is average). Possible alternatives to

PCB filled transformers may include dry transformers (which are larger) as well as transformers filled with silicone fluids or other materials under evaluation (Dow Corning, 1975).

PCB in Aroclor

Naming

The industrial trade name Aroclor is followed by four digits. The two first digits (e.g. 12) in Aroclor is the number of carbon atoms that makes up the biphenyls. The two last digits (e.g. 42) is the amount of chlorine by weight percent. Aroclor 1254 contains approximately 54% chlorine by weight (second two digits). This holds true for most of the Aroclors except for 1016, which is a distillate from Aroclor 1242, both containing about 42% chlorine w/w.

Composition

Table 8 The average molecular composition (ww%) of some Aroclors

	Aroclor						
***n*[1]**	**1221**	**1232**	**1016**	**1242**	**1248**	**1254**	**1260**
1	50	26	2	1			
2	35	29	19	13	1		
3	4	24	57	45	21	1	
4	1	15	22	31	49	15	
5				10	27	53	12
6					2	26	42
7						4	38
8							7
9							1

n in $C_{12}H_{10-n}Cl_n$

Table 9 Approximate chlorine content of Aroclor Mixtures.

Aroclor 1221*	Aroclor 1242*	Aroclor 1016	Aroclor 1254*	Aroclor 1260†
21%	42%	41-42%	54%	60%

Notes: a particular product may vary in chemical composition from batch to batch.
* Weight-weight percent.
† Percent. Source of component compositions, A., PCB Newsletter, No. 3, July 1971, quoted in Hutzinger, O. *et al.*1974

Table 10 The chemical composition of the different Aroclors (Hutzinger *et al.* 1985)

PCB	**Mol. % in**		
	1254	**1242**	**1016**
Benzyl phenyl (BP)		0.01	0.50
2		0.68	0.80
3		0.04	0.10
4		0.22	1.00
2,6		0.13	0.20
2,2'		3.99	4.36

2,5		0.31	0.34
2,4		1.04	1.16
2,3'	0.07	1.24	1.37
2,4'	-	8.97	10.30
3,5		0.35	0.37
3,4		0.09	0.11
3,4'		0.12	0.12
4,4'		0.99	1.07
2,6,2		0.97	1.08
2,5,2'	0.07	9.36	10.87
2,4,2'	-	2.92	3.14
2,3,2'	-	3.25	3.50
2,6,3'		0.54	0.58
2,6,4'	-	2.15	2.31
2,5,3'	-	0.55	0.62
2,5,4'	0.72	4.53	4.72
2,4,3'		1.68	1.79
2,4,4'	-	13.30	14.48
2,3,3'		3.64	3.99
2,3,4'	Trace	2.64	2.80
3,4,2'		2.83	3.08
3,4,3'		0.66	0.38
3,4,4'	0.20	1.62	1.89
3,5,4'		1.03	1.08
2,6,2',6'		0.17	0.19
2,3,6,2'	0.15	0.90	1.00
2,5,2',6'	0.13	0.97	1.07
2,5,2',5' (BZ 52)	4.36	4.08	4.35
2,5,2',4'	1.63		
2,4,6,4'		2.18	2.40
2,3,4,3'	0.43		
2,3,5,2'		0.44	0.47
2,3,2',6'		0.31	0.33
2,4,5,2'		1.33	1.41
2,4,2',5' (BZ 49)		3.28	3.48
2,3,2',5' (BZ 44)		1.06	1.14
2,3,4,2'		1.67	2.00
2,3,2',3'	0.26	0.15	0.18
2,3,3',4'	0.18	0.60	-
2,4,2',4'	0.52	1.65	1.81
2,4,2',3'	2.18		
2,4,5,4' (BZ 74)	0.30	2.02	1.35
2,5,3',4'	4.75	1.11	-
2,6,3',4'	-		
3,4,5,2'	0.18	Trace	-
3,4,5,3'		0.52	-
3,4,5,4'		0.28	-
3,4,3',4' (BZ 77)	0.12	0.34	-
2,5,3',5'	1.01	0.33	-
2,4,3',4'	2.24	0.81	0.14
3,4,3',5'	0.23	0.24	-
3,5,3',5'	Trace		
2,3,4,4'		0.21	-
2,4,5,2',3'	2.59		
2,4,6,3',5'	3.51	0.92	-
2,4,6,2',5'	0.29		

2,4,6,2',3'		0.13	0.04
2,3,6,2',5'		0.53	0.18
2,3,6,3',5'	Trace	0.39	0.01
2,3,6,2',4'	5.00	Trace	-
2,3,6,2',3'	1.72	0.38	0.01
2,3,4,3',5'		0.46	0.16
2,3,4,2',4'	2.15	0.40	-
2,3,4,2',5'	3.81	0.09	-
2,3,4,3',4' (BZ 105)	Trace	0.25	-
2,3,4,5,3'	0.40		
2,3,4,5,4'	0.25		
2,3,5,2',3'	0.32		
2,3,5,2',5'	0.63	0.12	-
2,3,6,3',4'	8.51		
2,4,5,2',4' (BZ 99)	6.10	0.55	-
2,4,5,2',5' (BZ 101)	6.98	0.27	-
2,4,5,2',6'	Trace		
2,4,5,3',4' (BZ 118)	8.09		
2,4,5,3',5'	0.15	0.31	-
3,4,5,2',3'	0.76		
3,4,5,2',4'		0.36	-
3,4,5,3',5'		0.05	-
3,4,5,3',4'	0.16	0.03	-
2,3,4,2',3',4' (BZ 128)	1.31		
2,3,4,5,2',6'		0.07	-
2,3,4,6,3',4'	0.46		
2,3,4,2',3',6'	2.00		
2,3,4,2',4',5' (BZ 138)	4.17	0.08	-
2,3,4,6,2',3'	0.14		
2,3,5,2',3',5'	0.03		
2,3,5,2',3',6'	0.20		
2,3,5,6,2',5'	0.33		
2,3,5,6,2',3'	0.38		
2,3,5,6,3',4'	-		
2,3,6,2',3',6'	0.34		
2,4,5,2',4',5' (BZ 153)	3.32	0.02	-
2,4,5,2',4',6'	-		
2,4,5,2',3',5'	0.75		
2,4,5,2',3',6'	3.59		
2,4,6,3',4',5'	4.23		
2,3,4,6,2',3',6'	Trace		
2,3,5,2',4',6'	Trace		
2,3,4,5,2',4',5' (BZ 180)	0.76		
2,3,4,5,6,2',4'	0.28		
2,3,4,5,6,2',6'	Trace		
2,3,5,6,2',3',6'	0.56		
2,3,4,6,2',4',5'	1.16		
2,3,4,5,6,2',5'	1.11		
2,3,4,6,2',3',4'	0.30		
2,3,5,6,2',4',5' (BZ 187)	0.48		
2,3,5,6,2',4',6'	0.07		
2,3,5,6,2',3',5',6'	Trace		
Unknown	0.31		
Monochloro (%)	0	0.94	2.40
Dichloro (%)	0.07	17.23	19.40
Trichloro (%)	1.02	51.67	56.31

Tetrachloro (%)	19.22	24.65	21.32
Pentachloro (%)	52.94	5.24	0.40
Hexachloro (%)	21.88	0.17	-
Heptachloro (%)	4.86		

Impurities in Aroclors

PCDFs have been found as contaminants in virtually all commercial PCB mixtures, both North American and European. However, there has been very little effort to determine if these levels increase during the operation of PCB-filled electrical equipment and, if they do, what factors are responsible. The table below shows an overview of PCDFs found in Aroclor (Hutzinger *et al.* 1985).

Table 11 Impurities in Aroclors (Phillip *et al.* 1979)

PCB	PCDF s, ppm			
	Cl_4	Cl_5	Cl_6	Total
Aroclor 1248 (1969)	0.5	1.2	0.3	2.0
Aroclor 1254 (1969)	0.1	0.2	1.4	1.7
Aroclor 1254 (1970)	0.2	0.4	0.9	1.5
Aroclor 1260 (1959)	0.1	0.4	0.5	1.0
Aroclor 1260 (lot AK3)	0.2	0.3	0.3	0.8
Aroclor 1016 (1972)	ND	ND	ND	-

Stabilizers

Mixtures put into the capacitors contained about 0.5% of epoxide stabilizers and sometimes trichlorobenzene as well. It is not known whether Westinghouse used these or other stabilizers, or none.

Aroclor 1254

More than half of this mixture is pentachloro biphenyls (52%). Tetra and hexa chloro biphenyls are the two other main components, 19 and 20% respectively (table 8).

Aroclor 1242 / Aroclor 1016

Aroclor 1242 contained less than 0.05 mol % chloronaphthalenes, while Aroclor 1016 contained less than 0.06 mol.% of these compounds. Aroclor 1242 had approximately 150 ppb of chlorinated dibenzofuranes, of which 43% was the toxic 2,3,7,8-tetrachloro isomer. In the Albro and Parker paper (1979) they compare the American PCB mixture Aroclor 1242 with its more modern replacement, Aroclor 1016, in terms of their PCB, chlorinated naphthalene and chlorinated dibenzofurane compositions.

Chlorinated dibenzofurans were detected in Aroclor 1242; 2,3,6-trichloro- (47 ng/g), 1,3,6,7-tetrachloro (7 ng/g), 2,3,7,8-tetrachloro (64 ng/g), 2,3,4,7,8-pentachloro (28 ng/g), and 1,2,3,6,7,8-hexachlorodibenzofurans (<3 ng/g). These compounds were not seen in Aroclor 1016. This Albro and Parker study indicates the presence of two presumably toxic PCB isomers; 3,4,3',4'-tetrachlorobiphenyl and 2,3,4,3',4'-pentachlorobiphenyl, and of a series of chlorinated dibenzofurans including the extremely toxic 2,3,7,8-tetrachloro isomer in Aroclor 1242 but absent or in greatly reduced concentrations in Aroclor 1016 (Phillip *et al.* 1979).

Aroclor 1242 and 1016 differ from Aroclor 1248, 1254, and 1260 in the higher chlorinated PCB isomers. The three latter Aroclors have higher concentrations of higher chlorinated PCBs. Aroclors 1242 and 1016 have similar PCB compositions up to tetrachloro isomers. Aroclor 1016 lacks the more polar tetrachloro, most of the pentachloro, and essentially all of the hexachloro isomers present in Aroclor 1242. Nothing can be said at this point about the possible effects of lot-to-lot variations on these analytical results.

What Aroclors were used over time at Westinghouse?

From 1957 to 1977, the Westinghouse Electric Corporation manufactured electrical capacitors in Bloomington. The dielectric fluid was according to EPA "Inerteen" (a mixture of Aroclors in mineral oil) but in NIOSH reports from walk-through surveys during the manufacturing ages the dielectric fluid was reported as Aroclor. There are uncertainties regarding what type of Aroclors used at Westinghouse during their capacitor production time.

Letter 1975. In a letter to Westinghouse of October 10 1975, NIOSH (D.P. Brown) asked what year the production process started where PCBs were used. The reply from Westinghouse (F.A.Bean) was as follows: "Westinghouse started using Aroclor in the manufacture of capacitors in 1934." Since the Westinghouse, Indiana plant started production in 1957-58, this response probably refers to the Sharonville, PA plant. The Westinghouse Electric Corporation announced that effective July 15, 1976, no new quotations would be made for units filled with PCBs for shipment after December 31, 1976.

Kacir (1983) is quoted several times in EPA's report about the Superfund site; Bloomington, Indiana. In this report it is stated that "Westinghouse purchased PCBs from Monsanto in various formulations. Information from a legal memo prepared in 1983 indicates that from 1966 to 1971, Aroclor 1242 was used to fill capacitors. Aroclor 1016 replaced Aroclor 1242 in the fall of 1971, and it was used through at least May of 1972." The EPA report states that information on PCB formulations used at the plant prior to 1966 or after 1972 is not available. The EPA report also mentions that the presence of high concentrations of PCB Aroclors 1248, 1254 and 1260 at Neal's Dump, Neal's Landfill, and Lemon Lane Landfill indicate that these PCB formulations were also used at the Westinghouse plant.

Survey report 1977 by Mark Jones. The report of a NIOSH walk-through survey of Westinghouse in Bloomington, Indiana, December 1975, states that from 1958 to 1971 Monsanto's polychlorinated biphenyl, Aroclor 1242 was used, at the time of the walk-through survey, Monsanto's Aroclor 1016 was used.

We will develop the JEM based on Aroclor use with two separate time categories during the PCB capacitor production time from 1958 until 1977. The two time eras are:

1. Aroclor 1242: 1958-1971
2. Aroclor 1016: 1971-1977

Amount of PCB used during the capacitor production at Westinghouse?

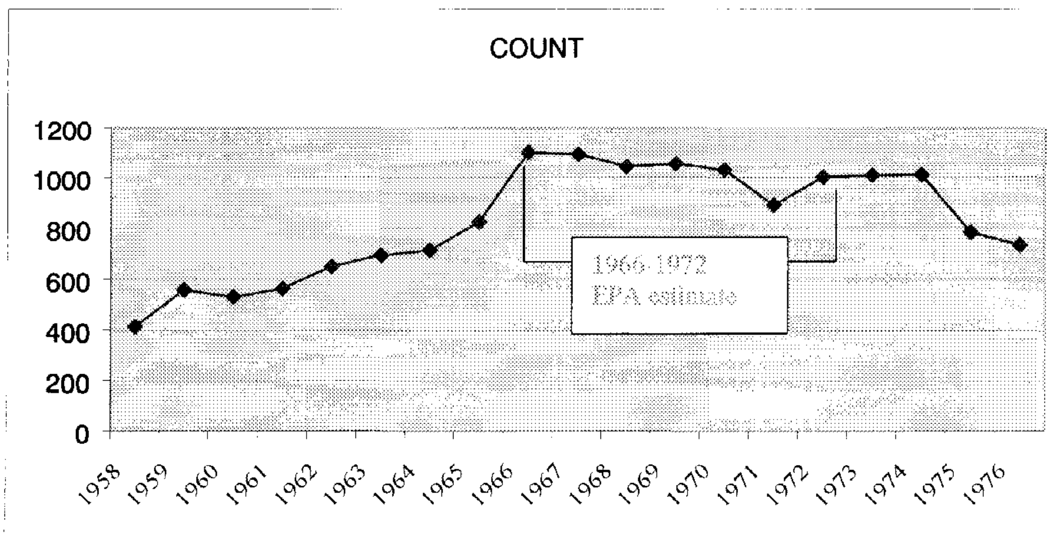
Monsanto was the sole U. S. manufacturer of PCBs. Purchase records documenting the quantity of PCB used at the plant are not available. Therefore, EPA used Westinghouse production data, which we do not possess, to estimate the total amount of PCBs purchased. "Available production data for the period 1966 - 1972 (Kacir 1983) indicates that 15,824,641 pounds of Inerteen was used to manufacture 461,256 capacitors. If this production data is extrapolated to the entire period of study (1958 -1977), the following estimations can be made:

A total of 50 million pounds of Inerteen was used to fill 1. 4 million capacitors, Large capacitors contained between 16 and 106 pounds of Inerteen each, and an average of 63,500 large capacitors were produced annually. Small capacitors contained approximately 1.4 pounds of Inerteen each, and an average of

8,600 small capacitors were produced each year. Each year, approximately 2.5 million pounds of Inerteen was used to fill 72,000 capacitors of various sizes."

Examination of production records for a 6.4-year period between 1966 and 1972 indicated that almost 16 million pounds of PCBs were used in production during those years (Kacir 1983). Extrapolation of these production rates to the entire period of study suggests that close to 50 million pounds of PCBs were used in the production of capacitors between 1958 and 1977. This does not account for spillage or waste. This estimate is based on peak production rates. Generally, the max output will not occur in a start-up phase of a plant, nor when the production is sizing down. Applying this, the EPA estimate would be regarded as high, so rephrasing the statement, no more than 50 million pounds of PCB was used in the given timeframe.

Figure 3 Number of workers at Westinghouse, Bloomington IN, from 1958-1977



The amount of PCB used in the capacitors differed according to the size of the capacitors. A number of different types of capacitors ranged from small ones for consumer electronic applications to large power handling devices for use by electric utilities and industry.

The EPA report listed pathways for PCBs to leave the Westinghouse Plant. Clay was used to purify Inerteen. Based on information in the Kacir memo (Kacir 1983), it is estimated that approximately 30,000 pounds per year of PCB- contaminated clay was disposed of locally at the landfills. Some spills inside the plant may have been cleaned up with sawdust or other materials, and these materials would have been disposed of at local landfills. The EPA report stated that Westinghouse paid the bidder (individuals with a pickup truck) to haul the capacitors to landfills, primarily the five major dumps. If this is true then truck drivers who had direct exposure to PCB are left out of our cohort. Reports of spills are not available but assuming, as the EPA did, that they did occur, the workers cleaning up the spill would likely experience peak PCB exposures.

Some spills of Inerteen inside the plant entered the sanitary sewer leading to the Winston-Thomas Wastewater Treatment Plant (WTTP). PCBs rinsed from the outside of capacitors or manufacturing equipment were also discharged to WTTP through the sanitary sewer. In the early 1970s, Westinghouse estimated the magnitude of these discharges to WTTP to be 25 pounds of PCBs per day (Munson undated, Munson 1972). After the WTTP plant was notified of these discharges in 1975, PCB discharges to WTTP continued but were rerouted. Some waste PCBs were collected for off-site recycling or disposal.

Available data indicates that 5 to 10 percent of capacitors manufactured were scrapped due to defects or overproduction. Some capacitors were partially drained of Inerteen prior to disposal, but draining removed only half of the Inerteen. Prior to 1970, none of the small capacitors and fewer than half of the large capacitors were drained. After 1970, all capacitors were drained prior to disposal (Kacir 1983). Taking this into consideration, approximately 2.3 million pounds of Inerteen entered the local dumps when the capacitors were disposed of. This drainage of capacitors was done by the salvage and repair department. Some PCBs were spilled onto the plant property during transportation, handling, or capacitor production. This is the background exposure all workers at the plant were continuously exposed to. This level is estimated in chapter 4.

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Chapter 4 Exposure measures

Introduction

Congress created the Occupational Safety and Health Administration (OSHA) under the Occupational Safety and Health Act (OSH Act) on December 29, 1970. This Act also established NIOSH. This Act set forth several standards for occupational exposure levels, OELs, at workplaces. When these OEL standards were set, there were no guidelines or standards for how to conduct sampling and perform analysis. NIOSH, OSHA's research partner, had to come up with sampling and analysis standards for these chemicals which now had an OEL. This had to be done fairly quickly, and NIOSH hired contractors to do this, and the S-series for sampling and analysis of contaminants in workplace air was created in 1975-76. Two methods were created for PCB: S120 for 42% chlorinated PCB, and S121 for 54% chlorinated PCB. These were later reviewed by in-house NIOSH researchers and a new series Physical and Chemical Analysis Methods (P&CAM) was developed. The new methods for sampling and analyzing PCBs were developed in 1976; P&CAM253 for Aroclor 1016 and P&CAM244 for all Aroclors. The latest standardized method for PCB sampling and analysis under the program NIOSH Manual of Analytical Methods (NMAM), is 5503. This method was first issued early 1984, and was later revised in 1987, and a second revision was published in 1994. This is the standard method used today.

Industrial Hygiene Measurements

Measurement methods

The five different methods have become more general over the years. The first methods could only handle a certain concentration of chlorine in the PCB mixture while the later methods handle the whole spectrum of chlorinated compounds. The sampling device has changed quite a bit over time. Method S120 uses a glass fiber filter connected in series with a single midget bubbler / impinger, while S121 uses a cellulose membrane filter or Millipore filter in polystyrene filter holders. The P&CAM methods both use a Florisil tube as the adsorbent, and the newest method combines several methods and use a glass fiber filter with Florisil. Florisil is activated magnesium silicate, $MgO*SiO_2$, an inorganic solid. The desorption medium has also changed with the developing of the methods. The S-methods use iso-octane (S-120), and petroleum ether (30-60 °C) (S-121). The P&CAM methods use hexane as does the NMAM 5503. The technique used for analysis was packed gas chromatograph (GC) with electron capture detector (ECD) detector for all methods. The P&CAM methods combined this technique with perchlorination with $SbCl_5$ (P&CAM253) or quantitation specified by the Webb-McCall method (GC/mass spectroscopi (MS) with electrolytic conductivity detector) (P&CAM244). All the methods used a calibration standard, which also changed over time. The limits of detection (LOD) are not calculated for the earlier methods but are given for the P&CAM methods (32 pico grams per injection) and NMAM 5503 (0.03 μg per sample).

Personal and area air concentrations

Both personal and area air samples were collected throughout the facility. Sipin SP1 pumps were used to collect the air samples in tubes containing a magnesium silicate adsorbent called Florisil. The tubes have a 100 mg primary section and a 50 mg backup section. Samples were collected for two to seven hours at a flow rate of approximately 200 cc/min. The PCBs were desorbed from the Florisil with benzene and analyzed by using a gas chromatograph with an electron capture detector. (NIOSH Survey, 1977)

In addition, NIOSH conducted an exposure survey in 1977 sampling for iron, aluminum, tin, lead, zinc, trichloroethane, trichloroethylene, xylene, toluene, methyl ethyl ketone and ozone. Air samples were collected for ozone during the welding process using MSA Model G pumps with a midget impinger containing approximately 15 ml of an alkaline potassium iodide solution. In 1975 NIOSH industrial hygienist Mark Jones wrote that no industrial hygiene air sampling for PCB had been done at this plant. "This would be a good facility to conduct air sampling as the workers remain at one job location the whole work day." No other potential hazards were noted. (NIOSH Survey, 1976)

Air measurements of 1976

The Hazard Evaluation and Technical Assistance Branch of NIOSH surveyed Westinghouse two times for environmental and medical purposes after receiving complaints from workers who used PCBs. The 1976 survey was to evaluate exposures of Electrical Technicians and Materials Technicians to polychlorinated biphenyls. The survey took place in 1976, in June 1-3, and in September 9. The employees in the materials laboratory and engineering laboratory at Westinghouse, Bloomington, had potential exposure to PCBs. The areas in question were relatively small and approximately 10-12 workers were located there on a routine basis. An interview was done on the first day and blood was collected during the second visit. Only a total of 8 workers were evaluated for PCBs in the blood. Environmental air samples were also obtained in the two laboratories to determine the concentrations of PCBs in the work atmosphere. (NIOSH, 1977).

Another NIOSH survey was done on April 19-22, 1977. Fifty-eight air samples were collected for evaluation of polychlorinated biphenyl exposures. The time-weighted average (TWA) personal air samples ranged from a low of 4 $\mu g/m^3$ for a boilerhouse operator (an area of low exposure) to a high of 162 $\mu g/m^3$ for a capacitor repairman (an area of high exposure). Even those with potentially low PCB exposure had levels well above ambient levels, which were 4 $\mu g/m^3$. The highest concentration was 264 $\mu g/m^3$ for a capacitor repairman (NIOSH Survey, 1977).

Sipin pumps were used to draw air at a flow rate of 50 cc per minute through glass tubes containing Florisil, a magnesium silicate. Both breathing zone and general area samples were obtained in this manner. The samples were taken over the entire workday. Samples were analyzed in the NIOSH laboratories in Cincinnati on a GC equipped with an ECD. Results were reported as total PCB per sample (no distinction as to specific individual PCBs were made). (NIOSH, 1977).

Table 1 Breathing zone and area environmental concentrations of PCBs Westinghouse Bloomington Inc. June 2-3, and September 9, 1976 (NIOSH, 1977)

Sample description	Sample period	Concentration (mg/m^3) Corrected for blanks
June 2, 1976 Breathing zone		
Engineering lab	8:17-15:17	0.026
Engineering lab	8:18-15:15	0.041
Engineering lab	9:12-15:16	0.022
Engineering lab	9:22-15:14	0.073
Engineering lab	9:13-15:25	0.032
Model shop	8:32-15:23	0.021
Model shop	8:35-15:23	0.014
Materials lab	8:05-15:20	0.046
Materials lab	8:05-15:16	0.053
June 2, 1976 Area air		
Materials lab – by hood	8.13-15.20	0.043
Materials lab – by oven	8.12-15.18	0.042
Materials lab – by oven (sample obtained at 1.5 liter/min)	8.54-15.18	0.065
Engineering lab – work bench	7.58-15.11	0.013
Engineering lab – by oven	7.58-15.11	0.264
Engineering lab – by oven (sample obtained at 1.0 liter/min)	8.54-15.18	0.065
June 3, 1976 area air		
Engineering lab – by oven	7.53-12.03	0.210
June 3, 1976 Breathing zone		
Engineering lab	7.53-12.03	0.140
Engineering lab	7.54-12.25	0.160
Engineering lab	7.55-12.25	0.046
Engineering lab	8.05-12.25	0.023
Engineering lab	7.58-12.03	0.043
Model shop	7.55-12.25	0.050
Materials lab	8.00-12.25	0.047
Materials lab	8.00-12.25	0.043
Materials lab	8.02-12.01	0.029
Materials lab	8.02-12.01	0.008
September 9 1976 area		
Engineering lab – by oven	10.04-2.13	0.190
September 9 1976 Breathing zone		
Engineering lab – Short circuit	10.00-2.25	0.028
Engineering lab	10.09-2.23	0.061
Engineering lab	10.09-2.15	0.049
Engineering lab	10.47-2.11	0.066
Engineering lab	10.49-2.13	0.140
Materials lab	10.12-2.19	0.065
Materials lab	10.13-2.19	0.056
Materials lab	10.19-2.19	0.079
New Products	10.24-2.27	0.055
New Products	10.35-2.19	0.080

The highest concentrations were observed near the door to the oven in the Engineering Lab. This contamination may come from the oven itself or from prototype apparatus set on the floor by the oven prior to or after testing. A small hood over the oven door was not in operation at the time of the survey (NIOSH, 1976).

Air measurements of 1977

Table 2 Concentrations of PCB (detected as Aroclor 1016) in personal air samples, Westinghouse April 19-22 1977 (NIOSH Survey, 1977).

Personal air samples					
Job title	Date	Total sampling time (min)	Total volume (liters)	Concentration (μg/m^3)	TWA (μg/m^3)
Process control	4/21	451	87.9	100	67
Process control	4/20	462	89.0	34	
Boilerhouse operator	4/20	377	79.9	n.d.**	4
Boilerhouse operator	4/19	388	83.1	8	
Heaterman	4/20	393	78.7	42	
Heaterman	4/19	418	80.8	74	59
Heaterman	4/21	437	76.3	61	
Power test operator	4/20	444	90.5	48	
Power test operator	4/21	446	82.9	82	71
Power test operator	4/20	346*	69.2	51	
Power test operator	4/21	431	86.2	98	
Final assembly	4/21	449	91.5	46	
Final assembly	4/19	436	90.9	19	28
Final assembly	4/20	438	86.8	34	
Final assembly	4/19	220*	44.0	n.d.	
Solder	4/20	387	83.0	132	
Solder	4/19	445	84.1	69	
Solder	4/19	458	90.7	125	
Hanger	4/21	473	84.9	216	153
Solder/Hanger	4/21	478	93.4	170	
Solder	4/19	452	88.9	122	
Solder	4/21	477	94.8	222	
Miscellaneous Assembly	4/20	461	86.3	171	
Miscellaneous Assembly	4/19	440	92.1	88	
Miscellaneous Assembly	4/21	474	85.7	136	115
Miscellaneous Assembly	4/19	443	92.9	61	
Leak test operator	4/20	458	81.0	50	
Leak test operator	4/19	467	90.4	28	37
Leak test operator	4/21	50*	10.0	n.d.	
Painter	4/20	453	85.5	72	
Painter	4/19	460	100.5	18	52

Painter	4/19	269	53.7	27	
Painter	4/21	460	89.0	82	
Capacitor repairman	4/20	478	89.0	247	
Capacitor repairman	4/21	462	96.2	264	
Capacitor repairman	4/21	460	68.8	142	
Capacitor repairman	4/20	462	86.1	133	
Capacitor repairman	4/19	460	92.4	80	162
Capacitor repairman	4/19	321*	64.2	69	
Capacitor repairman	4/20	462	84.8	168	

*Calculated on assuming a flow rate of 200 cc/min and the known volume

** n.d. – Non detectable (limit of detection 0.01 μg/tube)

The above measurements are summarized below with range and the overall TWA for each of the 10 job titles. Overall there are 515 known job codes (204 for salaried workers and 311 for hourly workers).

Table 3 Summary from the personal air samples of concentrations of PCB (detected as Aroclor 1016), Westinghouse April 19-22 1977 (NIOSH Survey, 1977).

Personal air samples			
Job title	**Number of samples**	**Range (μg/m^3)**	**TWA (μg/m^3)**
Process Control	2	34-100	67
Boilerhouse operator	2	n.d.-8	4
Heaterman	3	42-74	59
Power test Operator	4	48-98	71
Final assembly	4	n.d.-46	28
Solder/Hanger	7	69-222	153
Miscellaneous Assembly	4	61-171	115
Leak test operator	3	n.d.-50	37
Painter	4	18-82	52
Capacitor repairman	7	69-264	162

n.d. – Non detectable (limit of detection 0.01 μg/tube)

Area air samples were taken throughout the plant. The table below is from a NIOSH survey in 1977. The locations are given a letter and a two digit number, corresponding to the plant map (next page).

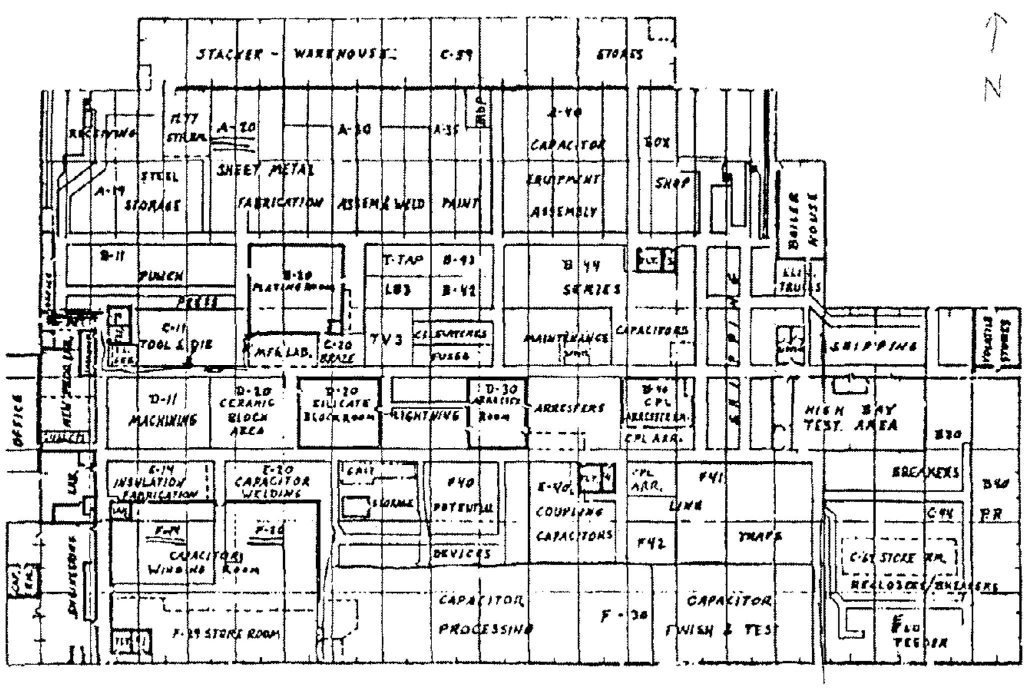
Table 4 Area air concentrations of PCB (detected as Aroclor 1016), Westinghouse April 19-22 1977 (NIOSH Survey, 1977).

Area air samples						
Location		Date	Tot. sampling time (min)	Tot. vol. (L)	Conc. (mg/m^3)	Conc. (μg/m^3)
F-18	Winding	4/21	362	77.8	0.05	47
Office area		4/22	454	48.6	0.03	26
A-20	Sheet metal	4/21	338	74.6	0.03	29
A-35	Paint	4/21	353	76.6	0.01	5
G-44		4/21	356	72.0	0.03	26
F-41	Line traps	4/21	360	71.4	0.05	52

E-50	Feeder	4/21	368	75.6	0.07	71
D-40	Arresters	4/22	435	85.6	0.08	80
D-20	Silicate block	4/22	408	79.3	0.02	20
F-40	Potential	4/22	431	77.9	0.15	146
B-44	Capacitor series	4/22	436	79.0	0.07	65
D-11	Machining	4/22	453	82.9	0.06	60
B-11	Punch	4/22	450	75.3	0.05	50
A-40	Capacitor equipment assembly	4/22	439	92.1	0.05	53
B-30	Plating	4/22	430	88.2	0.08	77
B-20		4/22	448	83.9	0.08	78

Layout

The layout from this period is given below and the names of the locations are taken from this plant layout. There are three areas that are not marked on the layout: office area, G-44 and B-20. The pattern of the numbering starts at A in the north-west corner and numbers the room eastwards, and continues the lettering in alphabetical orders going south. The C-59 area is the only area that does not follow this pattern and it is interpreted as a later addition to the plant.



Westinghouse Bloomington Plant Layout from Approximately 1970 Through Approximately 1977.

DEFENDANT'S DEPOSITION EXHIBIT
Bond #3
3-14-89

Forty personal and sixteen area air samples were collected. The TWA ranged from 4 g/μm^3 for the boilerhouse operator to 162 $\mu g/m^3$ for the capacitor repairman. The peak concentration was 264 $\mu g/m^3$ for a capacitor repairman.

Skin

Skin smears were collected on Whatman smear tabs #50 by wiping the forehead, nose and cheek area of each person. The samples were then analyzed by the same procedure (NIOSH survey of 1977 by Mark Jones). The results of the smear samples are presented in a table. All the smear samples showed an increase between the morning sample and afternoon sample (NIOSH Survey, 1977).

Table 5 Results from smear wipes collected at the Westinghouse facility in Bloomington Indiana on April 19-22 1977 (NIOSH Survey, 1977)

Job title	Weight before (µg)	Weight after (µg)
Solder	8.94	677
Solder	1.17	107
Hanger	2.40	39.1
Solder	6.46	14.0
Hanger	5.89	150
Heaterman	2.64	
Miscellaneous assembly	0.00	9.84
Capacitor repairman	0.85	240
Capacitor repairman	8.94	35.6

Other data

The NIOSH medical investigator attempted to interview and examine all of these workers, conducting medical interviews and physical examinations on the first visit and collecting blood for PCB analysis and liver profile (serum glutamic oxalic transaminase (SGOT), serum pyruvic glutamic transaminase (SGPT), alkaline phosphatase, and total bilirubin) on the second visit. Because of vacations and refusal to cooperate on the part of some employees, a total of eight workers were evaluated. Medical records of approximately 40 additional employees who had worked in these areas in the past were also reviewed." (NIOSH, 1977)

Pre-employment physical examinations were given to all the employees. These examinations include audiograms, eye examinations, and urine analysis along with other routine physical examinations. Periodic examinations were given every two years to those employees that were exposed to chemical hazards. This examination includes those tests conducted for the pre-employment examination plus x-rays and blood tests (NIOSH Survey,1977).

Reference:

NIOSH survey report (1976) December 4, 1975 by Jones, M., Brown, D., Murthy, L., Young, C., Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH)

NIOSH survey report (1977) April 1977 by Jones, M., Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH)

NIOSH (1977) Health Hazard Evaluation Determination Report: Westinghouse Electric Corporation Bloomington IN. Cincinnati, OH: U.S. Department of Health, Education, and Welfare Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) No. 76-52-381.

Chapter 5 Development of the Westinghouse JEM

PCB era at Westinghouse

The start date for when the manufacturing of capacitors at Westinghouse started is not clear. The start dates and end dates for the manufacture of capacitors at Westinghouse tend to vary depending on articles published. The different start and end dates found in the reviewed literature are given in table 1:

Table 1 Start / end dates of manufacture of PCB filled capacitors at Westinghouse, Bloomington, IN

Smith et al (1982)	1958- April 1977
Sinks et al (1992)	January 1957 – March 1977
HHE 76-52-381	Plant in existence in 1957
HHE 84-339-2054	Started in the fall of 1957
HHE 89-116	January 1, 1957 to March 1977
Protocol	Fall of 1957

The manufacture of capacitors started sometime between January 1st 1957 and January 1st 1958. In Westinghouse's family day folder (company comm.)[1] of 1973 it was stated: "The Distribution Apparatus Division of Westinghouse Electric Corporation is located three miles west of Bloomington, Indiana, on a 200 acre tract of land. Ground was broken for the construction of this plant on September 15, 1956 and the doors were officially opened on September 1 1957. After about a year of operation about 300 people were employed at DAD including around 90 experienced technical and management personnel who were transferred from the East Pittsburgh works." From our work history file we found that 21 employees were employed September 1, 1957, and during the month of September, additional workers started working. The first heaterman was hired 10-21-1957, the second 10-28-57, and the third 12-2-1957, which was a unique job code for the manufacture of capacitors. A logical start date would be January 1st 1958.

According to published data, the last date of PCB use was in March or April of 1977. A NIOSH survey was performed in April 1977. In the survey report of December 1977 it was stated: "Currently the plant is changing the insulation oil used in the capacitors from polychlorinated biphenyls to isopropyl biphenyl". When NIOSH was performing the survey the production process was only using PCBs and the production scale was normal. (Personal Communication, 2002)[2] Based on this trip report, the last date PCBs were used must be after April and before December 1977. In a letter from the Westinghouse Manager of Personnel Relations to the President of the Union regarding the dissatisfaction the Union had with the review of the Heaterman job dated October 19, 1977, it was stated: "A further review of this job indicates that some changes have occurred because of the conversion from Inerteen to Wemcol impregnating fluid. Although this conversion has just been completed, other changes in the process will be made during the next several months. Therefore, it is not appropriate to revise the job description until these changes are completed."(Industry communication)[3] From these statements it was concluded that Aroclor use had just ended, and the last date of use should be close to September 30, 1977. However, when NIOSH went back to the plant to microfilm and update the work histories in 1985, the NIOSH investigators only microfilmed

[1] Westinghouse apparently had a day for family members or others to visit the production plant with a guided tour through this area. We have a pamphlet showing and describing this tour done in 1974.
[2] Personal communication with David Marlow, one of the industrial hygienists performing the survey in April 1977.
[3] Letter located in the job code description folder under heaterman jobcode 10BH6

work histories from workers whose blood had been drawn. Later records were unavailable for updating. Most of the microfilmed work histories end on or before April 1, 1977. For the purpose of this exposure assessment we have assumed that the end-date of this study to be April 1st 1977.

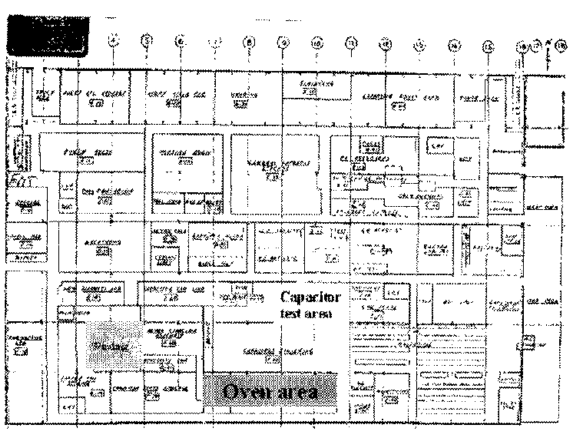
Study population

NIOSH (Brown 1975) wrote in a trip report to Westinghouse Electric Corporation in Bloomington, Indiana, December 4, 1975, that at peak production, there were about 1,000 workers and 15 of these workers were in the capacitor plant, and assessed that approximately 5 people were directly exposed to PCBs on each of the three eight hour shifts.

At the time of the NIOSH survey in April 1977, there were approximately 745 employees; the total number of individuals ever employed was 3643 (Sinks, 1991). NIOSH had estimated that approximately 10% of the work force had had direct involvement in PCB-containing capacitor production (Sinks, 1992).

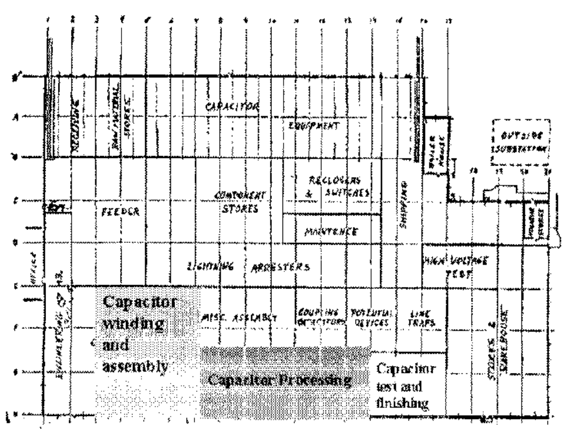
In our work history files the number of workers who worked in March of 1977 was 695. Workers hired on an hourly basis made up 62.5% of the cohort and salaried workers were 37.5%. There were 150 women (20%) at the plant at this time. Of the hourly workers 23% were women. In 1985 when the second blood draws were made, the active workforce was 67.8% hourly workers and 32.2% salaried workers. There were only 5% women at the plant at this time.

Layout



Westinghouse Bloomington plant layout from 1958 through approximately 1965.

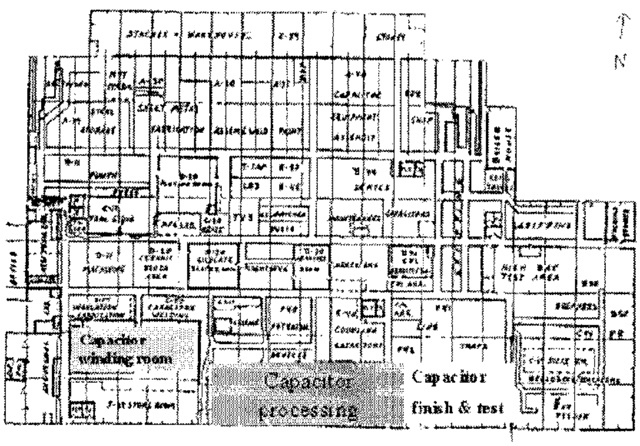
The plant changed its layout over time as shown in detail in chapter 4. Westinghouse has provided three time dependent layouts of the plant; 1958-1965,



Westinghouse Bloomington plant layout from 1965 through approximately 1970

1966-1970, and 1970-1977. The winding area is color-coded pink, the test area yellow, and impregnation area green.

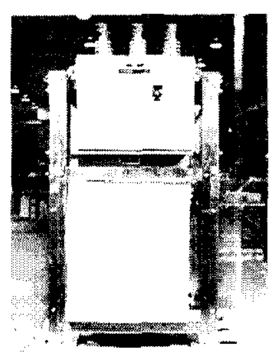
Apparently the capacitor processing area was never moved. The surface contamination build-up of PCBs in this area was considered to be continuous from when production process started in 1958 through end of PCB use in 1977. Other areas in the plant were probably never as contaminated as the oven area, as they might potentially have been if this process had been moved around. However, the impregnation capacitor post-testing, a wet PCB task, was relocated once from 1965-66 (see layouts). The capacitor impregnation area probably became more PCB contaminated at this point. Overall it does not seem like the plant physically changed much throughout the years PCB was in use.



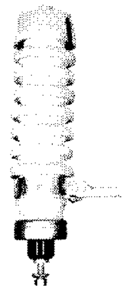
Westinghouse Bloomington plant layout from approximately 1970 through approximately 1977

Process description

Process descriptions were scarce but in 1948 Westinghouse published a book about Power Capacitor Manufacture showing pictures from one of their plants. Since the process description in the survey report from Westinghouse Bloomington dated 1977 and the process description at "a Westinghouse plant" in the book were very similar, we concluded that the Bloomington plant had much in common with the Westinghouse plant pictured in the book which was far better than the trip report on descriptive details of the process. The filling of the capacitors at Bloomington was always done manually, pulling the filling hose/ pipe from the ceiling and inserting the nozzle in the hole of the capacitor top before impregnation in the ovens.



Other descriptive determinants that needed to be assessed include; where the



highest and lowest exposures were, and their causes. Vaporized PCBs may settle on surfaces of the facility, providing exposure opportunity to workers in the plant who did not necessarily have direct contact with liquid PCBs. The highest levels of PCB exposure were expected to be close to the ovens, but the highest concentrations were observed near the door to the oven in the Engineering Lab. This contamination may have come from the oven itself or from prototype apparatus set on the floor by the oven prior to or after a testing. A small hood over the oven door was not in operation at the time of the survey and may explain the high levels of PCB (HHE No. 76-52-381, 1976).

Some workers, because of the nature of their jobs, moved around in the plant and experienced large differences in levels of PCB exposures. In particular, janitors, material handlers, and maintenance workers had great fluctuations in PCB levels on a daily basis. Maintenance could have been needed in the offices one time and later in the process area. In addition to the three exposure determinants: changes in automation, process releases, and mobility of worker; the process frequency also played a role in fluctuating the PCB levels. Workers in the oven area experienced a difference in exposure level according to the production rate and the size of capacitors they produced that day/week/month.

Other processes in addition to the capacitor manufacturing at this plant were: the manufacture of arresters, reclosers, breakers, line traps, potential devices, and tap-switches.

Job titles/ job tasks/ job codes and descriptions

The job code in the work histories were identified as 5-6 characters long with the following characteristics: 1-2 digits, two letters, and consecutive 1-2 digits. Hourly jobs were coded with the letters BH and salaried jobs with the letters BN or BX. The job codes had associated job titles, and all hourly job codes had detailed job descriptions provided by the company. The majority of salaried job codes did not have a job activity description affiliated to it.

In the NIOSH April 1977 survey personal air measurements was only sampled for workers in high exposure jobs. High exposure jobs were identified by the NIOSH investigators based on industrial hygiene professional judgments using information gained during the survey, including production process descriptions and plant layout. Table 2 is a reproduction of a table in the 1977 NIOSH survey report listing the high exposed jobs with descriptions. (The area is added to facilitate the localization of the workers in the layouts provided.)

Table 2 Job code descriptions given in NIOSH survey report, 1977.

Job title	**Area**	**Description of job**
Process control	F-30	Insures that the impregnation chambers are working properly.
Boilerhouse operator	Boilerhouse	In charge of the boiler room and makes sure furnaces are working
Heaterman	F-30	Pumps PCBs into and out of impregnation chambers
Power test operator	F-30	Makes sure the finished capacitors operate properly
Final assembly	A-40	Prepares capacitors for shipping
Solder/Hanger	F-30	Solders impregnation holes, moves capacitor to degreaser and then takes capacitor out of degreaser and places it on an overhead conveyor system.
Miscellaneous assembly	F-30	Works in area near impregnation chambers
Leak test operator	F-30	Tests capacitor to make sure it does not leak
Painter	A-35	Paints capacitor
Capacitor repairman	F-42	Works on capacitors that have failed to pass inspection.

Hourly workers.

Impregnation and wet capacitor sealing processes resulted in considerable levels of PCB in air and surface contamination. There were considerable opportunities for both dermal and respiratory uptake among individuals performing jobs related to these manufacturing operations. Plant maintenance workers, through the nature of their work, spent considerable time in the impregnation, sealing, and washing areas of this plant. Although they were not directly involved in these operations, they were exposed to flooring, absorbent materials on the floor, equipment, and other surfaces contaminated with PCBs. Due to the labor-intensive operation of draining the dielectric fluid from the capacitor, rejected capacitors were disposed of while still containing their original quantity of dielectric fluid (HETA 84-339-2054). NIOSH (D.P. Brown) asked in a letter to Westinghouse October 10, 1975 (Company comm. 3), for the number of workers potentially exposed to PCB. The reply from Westinghouse (Company comm. 4) was as follows: "There are approximately 15 jobs in our factory that require an association with Aroclor No 1016. Most of these jobs are classified as unskilled so the turnover of people on these jobs is very high. Our total work force will vary from 600-1,000. All of these people could possibly have been in a job that required an association with Aroclor No. 1016 at one time or another."

Below are two examples of information given in the detailed job activity description received from the company.

Ex. 1

A description of the job "**Assembler – Capacitors**" at department F-20 Bloomington, Indiana. This document is dated 3/1/72 and has the plant job and occupation no. 2 BH 1 Rev. #3. The description is reproduced below:

1. *Primary function: Connect and solder leads and other components to group assemblies. Assemble group assemblies, detail parts and sub-assemblies for power and low voltage capacitors. Operate stamping machine to stamp nameplates.*
2. *Tools and Equipment: Resistor crimping machine; resistance checker; air press; nameplate stamping machine, spot welder; hand tools such as wire cutters, wrenches, tin shears, knife, temperature controlled soldering iron; clamps; rags; etc.*
3. *Material: Group assemblies, capacitor sections, complete units, paper, fiber, porcelain, lead wires, terminals, resistors, nameplates, identification strips, solder, flux, cot tape, steel wool, etc.*
4. *Direction of others: None*
5. *Working procedure:*
6. *Receive instructions and work assignments from supervisor*
7. *Work from work order, drawings, job instruction sheet, wiring diagrams, written and/or oral instructions*
8. *Materials usually delivered to and removed from work station by conveyor and/ or other means*
9. *Assemble, connect and solder leads and other electrical components to capacitor group assemblies following wiring diagram and/or instructions of supervisor*
10. *Group, cut and solder leads as indicated using knife or other holding device to hold down leads during solder operations*
11. *Make ordinary sub-assemblies such as resistor assemblies. Assemble insulation clip, tin, twist, crimp and solder leads, and perform similar assembly operations as required*
12. *Assemble, connect and/or solder leads, terminals, resistors, insulation and similar parts and materials to group assemblies as required by wiring diagrams or work order. Methods are established.*
13. *Check resistors and resistor assemblies following prescribed operation procedures. Identity and segregate defective parts*

14. *Operate stamping machine to stamp nameplates for a variety of items*
15. *Adjust stamping head according to thickness of material to be stamped*
16. *Locate nameplate-identification strip in guides or fixtures on machines*
17. *Use selection wheel to select type*
18. *Operate machine by hand lever and/or foot pedal*
19. *Group nameplates/identification strips in order and wrap with tape where necessary, to maintain order*
20. *Perform listed duties and similar functions on units or material processed as repair work*
21. *Maintain clean and orderly equipment.*

Ex.2

A description of the job "**Janitor**" at department Maintenance Bloomington, Indiana. This document is dated 3-1-61. The Division is Distribution Apparatus and the plant job and occupation are designated as no. 2 BH 2 Rev. #2. The description is given below:

1. *Primary function: Maintain shop areas, office buildings and washrooms in a clean, neat and orderly condition; maintain adequate washroom supplies; police area surrounding plant.*
2. *Tools and Equipment: Hand truck, electric floor waxer, power sweeper, brooms, mops, buckets, shovel, brushes, rags, etc.*
3. *Material: Cleaning compounds, soap, wax, disinfectants, washroom supplies, etc..*
4. *Direction of others: None*
5. *Working procedure:*
6. *Receives instructions, work assignment and schedule from foreman. May be assigned to maintenance or manufacturing departments*
7. *Perform outlined job duties as they apply on plant grounds, in shop areas and/or office building.*
8. *Sweep and/or wash and wax floors and stairs, and/or operate vacuum cleaner and power sweeper following prescribed routine and schedule*
9. *Wash walls, partitions, windows, glass doors, as required and directed*
10. *Dust, clean, polish or wax office furniture and equipment, including shop offices*
11. *Remove waste paper, trash, sweepings, empty cartons and similar material from in and outside plant to designated areas. Burn trash as required.*
12. *Empty waste containers including trash trailers and spot at designated locations*
13. *Clean washrooms, toilets, cloakrooms, and drinking fountains, and maintain in sanitary condition. Utilize disinfectant as required or directed. Keep dispensers filled. Replace clerical lamps. Notify supervisor of needed supplies; obtain supplies from storeroom*
14. *Clean machines, conveyors, equipment, workbenches, and storage areas as required.*
15. *Maintain clean and orderly equipment and storage area.*

The job that resulted in the highest PCB exposures was that of a heaterman. An extract from the detailed job activity:

Heaterman: The materials were usually delivered to and removed from work area by conveyor and / or piping. The heaterman had to operate a semi-automatic transfer truck load and unload trays from pre-heating and impregnating ovens, place capacitors on, position and remove from conveyors, and open and close oven doors. After the flood filling was done, the heaterman would clean ovens and tanks, and drain drip pans. Then this worker would prepare for a new load, adjusting the temperature, check and adjust connections and pressure, operate oil upgrading equipment to remove gasses, moisture and other impurities from capacitor impregnating oil. The heaterman would load and unload clay additive from thermostatically controlled oven, clean filter press and tower of spent clay, place in containers for removal.

In a letter dated February 1st 1990 to the Indiana State Board of Health (ISBH) the NIOSH investigator wrote (Government comm.):

"We have completed most of the detailed job history coding for the Westinghouse Electric Corporation Mortality study. As I mentioned before, the department codes have been used to place workers at a site in the plant rather than identity specific job tasks. I believe this is warranted since polychlorinated biphenyl (PCB) exposure was (primarily) a consequence of proximity to the point source exposure from the ovens. While I have located all departments within the plant, work areas for a few salaried workers remain unclear. Listed below are the salaried job titles of those jobs with remain to be placed within the Westinghouse facility. Please try to locate each job within the facility by primary work area (A-G by ##)."

Table 3 Salaried job titles where location was missing was filled out (work area) in a letter from ISBH in February of 1990 (NIOSH letter 02-01-90 to Indiana State Board of Health). It is not understood where some of these work areas were situated.

Department code	Job title	Job number	Work area
Electrical Test			
	Senior Maint Tech	14BN2	140
	Maintenance Tech	12BN7	140
	Electrical Tech A	11BN4	140
	Electrical Repair Tech	12BN6	140
	Ceramic Tech A	11BN3	420
	Electrical Tech B	9BN7	420
	Electrical Tech C	6BN13	420
	Electrical Checker	3BN1	630
Drafting			
	Layout Draftsman	14BN1	900 Main office
	BMP Loader Coordinator	12BN14	900 Main office
	Layout Draftsman B	12BN9	900 Main office
	Detail Draftsman A	10BN1	900 Main office
	Detail Draftsman B	8BN17	900 Main office
Model Maker			
	Model Maker A	9BN3	C11 - 311
	Model Maker B	6BN6	C11 – 311

Industrial engineer		
Routing and Time Standards Cl	9BN9	900 Main office
Tool Designer	13BN2	900 Main office
Traffic Clerk	10BN15	350 Shipping
Materials Tech		
Materials Engineering Tech A	1BN6	900 Main office
Materials Engineering Tech B	9BN8	900 Main office
Materials Engineering Tech C	6BN15	900 Main office
Inspection		
Master inspector	12BN5	241
Order Inspector	12BN4	Throughout the plant
Inspector A	10BN4	Throughout the plant
Inspector B	8BN9	
Inspector C	6BN11	

Salaried workers were generally exposed to a lesser degree than hourly workers. They usually served as some form of supervisor and hence had an office, e.g. location main office, or they had overseer jobs and spent a minimum amount of time in the area where the hourly workers performed their tasks. All the job codes (n=884 from 1958-77) in this cohort were assessed for exposure determinants such as activities, mobility, and plant location. Descriptions of all job codes are given in Appendix A.

Other classification schemes

In Sinks *et al.* (1992), PCB exposures were assessed using several proxy measures including years since first employment, duration of employment, and three different weighting schemes for estimated cumulative exposure based on where in the plant the employee worked. Estimated cumulative dose measures were developed using knowledge of the manufacturing process and available environmental data, assuming airborne and dermal exposure to PCBs decreased with increasing distance from the chambers/ovens (used for impregnation of capacitors with dielectric fluid containing PCBs). For the first classification scheme (called cumulative PCB1), office areas, deemed to have the lowest exposure, were given a weight of 1 (and called Zone 1). Four additional zones were designated, with the highest exposure occurring closest to the vacuum chambers.

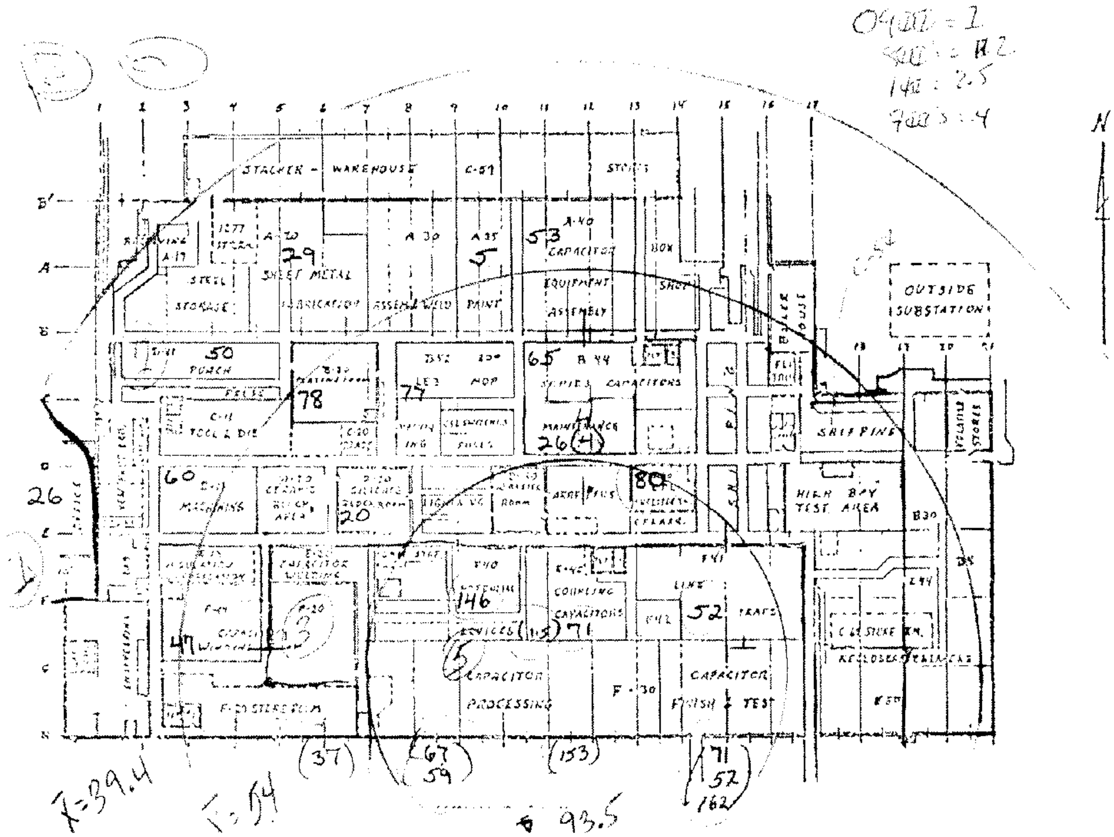


Figure 1 Sinks *et al.* (1991) exposure scheme

The production area was divided by three equi-distant and constructed semi-circles centered on the impregnation ovens. The zone surrounding the capacitor impregnation ovens was assigned an exposure score of 5 based on the environmental sampling results. The process area furthest from the ovens was assigned an exposure score of 2 (Zone 2) and the area adjacent to the ovens a score of 3 (Zone 3). Departments were assigned an exposure weight according to the zone which contained 50% or more of that department. If a department was equally divided by two zones, it was assigned an average weight. Maintenance workers were assigned to Zone 5 if they worked in department F-44, located within Zone 5, or to Zone 4 (n=34) if their primary work area was in Zone 3 but they were called upon to work in Zone 5. The paint area (Department A-35; n=36) was reassigned a score of 1 because it was isolated from the remainder of zone 2, had a separate ventilation system, and had the lowest reported area PCB air sample result (5 μg/m^3). Hourly workers who could not be located by department (n=125) were assigned to Zone 2.

Each worker's cumulative exposure to PCBs was calculated by multiplying the number of days worked in each zone by its weight, and summed across all work histories. Five cumulative dose estimate (CUMYR) units were equivalent to working in Zone 5 for one year or working in Zone 1 for five years. While the environmental data lend support to the weighting system for CUMYR, these data include only 14 area samples collected outside Zone 5. Since the accuracy of CUMYR could not be verified, Sinks *et al.* estimated cumulative PCB exposure using two additional weighting schemes. One estimate (DURZONES) was based on the serum PCB data, assigning a weighting factor of 1 to Zones 1-4 and a weighting factor of 5 to Zone 5. The second estimate (CUM2.5) assumed no exposure difference in Zones 2-4, which were weighted by a factor of 2.5. Zone 1 and Zone 5 retained their original weights.

Table 4 Environmental measurements used to calculate doses for their zones Sinks *et al.* (1991)

Environmental Measurements

	Zone 1			Zone 2			Zone 3			Zone 5		
Sampling type	N	mean	(sd)	N	mean	(sd)	N	mean	(sd)	N	mean	(sd)
Area air	2	16 μg/m^3	(15)	4	48 μg/m^3	13	8	59 μg/m^3	19	4	76 μg/m^3	52
Personal	ns			ns			ns			38	94	68

Serum measurements; μg/L

	Salaried			Hourly Zone 2			Zone 3			Zone 5		
Current job	66	126	101	51	199	377	23	98	45	71	305	479
Only worked in	36	119	26	7	121	61	5	100	27	8	763	1117

n.s. = not sampled
No environmental or serum data were collected for Zone 4
Salaried workers could not be separated into exposure zones according to serum PCB values.

Additional chemical exposures

During the NIOSH surveys at Westinghouse other chemical exposures in addition to PCBs were measured. Metallic fumes arise when heat is applied to metal as it is in welding and soldering processes. The NIOSH team of 1977 collected air samples for aluminum and iron during the welding operations and for zinc, tin and lead during soldering operations. Organic vapors were released in areas where painting or cleaning operations were performed. During the same survey air samples were collected for toluene, xylene and methyl ethyl ketone during painting operations and for trichloroethylene and 1,1,1-trichloroethane during degreasing and cleaning operations.

Categorization of job codes

In the development of the JEM three sources were used to categorize the job codes: Knowledge of the capacitor manufacturing process and other processes taking place at the plant, the layout of the plant and location of the processes, and description of all hourly job codes.

Salaried workers

We started categorizing the job codes by eliminating all empty job codes, e.g. job codes that were not assigned to any worker in the timeframe of the cohort study (some job codes were carried over from other plants with same owner). Then we separated the hourly workers from the salaried workers because the salaried workers' exposure levels, differed due to their type of job activity. The salaried job codes were easily identified as non-BH codes. The salaried workers were assigned their own category (cat. 19).

Hourly workers

The hourly workers were then divided into "capacitor processing" or "non-processing capacitors". "Non-processing capacitors" include, for example, maintenance of the facility, tool and die makers, construction welders, and boilerhouse workers. The two groups were very diverse, and needed several sub-categories to reflect their differences. The "non-capacitor processing" group was divided into similar job activity categories, as for example: boilerhouse workers were separated out due to their difference from all other groups (cat. 13) (not being part of any manufacturing processes at the plant).
See Appendix B for categorization of the job codes.

Other production processes such as breakers, reclosers, switches, and potentials manufacturing, were operating at the same time as the capacitor manufacturing. Recloser manufacturing was located in only two areas, and did not involve the use of PCBs. However, these areas were next to capacitor salvage and repair and hence the PCB air concentration levels in these areas would be elevated. Because of this the recloser workers have their own group (cat. 5). Arrester manufacturing (cat. 11) was separated out in to area D (see layout) of the plant and involved the use of dry ceramic oxide powder and a kiln. These two exposure components; inorganic dust and elevated temperatures, may impact PCB exposures in this area by PCB aggregating on the surface of the powder and evaporating at a higher rate due to elevated temperature, in spite of PCBs not being used in this particular process. The arresters were also treated with zinc oxide. Other metal plating jobs were also performed at this plant. Workers exposed to metal fumes were separated out into one group (cat. 16). The research and development department made new or custom-ordered capacitors. Their jobs were hands-on, involving direct contact with PCBs but to a much lesser extent than production workers. Depending on what the research and development employees were currently working on, they were located in the A area or in F20 (cat. 6). Machines were designed to make assembly lines work faster and more efficient. Workers who operated these types of machines were categorized together based for the most part on their similar job activities, not so much location, although none of these workers worked in the F30 area (cat. 15).

Pre-assembly included two processes: metal shearing for making the capacitor casings which involved metal cutting, bending, stamping etc., and coil and foil and paper winding. The case and the wound insert were assembled prior to any contact with PCB. The pre-assembly jobs were not all similar and hence they were divided into four categories: inspectors and testers (cat. 9), pre-assembly & process control (cat. 10), welding, braze and solder (cat. 12), and film and winding (cat. 17). Working with metal, performing operations such as welding, brazing, soldering, bending etc. were associated with hazards that were not encountered in the three categories 9, 10, and 17, and for this reason were separated out (cat. 12). Winding, foil and coil were regarded as the cleanest part of a capacitor process because if dust was trapped in the coils this would have interfered with the conductivity of the capacitors. Due to this, category 17 was reserved for workers in these departments. The water leak testers who tested the casings for leaks prior to the fill station were included in the inspectors and testers category (cat. 9). After separating out these three very different job activities in the pre-assembly, the rest of the pre-assembly job codes were kept in one category (cat. 10).

The next major step in the process was filling the pre-fabricated casings with PCB. The job activities associated with this job were very distinct: the fill and solder operator, the manifold fill operator, and the heaterman. The commonality was their high degree of contact with PCBs, which was high but according to air measurements not as high as that of the leak tester or the salvage and repair workers.

After filling the capacitors with PCBs, the capacitors arrived at what was known as post-assembly. They were received on an assembly line from the impregnation oven and the post-assembly workers set up workstations to assemble coupling capacitors, load and unload semi-finished capacitors in and out of machines, trays, or bands. The commonality for this group of workers was the handling of semi-finished capacitors and units, which had just been filled with PCBs and had not yet been sealed (cat. 18). The capacitors were then sealed and washed free of PCBs. Some capacitors were spray-painted. Mixed-epoxy resin was used in the paint. We do not know what type of epoxy resins were used at Westinghouse. In addition, spray-coating generated aerosols, which increased the potential for inhalation exposure of paint. Other chemical exposures were reasons for keeping these job codes separately (cat. 15). Leak testers tested the capacitors for performance after impregnation, and this was a very greasy job. Workers set-up and conducted tests to determine the condition of returned apparatus, and leaking capacitors were set aside on pallets for later transport to the repair station. The testers were placed in their own category (cat.3).

Capacitors which had passed all tests were ready to be shipped. Category 7 consists of jobs for which workers who received, counted, packed, sorted, and stored capacitors, in addition to identifying all types of incoming loads of materials in receiving areas. The packing task included packing apparatus material and/or parts in standard packing containers. Boxes and crates were made from cutting sheets.

The workers who transported the capacitors from one place to the next when they were not loaded on to conveyor belts were the material handlers. These jobs were categorized together with the truck drivers due to their similar exposure patterns. The similarity between a material handler, truck driver and driver would be their constant touching of contaminated surfaces like the steering wheel, machinery, and other equipment (material handler and driver cat. 8).

If the capacitors did not meet their specifications they were sent to salvage and repair (cat.1). The similar exposure determinants for this category, was that the job codes involved repairing and / or salvaging capacitors already filled with PCBs. The repair workers had to open the sealed capacitors and repair the faults such as switches or loose couplings. The salvage personnel worked with irreparable PCB filled capacitors. These job activities were performed throughout the plant, but two patterns can be detected:

repairs in the E and F areas were where in the periphery of the oven areas. The A and B areas were located further away from the ovens in the same building.

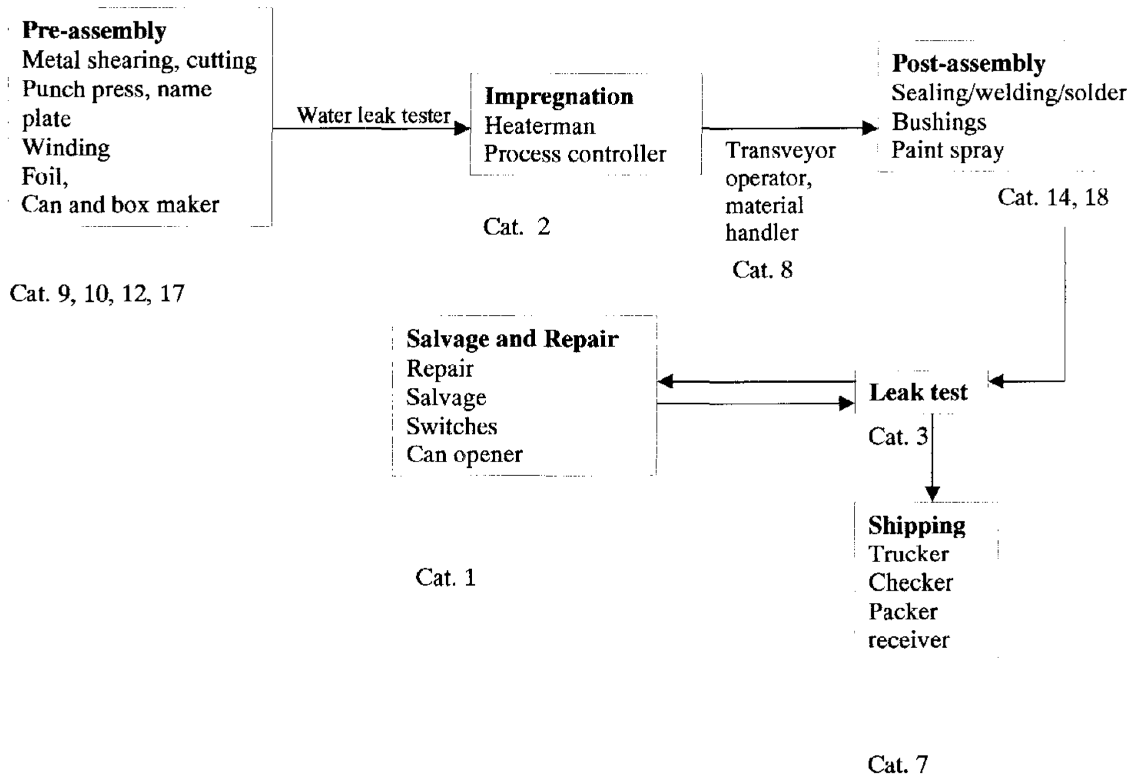


Figure 2 Flow chart of the Westinghouse process with some key job operations. For further details see appendix B and C

Ranking of categories

When all job codes were ranked on previously determined exposure determinants (job description/job task or title, hygiene information, air levels, proximity to PCB source, process description, chemical use, job labor involved, temperature, and ventilation), and collapsed into 19 categories, the ranking of exposure intensity and exposure frequency for each category was performed. For each category, intensity needed to be assessed. Sinks *et al.* (1992) assigned an intensity scale from 1 through 5. We believe we have sufficient information to do more than just classifying the jobs as exposed or not exposed but do not have enough information to divide the categories into five exposure intensity rankings. Our intensity ranking will be high, medium, low and background exposure.

Inhalation intensity

Four categories were ranked as high inhalation exposure intensity; salvage and repair (cat. 1), fill, solder and impregnate (cat. 2), and leak tester (cat. 3). Only category 8 (Material handlers & drivers) was ranked with medium inhalation intensity. Low inhalation intensity was assigned to the rest of the categories (4-7, 9-18) except for salaried jobs (cat. 19) which were assigned background exposure to PCB.

Dermal intensity

The assignment of dermal exposure intensity corresponded with the assignment of inhalation exposure intensity except for maintenance (cat. 4), research & development (cat. 6), checker/receiver/packer/shipping/stocker (cat. 7), material handler & drivers (cat. 8), and post-assembly (cat. 18). These categories were given a dermal intensity of medium. In maintenance, inhalation intensity was low but these workers touched surfaces that were heavily contaminated with PCBs. When new capacitors were tested, it was inevitable to avoid dermal contact with the PCB oil. Checkers and receivers (cat. 7) handled everything from PCBs to sealed capacitors, and cleaned up spills after leaks or accidents. Post-assembly (cat. 18) tasks involved direct contact with PCBs although not to the extent salvage and repair job tasks would.

Each job task involved several activities with associated exposure intensities, some of the activities were repeated throughout a workday, others occurred weekly or monthly. If the various activities performed during a work day, work week or month had the same or approximately the same exposure intensity, then continuous frequency was assigned. If the activities varied in intensity, then the frequency was assigned intermittent. All other categories were assigned continuous inhalation frequency.

Inhalation frequency

Six of the 19 categories were assigned intermittent frequency for inhalation exposure: salvage and repair (cat. 1), leak tester (cat. 3), maintenance (cat. 6), research and development (cat. 4), checker and receiver (cat. 7), material handler, drivers, and process control (cat. 8). The exposure to salvage and repair workers depended on the production rate of faulty capacitors, which likely varied; therefore this category was assigned an intermittent inhalation exposure. The same rationale was used for leak testers and maintenance workers. Research and development personnel experienced fluctuating exposures depending on the activity of the day. The rest of the categories were assigned continuous inhalation frequency.

Dermal frequency

Three categories were assigned intermittent dermal frequency because: maintenance (cat. 4) was performed in areas with low and high exposure areas, giving a variable dermal exposure; checkers and receivers (cat.7) would primarily be dermally exposed during occasional spills, and research & development (cat. 6) would be dermally exposed depending on the periodically experiments performed with PCBs. As opposed to inhalation frequency, dermal frequency was considered continuous for salvage and repair, leak tester, and material handler, drivers, and process control workers. Their workplace surfaces always had levels of PCB contamination.

Table 5 JEM with inhalation and dermal exposure intensity and frequency rating for all categories.

Cat.	***Cat name***	**Inhalation**				**Dermal exposure**			
		Intensity	*Frequency*	*Intensity*	*Frequency*	*Intensity*	*Frequency*	*Intensity*	*Frequency*
1	*Salvage and repair*	high	intermittent	medium	intermittent	high	continuous		
2	*Fill, solder, and impregnate*	high	continuous			high	continuous		
3	*Leak tester*	high	intermittent	medium	intermittent	high	continuous		
4	*Maintenance*	low	intermittent	background	intermittent	medium	intermittent	low	intermittent
5	*Recloser*	low	continuous			low	continuous		
6	*Research and development*	low	intermittent	background	intermittent	medium	intermittent	low	intermittent
7	*Checker / receiving / packer / shipping / stock*	low	intermittent	background	intermittent	medium	intermittent	low	intermittent
8	*Material Handler, truck driver, driver*	medium	intermittent	low	intermittent	medium	continuous		
9	*Inspectors and testers*	low	continuous			low	continuous		
10	*Pre-assembly*	low	continuous			low	continuous		
11	*Arresters*	low	continuous			low	continuous		
12	*Welding (incl. Assemble and weld), Braze and solder*	low	continuous			low	continuous		
13	*Boiler*	background	continuous			low	continuous		
14	*Set-up and / or operate wet machines*	low	continuous			low	continuous		
15	*Set-up and / or operate dry machines*	low	continuous			low	continuous		
16	*Electroplating, Metal oxide*	low	continuous			low	continuous		

	processing				
17	*Film, Winding*	low	continuous	low	continuous
18	*Post-assembly*	low	continuous	medium	continuous
19	*SAL*	background	continuous	background	continuous

All areas of the plant were considered exposed to PCB. The value for the PCB background level was based on measurements taken in areas where PCBs were never used. Air measurements from the offices guided the determination of the background concentration. Only one area air measurement was available, and gave a background level of 25 $\mu g/m^3$. All boilerhouse (cat. 13) and salaried (cat. 19) worker tasks were assigned background exposure on a continuous basis

The air concentration measurements from the 1977 survey were used to assign values for the high, medium, low, and background intensity ratings. The total range of the air concentrations gave approximate boundaries for minimum and maximum values for this JEM (n.d. – 264 $\mu g/m^3$). The ranges of personal air measurements for the 3 intensity exposure groups were: n.d.-82 $\mu g/m^3$, 61-171 $\mu g/m^3$, and 42-264 $\mu g/m^3$ for low, medium, and high, respectively. The qualitative job category rankings were based on exposure determinants. Since few air concentration measurements for a small fraction of the job titles at the plant were available, the air measurements were used only to guide assignments of air concentrations to job categories. The baseline value was based on the single area air concentration from the office area and was assigned 25 $\mu g/m^3$. The values assigned to the low, medium, and high exposure groups were: 50 $\mu g/m^3$, 140 $\mu g/m^3$, and 230 $\mu g/m^3$, respectively. Inhalation and dermal exposures were weighted equally.

Category 1 Salvage and repair: Seven personal air samples were collected for capacitor repairmen, with an average of 162 $\mu g/m^3$ and a range of 69-264 $\mu g/m^3$. The salvage and repair category (cat. 1) was ranked intermittent high for inhalation exposure and continuously high for dermal exposure.

Category 19 Post-assembly: Personal samples for final assembly had an average level of 28 $\mu g/m^3$ and range [n.d.-46], and those for painter average 52 $\mu g/m^3$ [18-82 $\mu g/m^3$]. The painting area had an area air measurement of 5 $\mu g/m^3$. Category 19 was ranked as continuously low for inhalation and continuously medium for dermal exposure.

Frequency. Continuous frequency exposure indicated that the exposure did not fluctuate much across the category. Intermittent frequency exposure accounts for fluctuation of intensity across within a job code within a category. A category with intermittent frequency to one intensity level also needed a second intensity assignment to account for the intensity of exposure for the balance of their workday. The primary intensity level was based on the highest intensity tasks performed. The secondary intensity level, accounting for the balance of the day, was assigned as the next lowest intensity level. Thus continuous frequency exposure indicates exposure over the entire day, week or month – a constant exposure at the assigned intensity. Intermittent frequency exposure accounts for fluctuating PCB exposure levels.

The *value* calculated for exposure is frequency multiplied with intensity. For categories with intermittent exposure this is performed twice. Frequency was used as a multiplicative weighting factor for the assigned intensity levels. Continuous exposures were weighted by 1 and intermittent exposures by 0.5.

Table 6 Inhalation values for all categories

Cat.	***Cat name***	**Inhalation** μg/m^3					**Inhalation values**
		Rank	*Primary Intensity*	*Primary Frequency*	*Secondary Intensity*	*Secondary Frequency*	
1	*Salvage and repair*	H	230	0.5	140	0.5	185
2	*Fill, solder, and impregnate*	H	230	1			230
3	*Leak tester*	H	230	0.5	140	0.5	185
4	*Maintenance*	L	50	0.5	5	0.5	27.5
5	*Recloser*	L	50	1			50
6	*Research & development*	L	50	0.5	5	0.5	27.5
7	*Checker / receiving / packer / shipping / stock*	L	50	0.5	5	0.5	27.5
8	*Material handler & driver*	M	140	0.5	50	0.5	95
9	*Inspectors and testers*	L	50	1			50
10	*Pre-assembly & process control*	L	50	1			50
11	*Arresters*	L	50	1			50
12	*Welding, braze & solder*	L	50	1			50
13	*Boiler*	B	25	1			25
14	*Set-up and / or operate wet machines*	L	50	1			50
15	*Set-up and / or operate dry machines*	L	50	1			50
16	*Electroplating, Metal oxide processing*	L	50	1			50
17	*Film, Winding*	L	50	1			50
18	*Post-assembly*	L	50	1			50
19	*SAL*	B	25	1			25

Table 7 Dermal values for all categories

Cat.	Cat name	Dermal intensity					Dermal values
		Rank	Primary intensity	Primary frequency	Secondary intensity	Secondary frequency	
1	Salvage and repair	H	230	1			230
2	Fill, solder, and impregnate	H	230	1			230
3	Leak tester	H	230	1			230
4	Maintenance	M	140	0.5	50	0.5	95
5	Recloser	L	50	1			50
6	Research and development	M	140	0.5	50	0.5	95
7	Checker / receiving / packer / shipping / stock	M	140	0.5	50	0.5	95
8	Material handler & driver	M	140	1			140
9	Inspectors and testers	L	50	1			50
10	Pre-assembly & process control	L	50	1			50
11	Arresters	L	50	1			50
12	Welding, braze & solder	L	50	1			50
13	Boiler	B	25	1			25
14	Set-up and / or operate wet machines	L	50	1			50
15	Set-up and / or operate dry machines	L	50	1			50
16	Electroplating, Metal oxide processing	L	50	1			50
17	Film, Winding	L	50	1			50
18	Post-assembly	M	140	1			140
19	SAL	B	25	1			25

The chart below shows how categories are ranked for dermal and inhalation exposure:

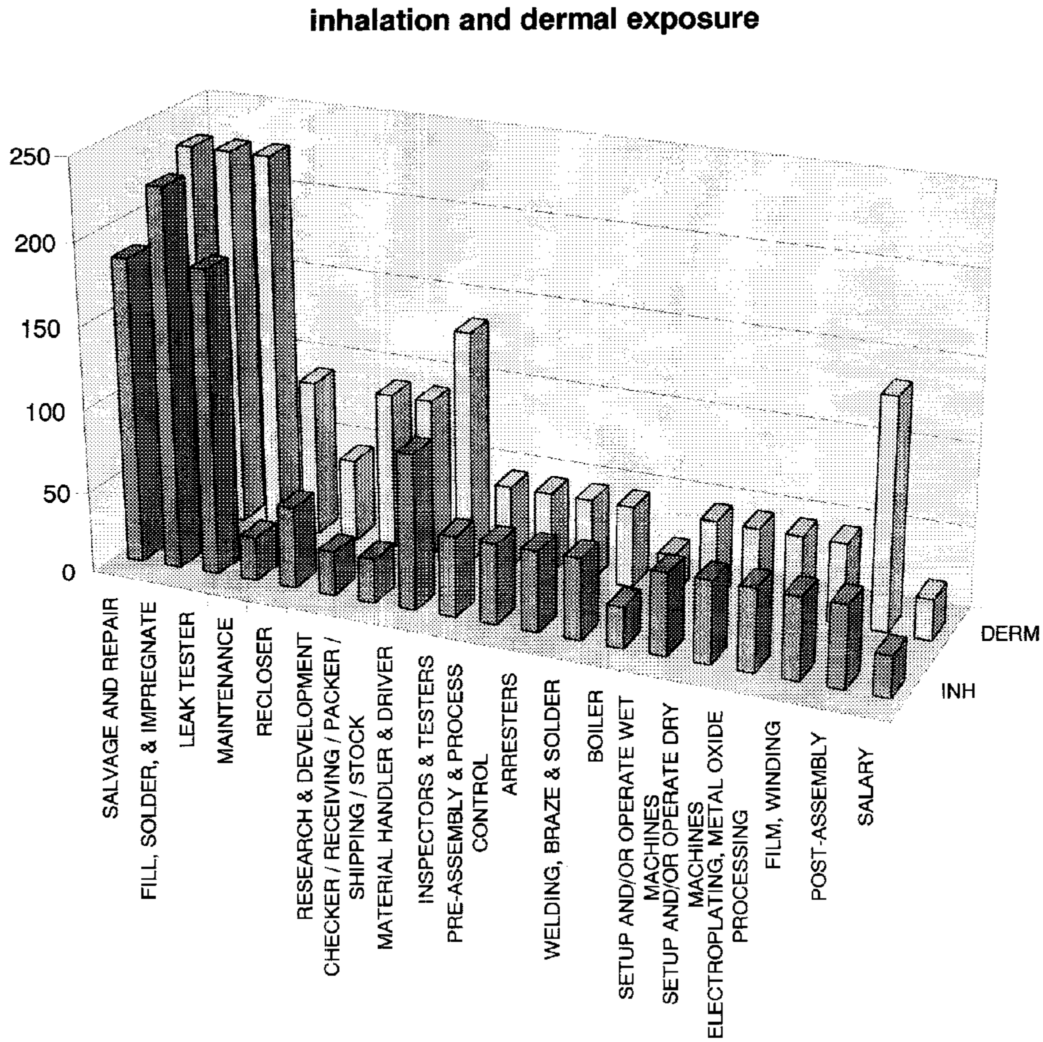


Figure 3 Inhalation and dermal exposure values for each category (n=19)

Table 8 Dermal and inhalation exposure values based on intensity multiplied with frequency (primary and secondary)

Cat.	*Cat name*	**Dermal exposure**				**Dermal values**	**Inhalation exposure**				**Inhalation values**
		1° intensity	*1° frequency*	*2° intensity*	*2° frequency*		*1° intensity*	*1° frequency*	*2° intensity*	*2° frequency*	
1	*Salvage and repair*	230	1			230	230	0.5	140	0.5	185
2	*Fill, solder, and impregnate*	230	1			230	230	1			230
3	*Leak tester*	230	1			230	230	0.5	140	0.5	185
4	*Maintenance*	140	0.5	50	0.5	95	50	0.5	5	0.5	27.5
5	*Recloser*	50	1			50	50	1			50
6	*Research & development*	140	0.5	50	0.5	95	50	0.5	5	0.5	27.5
7	*Checker / receiving / packer / shipping / stock*	140	0.5	50	0.5	95	50	0.5	5	0.5	27.5
8	*Material handler & driver*	140	1			140	140	0.5	50	0.5	95
9	*Inspectors & testers*	50	1			50	50	1			50
10	*Pre-assembly & process control*	50	1			50	50	1			50
11	*Arresters*	50	1			50	50	1			50
12	*Welding, braze & solder*	50	1			50	50	1			50
13	*Boiler*	25	1			25	25	1			25
14	*Set-up and / or operate wet machines*	50	1			50	50	1			50
15	*Set-up and / or operate dry machines*	50	1			50	50	1			50
16	*Electroplating, Metal oxide processing*	50	1			50	50	1			50
17	*Film, Winding*	50	1			50	50	1			50
18	*Post-assembly*	140	1			140	50	1			50
19	*Salaried workers*	25	1			25	25	1			25

Developing the JEM

The process of how we developed our job exposure matrix (JEM) can be summed up in five 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 20 categories,

(3) for each category, exposure intensity (high-medium-low-baseline) and frequency (continuous-intermittent) were qualitatively rated separately for inhalation and dermal uptake,

(4) for each category, the product of intensity (assigned based on the air sampling data) and frequency (fraction of day exposed) was calculated, and

Each job code was then assigned to one of the twenty exposure groups.

We consider the earlier time period to be of a more polluted character than the later JEM. In order to show this, the already developed JEM needs to be multiplied with a modification factor. This modification factor does not represent the weight between the JEMs, it is used for the purpose of distinguishing the two. Below is the schematically overview of the matrix where I is inhalation value, F is frequency value, inh is inhalation, derm is dermal, ACE is additional chemical exposure:

$$Combo\text{-}JEM = f_{era}\{ \tfrac{1}{2} [(I_1F_1+I_2F_2)_{inh}] + \tfrac{1}{2} [(I_1F_1+I_2F_2)_{derm}]\} : ACE$$

⇓ where $I_1F_1+I_2F_2$=exposure level (EL)
DEL for dermal exposure level
IEL for inhalation exposure level

Combo-JEM = f_{era} [½ IEL + ½ DEL]
f_{era} where era=1 1958-1967 f=1.2
f_{era} where era=2 1968-1977 f=1.0

for the two separate JEMs:

Inhalation-JEM = f_{era} IEL
Dermal-JEM = f_{era} DEL

Figure 4 The formula for the job exposure matrix. The group with its inhalation and dermal metrics are adjusted with a factor f, for difference over time. ACE is additional chemical exposure, f is modification factor.

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