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Polychlorinated Biphenyls (PCB's):

Potential Health Hazards from Electrical Equipment Fires or Failures



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

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FOREWORD

Current Intelligence Bulletins (CIB's) are reports issued by the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control, Atlanta, Georgia, for the purpose of disseminating new scientific information about occupational hazards. A CIB may draw attention to a hazard previously unrecognized or may report new data suggesting that a known hazard is either more or less dangerous than was previously thought.

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Because of the recent attention given to human exposure to polychlorinated biphenyls (PCB's), polychlorinated dibenzofurans (PCDF's), polychlorinated dibenzo-p-dioxins (PCDD's), and related compounds resulting from electrical equipment fires or failures, we think it necessary to present a review of the pertinent data and a summary of findings related to the potential human health hazards of these compounds. Because the voluminous literature on PCB's, PCDF's, and PCDD's has been compressed in this bulletin, it is suggested that readers wanting additional details of the reported studies consult the appended references.

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CURRENT INTELLIGENCE BULLETIN #45

POLYCHLORINATED BIPHENYLS (PCB's): POTENTIAL HEALTH HAZARDS FROM ELECTRICAL EQUIPMENT FIRES OR FAILURES

FEBRUARY 24, 1986

ABSTRACT

Numerous fire-related incidents involving electrical equipment containing polychlorinated biphenyls (PCB's) have resulted in widespread contamination of buildings with PCB's and, in some cases, with polychlorinated dibenzofurans (PCDF's) and polychlorinated dibenzo-p-dioxins (PCDD's), including 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Emergency response personnel, maintenance or cleanup workers, or building occupants may be exposed to the compounds by inhalation, ingestion, or skin contact.

In experimental animal studies, exposure to PCB's, PCDF's, or PCDD's has resulted in various effects, including decreased body weights, hepatic lesions, thymic atrophy, and adverse reproductive effects, at a wide range of exposure concentrations. In addition, PCB's and TCDD have been shown to be carcinogenic in rats and mice. Humans exposed to PCB's, PCDF's, or PCDD's have developed chloracne, gastrointestinal disturbances, elevated serum enzyme and triglyceride levels, and numbness of the extremities. Epidemiologic studies of humans exposed to PCB's or PCDD's including TCDD are suggestive of an association between exposure to these compounds and increased incidences of cancer.

Based on existing evidence, the National Institute for Occupational Safety and Health (NIOSH) continues to recommend that PCB's and TCDD be regarded as potential human carcinogens in the workplace. Existing evidence also suggests that PCDF's may pose a risk to human health. Therefore, NIOSH recommends that occupational exposure to PCB's, PCDF's, and PCDD's resulting from electrical equipment fires or failures be controlled to the lowest feasible limit, and that workers involved in decontamination activities use all necessary protective measures to prevent exposure.

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BACKGROUND

Physical and Chemical Properties of Polychlorinated Biphenyls (PCB's)

Polychlorinated biphenyls (PCB's)* comprise a class of nonpolar chlorinated hydrocarbons with a biphenyl nucleus in which any or all of the hydrogen atoms have been replaced by chlorine [1]. Commercial PCB's are mixtures of isomers of chlorinated biphenyls exhibiting varying degrees of chlorination. Although there are 209 possible positional chlorobiphenyl isomers, only 100 individual isomers are likely to occur at significant concentrations in commercial PCB mixtures [2].

In pure form, the individual chlorobiphenyl isomers are colorless crystals, but the commercial mixtures are liquid due to depression of the melting points through interaction of the individual isomers [3]. The physical and chemical properties of the individual isomers vary widely according to the degree and to the position of chlorination. The PCB compounds have low solubilities in water (0.007 to 5.9 milligrams per liter) [3] and low vapor pressures (10^{-6} to 10^{-3} millimeters of mercury at 20°C) [1]. PCB's are soluble in most of the common organic solvents, oils, and fats. The compounds are stable to acids and alkali and are resistant to oxidation but are subject to photodechlorination when exposed to sunlight (spectral region above 290 nanometers) [1].

Use of PCB's in Electrical Equipment

Commercial products containing PCB's were widely distributed between 1957 and 1977, when large quantities of PCB's were manufactured in the United States and marketed under the trade name Aroclor®. The Aroclor products were designated by numbers such as 1221, 1242, 1248, 1254, and 1260, with the last two digits representing the approximate percent by weight of chlorine in the mixtures. Aroclor 1016, however, contained 41% chlorine [1].

Properties of PCB's such as thermal stability, nonflammability, and dielectric capability resulted in their use in electrical capacitors and transformers. Electrical capacitors (small and large) contained nearly 100% PCB's [4]. Small capacitors containing 0.1-0.6 pound of PCB's were commonly used in household appliances such as television sets, air conditioners, and fluorescent light fixtures, and have been estimated to have service lives of at least 10 years [5]. Based on Environmental Protection Agency (EPA) estimates that 10% of the small PCB capacitors (<3 pounds of dielectric fluid) are removed from service annually [4], approximately 350 million of

*Abbreviations used for chemical compounds are:
PCB -- polychlorinated biphenyl
PCDF -- polychlorinated dibenzofuran
PCDD -- polychlorinated dibenzo-p-dioxin
TCDF -- 2,3,7,8-tetrachlorodibenzofuran
TCDD -- 2,3,7,8-tetrachlorodibenzo-p-dioxin
CDF -- chlorodibenzofuran
CDD -- chlorodibenzo-p-dioxin

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the capacitors were still in use in 1984. Large capacitors, with a PCB content of more than 3 pounds, have been used in electrical substations, within buildings, and on utility poles. The latest available information indicates that there were approximately 3.3 million large PCB capacitors in service in 1981 [4].

In transformers containing PCB's, the dielectric fluid generally consists of 60-70% PCB's [4] and up to 40% chlorinated benzenes [6]. Trade names of PCB askarels (the generic term used to refer to a broad class of nonflammable, synthetic, chlorinated hydrocarbon insulating liquids) formulated in the United States include Pyranol®, Inerteen®, and Noflamol® [7]. The volume of fluid in transformers ranges from 40 to 1,500 gallons [8]. PCB transformers have been used mainly in or near buildings where the proximity of electrical equipment to people and/or property warranted the use of a fire-resistant dielectric fluid. According to EPA estimates, at the end of 1984 there were approximately 107,000 PCB transformers in use or in storage for reuse [9], including approximately 77,600 PCB transformers used in or near commercial buildings (e.g., office buildings, shopping centers, hospitals, and schools) [10].

In 1976, the United States Congress enacted the Toxic Substances Control Act (TSCA) (Public Law 94-469), which gave the EPA authority to control the production and use of chemicals in the United States. Under Section 6(e) of TSCA the manufacture, processing, distribution in commerce, and use of PCB's after January 1, 1978 was prohibited; however, the EPA may, by rule, allow a particular use of PCB's to continue. In 1982, the EPA issued a final rule on the use of PCB's in electrical equipment. This rule permits the use of certain electrical equipment containing PCB's (e.g., small capacitors, large capacitors, and transformers) to continue under specified conditions for their remaining useful service lives [4]. In 1985, the EPA issued a final rule on the use of PCB's in electrical transformers. The use of high secondary voltage network PCB transformers in or near commercial buildings (approximately 7,400 transformers) after October 1, 1990, is prohibited. Low secondary voltage network and high secondary voltage radial PCB transformers in or near commercial buildings (approximately 70,200 transformers) must be equipped with enhanced electrical protection devices by October 1, 1990, to avoid overheating from sustained electrical faults [10].

Potential for Exposure to PCB's and Related Compounds Following Electrical Equipment Fire or Failure

Fire-related incidents are defined as incidents involving electrical equipment containing PCB's in which sufficient heat from any source causes the release of PCB's from the equipment casing. In soot-producing incidents an actual fire occurs in or near the PCB-containing electrical equipment eventually resulting in exposure of the PCB's to extremely high temperatures and in the formation and distribution of a black, carbonaceous material. PCB's have been identified in soot following numerous electrical equipment fires [11-17]. Polychlorinated dibenzofurans (PCDF's) [11-15,17-20] and

polychlorinated dibenzo-p-dioxins (PCDD's) [12-15,17-20] have also been identified following this type of fire-related incident. Laboratory studies have confirmed that PCDF's and PCDD's are formed from the pyrolysis of PCB's [21-24] or chlorobenzenes [25] at temperatures ranging from 500° to 700°C (932° to 1292°F).

In addition to PCDD's and PCDF's, other polychlorinated hydrocarbons have been identified in soot from electrical equipment fires. Polychlorinated biphenylenes [13,26], polychlorinated pyrenes [26], and polychlorinated diphenyl ethers [18] have been detected in soot samples collected following capacitor or transformer fires.

Fire-related incidents in which soot is not produced have occurred from the release of PCB's through the pressure relief valves of overheated transformers [27-31]. The pressurized release of hot PCB vapors can entrain considerable quantities of liquid PCB's forming a fine aerosol. Documented safety valve releases of PCB's from transformers demonstrate that the aerosol can be distributed to areas beyond the transformer vault by convective air currents [27,28,30,31]. Although PCB's manufactured in the United States contained up to 2 micrograms of PCDF's per gram of PCB's (μg/g) [32], recent evidence indicates that additional PCDF's may be formed as a result of the sustained high temperatures in non-soot-producing incidents [31].

Air, soot, and surface values for PCB's, PCDF's, PCDD's, 2,3,7,8-tetrachlorodibenzofuran (TCDF), and 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) measured following fire-related incidents in the United States are presented in Table 1.

An example of each type of fire-related incident involving PCB transformers is described in the Appendix.

Exposure Limits

The Occupational Safety and Health Administration (OSHA) promulgated its permissible exposure limits (PEL) of 1 milligram per cubic meter of air (mg/m^3) for chlorodiphenyl products containing 42% chlorine and 0.5 mg/m^3 for chlorodiphenyl products containing 54% chlorine determined as 8-hour time-weighted average (TWA) concentrations [35] based on the 1968 Threshold Limit Values (TLVs®) of the American Conference of Governmental Industrial Hygienists (ACGIH) [36]. The TLVs, which have remained unchanged at 1 mg/m^3 (42%) and 0.5 mg/m^3 (54%) through 1985 [37], are based on the prevention of liver injury in exposed workers [38]. The ACGIH Short Term Exposure Limits (STEL) for chlorodiphenyls are 2 mg/m^3 and 1 mg/m^3 for 42% and 54% chlorine products, respectively. The OSHA PEL and the ACGIH TLV and STEL values include a "Skin" notation which refers to the potential contribution to overall exposure by the cutaneous route, including the mucous membranes and eyes, by either airborne or direct skin contact with PCB's [37].

TABLE 1. CONCENTRATIONS OF PCB's AND RELATED COMPOUNDS FOLLOWING FIRE-RELATED INCIDENTS IN THE UNITED STATES[a]

DATE	LOCATION	ELECT EQUIP	SAMPLING DATE	AIR ($\mu g/m^3$)[b] PCB	SOOT ($\mu g/g$) PCB	SOOT ($\mu g/g$) TCDF	SOOT ($\mu g/g$) PCDF	SOOT ($\mu g/g$) TCDD	SOOT ($\mu g/g$) PCDD	SURFACE ($\mu g/100 cm^2$)[c] PCB	SURFACE ($\mu g/100 cm^2$)[c] TCDF	SURFACE ($\mu g/100 cm^2$)[c] PCDF	SURFACE ($\mu g/100 cm^2$)[c] TCDD	SURFACE ($\mu g/100 cm^2$)[c] PCDD	REF
FIRES															
12/80	Cincinnati, OH	Cap	03/81	ND[d]	—	—	—	—	—	7,200	ND	ND	ND	ND	33
02/81	Binghamton, NY	Tran	02/81	80	200,000	12	2,160	0.6	19.9	—	—	—	—	—	13
10/81	Boston, MA	Tran	12/81	—	114,000	3	162	ND	ND	—	—	—	—	—	11
04/82	Miami, FL	Tran	04/82	—	—	ND	1.89	ND	ND	860	—	—	—	—	18
04/82	Tulsa, OK	Tran	04/85	0.5	11	0.007	0.11	ND	0.16	1,100	8.5[e]	81.6[e]	ND	1,408[e]	15
06/82	Jersey City, NJ	Caps	—	2.3	—	—	—	—	—	22	ND	0.14	ND	0.09	20
05/83	San Francisco, CA	Tran	05/83	1,500	86,000	6.3	28.9[f]	0.059	0.32[f]	—	29[e]	101.5[e]	—	—	17
09/83	Chicago, IL	Tran	09/83	58	39,100	—	—	—	—	3,263	0.41	12.2	ND	0.05	12
12/83	Tulsa, OK	Tran	01/84	—	—	—	—	—	—	1,607	—	—	—	—	34
03/84	Columbus, OH	Caps	04/84	—	6,415	3.2	46.4	0.016	4.1	—	—	—	—	—	19
05/84	Miami, FL	Tran	06/84	—	50,000	0.27	98.5	0.004	2.3	—	—	—	—	—	14
PRESSURIZED RELEASES					FLUID ($\mu g/g$)										
—/74	Wappingers Falls, NY	Tran	02/84	—	117,000	—	0.97	—	ND	92	—	—	—	—	30
06/82	Washington, DC	Tran	06/84	—	—	<.074[h]	<7.02[h]	ND	<1.3[h]	320,000	ND	<114[h]	ND	ND	28
06/82	Maplewood, MN	Tran	06/82	90	—	—	ND	—	ND	5,000	—	—	—	—	27
12/83	Syracuse, NY	Tran	12/83	1.1	—	—	—	—	—	7.3	0.02[i]	0.17[fi]	ND	—	29
06/85	Santa Fe, NM	Tran	06/85	41.9	870,000	1.6	44.2	ND	ND	280,000	0.41	3.99	ND	0.19	31

[a] Values represent the highest measurements reported
[b] Micrograms per cubic meter($\mu g/m^3$)
[c] Micrograms per 100 square centimeters ($\mu g/100\ cm^2$)
[d] None detected, ND
[e] Values expressed as nanograms per square meter (ng/m^2)
[f] Values represent total tetrachlorinated forms only
[h] Values represent results obtained in the presence of interfering chemicals
[i] Values reported as μg per wipe sample (area undefined)

Note: Cap = Capacitor
Caps = Capacitors
Tran = Transformer

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The National Institute for Occupational Safety and Health (NIOSH) recommends that exposure to PCB's in the workplace be limited at or below the minimum reliable detectable concentration of 1 $\mu g/m^3$ (using the recommended sampling and analytical methods) determined as a TWA for up to a 10-hour workday, 40-hour workweek. The NIOSH recommended exposure limit (REL) was based on the findings of adverse reproductive effects in experimental animals, on the conclusion that PCB's are carcinogens in rats and mice and, therefore, potential human carcinogens in the workplace, and on the conclusion that human and animal studies have not demonstrated a level of exposure to PCB's that will not subject the worker to possible liver injury [39].

TOXICITY

Results of Animal Studies

Effects of PCB's, PCDF's, and PCDD's

In general, the toxic responses observed in animals treated with PCB's, PCDF's, or PCDD's are similar, but the potencies of individual compounds vary according to the degree and position of chlorination. The tetra-, penta-, and hexa-chlorinated isomer groups exhibit greater toxicity than the other chlorinated forms [40-42]. Dibenzofuran and dibenzo-p-dioxin compounds with chlorine at positions 2, 3, 7, and 8 are particularly toxic [43-45]. The lethal doses in milligrams per kilogram of body weight (mg/kg) for 50% (LD_{50}) of the animals tested by the single oral administration of PCB's, TCDF, or TCDD in four animal species are presented in Table 2.

TABLE 2. ACUTE ORAL TOXICITY OF PCB's, TCDF, AND TCDD

	Single-Dose LD_{50} (mg/kg)		
	PCB's	TCDF	TCDD
Guinea pig	NR[a]	>.005 [46]	.0006 [47]
		<.010 [46]	.002 [43]
Monkey	NR	1.000 [46]	<.070 [48]
Rat	1,010 [49]	>1.000 [50]	.047 [48]
Mouse	1,900 [51]	>6.000 [50]	.114 [52]
			.284 [43]

[a]Not reported, NR

Mice, rats, guinea pigs, and monkeys displayed progressive weight loss with death occurring up to several weeks after administration of a single lethal dose of PCB's, TCDF, or TCDD. Few other overt signs of toxicity were observed in mice, rats, and guinea pigs. Monkeys exhibited facial edema, loss of eyelashes and fingernails, and acneform skin eruptions [46,48].

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Prominent histopathologic findings included: hepatic lesions in mice [43] and rats [53], hyperplasia of the urinary tract epithelial tissues and lymphoid hypoplasia in monkeys [46,48], and thymic atrophy in all four animal species.

Adverse reproductive effects in experimental animals have been observed in response to PCB's (rats, rabbits, monkeys, dogs, and pigs) [39], TCDD (mice and rats) [54], and TCDF (mice) [55,56]. Rats and mice exposed to PCB's [39] or TCDD [54] have developed liver cancers. No studies regarding the carcinogenicity of PCDF's in animals have been reported.

Effects of Soot Containing PCB's, PCDF's, and PCDD's

A composite sample of soot collected following a transformer fire in Binghamton, New York in 1981, contained 5,000 μg PCB's/g, 48 μg TCDF/g, and 1.2 μg TCDD/g. Single oral administration to guinea pigs of the soot in aqueous methyl cellulose or of a benzene extract of the soot in the same aqueous vehicle produced LD_{50} values of 410 and 327 mg/kg, respectively. Single oral administration of TCDD in aqueous methyl cellulose or in corn oil produced LD_{50} values of 19 and 2.5 μg/kg, respectively. Animals surviving for 42 days after administration of the soot showed dose-related evidence of decreased weight gain and kidney weight, thymic atrophy, increased serum triglycerides, goblet cell hyperplasia of pancreatic interlobular ducts, and metaplasia of salivary gland interlobular duct epithelium. In rabbits, dermal application of the saline-moistened soot or of a benzene extract of the soot at a dose comparable to 500 mg soot/kg body weight for 24 hours produced hypertrophy of centrilobular hepatocytes in 50% of the rabbits at the end of the 65-day observation period. No signs of overt toxicity were observed in the rabbits, except dermal inflammatory reactions noted in rabbits treated with the soot extract [57]. The dermal LD_{50} of TCDD in rabbits is 275 μg/kg [47], while the dermal minimum lethal dose of PCB's (as Aroclor 1260) is from 1.26 to 2.00 grams/kg [58]. Because the measured amounts of TCDF and TCDD in the soot were low, other congeners may have contributed to the toxic effects observed in guinea pigs and rabbits [16,57].

In a subchronic toxicity study, the total soot contained in food that was consumed in 90 days by guinea pigs was 1.2, 22, 55, or 275 mg soot/kg body weight. A fifth group of guinea pigs was terminated after 32 days (total consumption of 400 mg soot/kg body weight) because mortality had reached 35%. The intensities of the toxic responses were dose-related, but no signs of toxicity were detected in guinea pigs with a total consumption of 1.2 mg soot/kg body weight [59].

Human Health Effects

Several cases of chloracne, hyperpigmentation, gastrointestinal disturbances, elevated serum enzyme and triglyceride levels, and numbness of the extremities have been reported among people exposed to PCB's [39,60,61]

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or PCDD's [54,62]. Comparative human and animal studies indicate that PCDF's were the main causative agents of similar symptoms reported in individuals who ingested cooking oils contaminated with PCB's and PCDF's [63].

There is suggestive evidence of associations between increased incidences of cancer and exposure to PCB's [64], to PCB's containing significant PCDF's [65,66], and to phenoxyacetic herbicides contaminated with PCDD's including TCDD [67,68]. However, definite causal relationships between exposure and carcinogenic effects in humans remain unclear due to the inadequately defined populations studied and the influences of mixed exposures.

The firefighters and other workers involved in the Binghamton transformer fire cleanup have been followed through a medical surveillance program. Medical evaluation of these workers approximately one year after the fire showed slight increases in serum PCB levels but no observable adverse health effects from this exposure [69]. Selected workers from this study group have been found to have elevated adipose tissue levels of PCDF's and PCDD's [70] and associated histologic changes in the liver [71]. Further monitoring of this population is in progress.

RECOMMENDATIONS

There are several classifications for identifying a substance as a carcinogen. Such classifications have been developed by the National Toxicology Program (NTP) [72], the International Agency for Research on Cancer (IARC) [73], and OSHA in its "Identification, Classification, and Regulation of Potential Occupational Carcinogens" 29 CFR 1990 [74], also known as "The OSHA Cancer Policy." NIOSH considers the OSHA classification the most appropriate for use in identifying potential occupational carcinogens* [74]. Because exposure to PCB's or TCDD has been shown to produce malignant tumors in rats and mice, they meet the OSHA criteria. Therefore, NIOSH continues to recommend that PCB's and TCDD be considered as potential human carcinogens in the workplace. Limited evidence from animal and human studies suggests that PCDF's may also pose a risk to human health. As prudent public health policy, NIOSH recommends that occupational exposure to PCB's, PCDF's, and PCDD's resulting from electrical equipment fires or failures be controlled to the lowest feasible limit.

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*"'Potential occupational carcinogen' means any substance, or combination or mixture of substances, which causes an increased incidence of benign and/or malignant neoplasms, or a substantial decrease in the latency period between exposure and onset of neoplasms in humans or in one or more experimental mammalian species as the result of any oral, respiratory or dermal exposure, or any other exposure which results in the induction of tumors at a site other than the site of administration. This definition also includes any substance which is metabolized into one or more potential occupational carcinogens by mammals" (29 CFR 1990.103).

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As a result of fire-related incidents involving PCB-containing electrical equipment, emergency response personnel, maintenance and cleanup workers, and building occupants may be at risk of exposure to PCB's, PCDF's, and PCDD's. The following recommendations are intended to minimize worker exposure to these compounds and reflect experiences NIOSH personnel and others have gained in responding to such incidents. These recommendations focus primarily on PCB transformer fires, although many of the recommendations apply to other types of fire-related incidents involving PCB's.

Recognition of Potential Hazard

Emergency response personnel should be informed of the presence of PCB-containing electrical equipment and of the potential health hazards associated with exposure to emissions from such equipment. All workers should understand that exposure can occur through inhalation, ingestion, and skin absorption (by direct contact or by contact with contaminated surfaces, clothing, and equipment) and recognize that exposure to some of these compounds may result in long term health effects.

Required registration of PCB transformers with local fire departments [10] is intended to assure early recognition of the potential hazards when a fire-related incident occurs. The registration for each transformer should include: building location; location of transformer(s) within or near the building; transformer serial number, manufacturer, and kilovolt/amperage rating; and total volume and generic composition of the dielectric fluids. This information should be readily accessible to those persons responsible for the health and safety of emergency response personnel and others who may come into contact with PCB transformers.

To assist in the identification of PCB transformers the effective use of signs and labeling should be instituted. While labeling of PCB transformers is required (using the mark "M_L") [10], additional signs and labels should be placed in areas near the location of a PCB transformer(s).

The number of emergency response personnel or cleanup workers entering a potentially contaminated area(s), (e.g., interior of the building or transformer vault) should be limited. This action would minimize the number of workers exposed and would reduce the amount of protective clothing and equipment potentially contaminated.

Assessment of Exposure

Contamination assessment is necessary to determine the extent and relative degrees of contamination of an area following a fire-related incident. NIOSH's Occupational Exposure Sampling Strategy Manual is useful in developing appropriate strategies to monitor worker exposure to PCB's and related pyrolysis products [75]. Air and surface wipe samples should be collected in all areas potentially contaminated by the incident. Air sampling should include both the particulate and vapor phase. Wipe samples

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should be taken on both vertical and horizontal surfaces. Additional samples may include residual fluid in the transformer, fluid deposited in the vault, or soot. Air and surface wipe samples should be analyzed for PCB's, tetra- through octa-chloro homologs of PCDF and PCDD, and the respective 2,3,7,8-tetrachloro isomers. Detailed descriptions of sampling and analytical techniques for PCB's may be found in the NIOSH Manual of Analytical Methods [76,77]. Sampling procedures and sensitive methods for the analyses of PCDF's and PCDD's have been developed by the New York State Department of Health [16,78].

Personal Protective Clothing

All workers who may be exposed to PCB's, PCDF's, and PCDD's should be equipped with chemical protective clothing to ensure their protection. In the selection of protective clothing, consideration should be given to the utilization of disposable apparel because of the uncertainty of decontamination of reusable clothing.

Outer protective garments should consist of a zippered coverall with attached hood and draw string, elastic cuffs, gloves, and closure boots. If exposure to soot is anticipated, workers should wear outer coveralls made of a nonwoven fabric such as spunbonded Tyvek® to exclude particulates. If exposure to liquids or to both soot and liquids is anticipated, or if the form of the contaminants is unknown, the outer coveralls should be made of chemically resistant materials such as Saranax®-coated Tyvek or Viton®-coated neoprene. Gloves and boots should be made of neoprene, nitrile, butyl rubber, or Viton which have been shown to be resistant to permeation by PCB's [79,80]. For personal comfort workers may wear inner garments consisting of cotton coveralls, undershirts, undershorts, gloves, and socks. Inner garments should be disposed of after use because small amounts of contaminants may be transferred in removing outer garments [79]. All disposable clothing should be placed in approved containers and disposed of according to EPA disposal procedures [4].

Respiratory Protection

The use of respiratory protection for those involved in cleanup operations requires that a respiratory protection program be instituted which, at a minimum, meets the requirements of 29 CFR 1910.134 [81] and that the respirators selected be approved by the Mine Safety and Health Administration (MSHA) and by NIOSH. The respiratory protection program should include training of workers regarding the proper use, fit testing, inspection, maintenance, and cleaning of respirators. The program should be evaluated regularly.

Where a risk of exposure to airborne contaminants exists, such as when visible quantities of soot are to be removed, workers should wear a self-contained breathing apparatus with a full facepiece operated in pressure-demand or other positive pressure mode. Alternatively, a combination supplied air respirator, with full facepiece, operated in

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pressure-demand or other positive pressure mode and equipped with auxiliary positive pressure self-contained air supply can be used. When cleanup operations have advanced to a point where airborne PCB's can no longer be detected, air-purifying full facepiece respirators equipped with a high efficiency particulate air filter and organic vapor cartridge should be used, as a precaution, until final decontamination is completed [82].

Decontamination and Worker Protection Programs

In general, decontamination procedures must provide an organized process in which the extent and degree of contamination are systematically reduced. This should include procedures that take into account containment, collection, and disposal of contaminated solutions and residues generated during the incident and cleanup. Separate facilities should be provided for decontamination of large equipment. The EPA's Guide for Decontaminating Buildings, Structures, and Equipment at Superfund Sites provides information for developing a decontamination strategy [83].

Each stage of decontamination, such as gross decontamination and repetitive wash/rinse cycles, should be conducted separately, either by using different locations or by spacing in time. Personnel decontamination locations should be physically separated from the contaminated area(s) to prevent cross-contact and should be arranged in order of decreasing level of contamination. Separate entry/exit routes and locations should be well marked and controlled. Access to the decontamination area should be separate from the path between the contaminated and clean areas. Dressing stations for entry should be separate from redressing areas for exit.

All reusable clothing and equipment should be grouped according to perceived degree of contamination (i.e., high, moderate, or low) and thoroughly cleaned. Decisions concerning decontamination end points are often based on the lack of visible contamination; however, the absence of observable surface contamination does not necessarily indicate the absence of contaminants absorbed into the material. Reusable clothing and equipment should, therefore, be analyzed for residual contamination before reuse or storage.

Soot from transformer fires is typically black, friable, carbonaceous material. Preliminary cleanup of the areas visibly contaminated with soot should involve dry vacuuming of both horizontal and vertical surfaces with a vacuum cleaning system equipped with a high efficiency particulate (HEPA) filter.

Final cleanup methods should include washing surfaces with alkaline [27] or nonionic [84] synthetic detergents in water. The addition of a caustic agent, such as trisodium phosphate, may help to remove grease deposits, floor waxes, and furniture polishes. Waxed and polished surfaces tend to absorb contaminants from the air. Cleaning with organic solvents is useful for nonporous electrical and mechanical equipment where contact with water-based cleaning fluids may damage the equipment. Organic solvents,

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such as kerosene, mineral spirits, and trichlorotrifluoroethane, may carry contaminants deeper into porous materials and should not be used on these surfaces. Complete decontamination of porous surfaces, such as concrete and masonry surfaces in vaults, may not be possible; therefore, application of an elastomeric, abrasion- and flame-resistant sealant may be required.

Post-Decontamination Testing

The adequacy of the decontamination effort should be determined by followup sampling and analysis of the contaminated areas and reusable protective equipment. This testing should be conducted as each area is decontaminated and again after the entire facility has been cleaned. Decontamination guidelines for the cleanup of specific buildings following fires involving PCB transformers [83,85] have been proposed by the New York State Department of Health [86], the New Mexico Expert Advisory Panel [87], the California Department of Health Services [88], and the San Francisco Department of Health [89].

Medical Surveillance

A medical surveillance program should be established to prevent (or to attempt to detect at an early stage) adverse health effects in workers resulting from exposure to PCB's or related compounds. Medical and work histories, including previous exposure to PCB's or other toxic agents, should be taken for each worker prior to job placement and updated periodically. The physician responsible should be provided with information concerning the adverse health effects from exposure to PCB's and related compounds and an estimate of the worker's potential exposure, including any available workplace sampling results and a description of all protective clothing or equipment the worker may be required to use.

The examining physician should direct particular attention to the skin, liver, and nervous system as these are the most likely targets of exposure to PCB's and related compounds. Blood determinations which reflect liver function may be useful. Measurement of blood PCB's may also be useful but should not be interpreted as a sensitive indicator of acute exposure. Adipose tissue levels of PCB's, PCDF's, and PCDD's are indicative of total body burden, but these tissue samples are not routinely available. Further studies of exposed populations will permit more definitive medical monitoring recommendations.

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APPENDIX

REPORTS OF FIRE-RELATED INCIDENTS INVOLVING PCB TRANSFORMERS

Fire in a Multi-Story Office Building in Binghamton, New York

On February 5, 1981, an electrical fire occurred in the switchgear adjacent to a PCB transformer in the basement mechanical room of the Binghamton State Office Building. The transformer contained 1,060 gallons of askarel consisting of Aroclor 1254 (65%) and a mixture of tri- and tetra-chlorinated benzenes (35%). A ceramic bushing on the transformer cracked during the fire, resulting in the release of approximately 180 gallons of askarel onto the floor near the fire. The smoke was distributed by convection throughout the building through an open vertical shaft that extended from the mechanical room to the top of the building. The shaft contained the duct for the exhaust air from the restrooms on all the floors. The shaft and ducts were not airtight and allowed smoke and soot to contaminate the work areas of the building, air-conditioning ducts, false ceiling areas, and elevator shafts [13].

Analyses of the soot revealed significant concentrations of PCB's, PCDF's, TCDF, PCDD's, TCDD, and polychlorinated biphenylenes [13,16,90]. Based on analyses of dry surface wipe samples, horizontal surfaces showed higher levels of contamination than vertical surfaces [17]. In soot samples obtained from 11 floors of the building, the absolute amounts of the tetra- through octa-chlorodibenzofuran (CDF) isomer groups varied from sample to sample, but the relative proportions with respect to the amount of PCB in the soot were consistent. The ratio of PCDF to PCB averaged 0.067 $\pm$ 0.026 ($\pm$ one standard deviation) [16].

Air samples collected on the seventh floor after cleanup of most of the surface soot deposits contained 292 picograms of total tetra-CDF per cubic meter of air (pg/m^3) including 26 pg TCDF/m^3 and 5 pg total tetra-chlorodibenzo-p-dioxin (CDD)/m^3 including 3 pg TCDD/m^3 [16].

The cleanup of the Binghamton building has been complex and costly. The building remains closed to normal use pending complete cleaning and renovation. Criteria for reoccupancy are being considered by the New York State Department of Health Expert Advisory Panel based on toxicity studies in guinea pigs using the soot from the building, on chemical analyses of the soot, and on published toxicologic studies of TCDD [86].

Electrical Malfunction in an Office Building in Santa Fe, New Mexico

On June 17, 1985, an electrical malfunction occurred in a transformer located in the basement transformer vault in the main building of the New Mexico State Highway Department Office Building. The transformer contained 245 gallons of askarel consisting of Aroclor 1260 (87%) and a mixture of tri- and tetra-chlorinated benzenes (13%). The electrical malfunction caused the transformer to overheat resulting in the release of vaporized askarel through the safety valve which continued until the unit was de-energized (approximately 65 minutes after initial detection). There was

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no fire, but charred (blistered) paint on the transformer casing indicated that the temperature of the casing may have approached 316°C (600°F).

The emission products were distributed throughout the 2-story building by convective air currents and by mechanical transfer via the heating, ventilating, and air conditioning systems. Because the emitted vapor condensed as it reached cooler temperatures, the askarel apparently "rained" in the heavily contaminated rooms adjacent to and above the basement transformer vault.

Air, fluid, and surface wipe samples were collected within 7 days of the incident. Airborne concentrations of PCB's in the main building were 41.94 $\mu g/m^3$ inside the vault, 0.34-25.87 $\mu g/m^3$ in other basement areas, 1.00-19.45 $\mu g/m^3$ in first floor areas, and 0.73-5.96 $\mu g/m^3$ in second floor areas. PCDF's were detected at concentrations ranging from 10.4 to 501.6 pg/m^3 including 0.9-56.2 pg TCDF/m^3. Airborne PCDD's ranged from 7.1 to 21.0 pg/m^3 but TCDD was not detected.

The surface concentrations of PCB's were as high as 280,000 $\mu g/100\ cm^2$ in basement areas, 98,000 $\mu g/100\ cm^2$ in first floor areas, and 190 $\mu g/100\ cm^2$ in second floor areas. PCDF's, TCDF, and PCDD's were present in surface wipe samples from areas of the basement and first floor, but TCDD was not detected. Surface wipe samples from second floor areas were not submitted for measurement of the pyrolysis products [31].

The New Mexico PCB Expert Advisory Panel convened on July 16, 1985, to propose air and surface cleanup guidelines for the building. The guidelines were based on the potential risk of cancer resulting from exposure to PCB's, PCDF's, and PCDD's. Animal studies on the carcinogenicity of TCDD were used to estimate the potential cancer risks. It was also necessary to make certain judgments and assumptions regarding the toxicity of the related compounds and the potential for exposure to occupants of the building. The guidelines are intended to maintain the risk of developing cancer below one in one million for a person spending the rest of his/her working lifetime in the building. The Panel recommended cleanup levels of 2 pg TCDD equivalents/m^3 of air and 1 ng TCDD equivalents/m^2 of surface area. Values for other PCDF and PCDD isomer groups can be converted to TCDD equivalents using the following conversion factors:

TO CONVERT VALUES TO TCDD EQUIVALENTS

PCDF's	Factor	PCDD's	Factor
TCDF	0.33	TCDD	1.0
Other tetra-CDF's	0.0	Other tetra-CDD's	0.0
Penta-CDF's	0.17	Penta-CDD's	0.5
Hexa-CDF's	0.005	Hexa-CDD's	0.02
Hepta-CDF's	0.0005	Hepta-CDD's	0.0
Octa-CDF's	0.0	Octa-CDD's	0.0

Concentrations of these compounds can be converted to TCDD equivalents by multiplying the measured values by the appropriate conversion factor. The TCDD equivalents can then be summed and compared to the guideline values. The Panel did not establish cleanup guidelines for PCB's on surfaces [87].

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