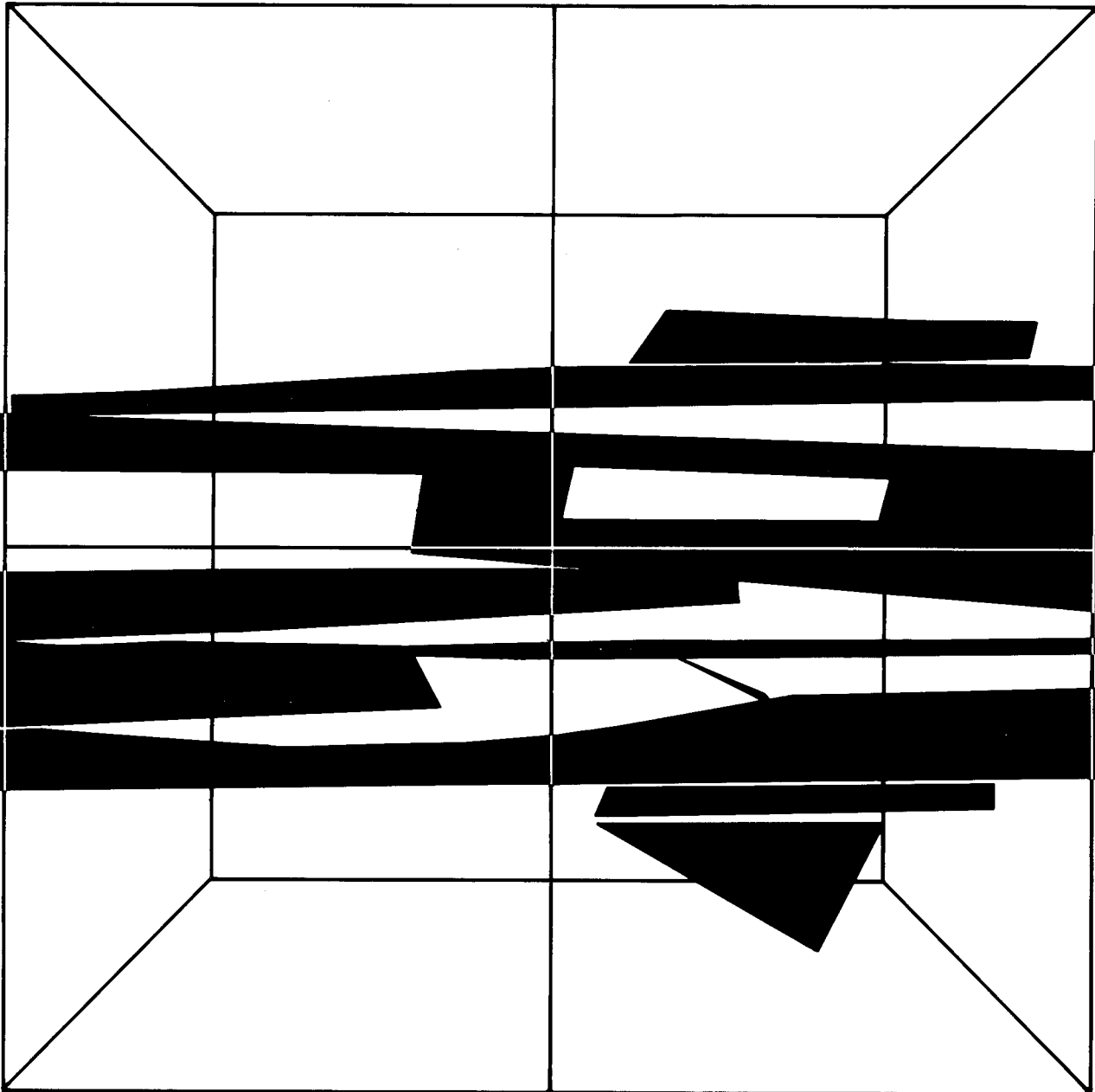


# Fires in Electrical Equipment Containing PCBs: Recommendations to Prevent Contamination by PCDFs

First Edition

Report EPS 1/CC/2  
March 1985



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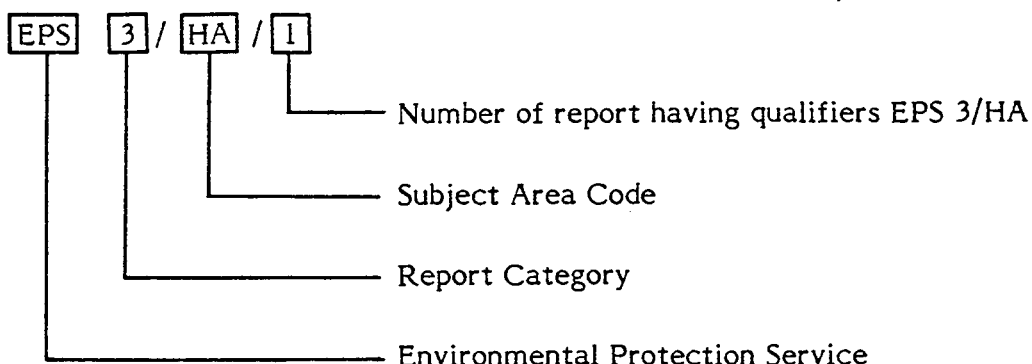
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**FIRES IN ELECTRICAL EQUIPMENT CONTAINING PCBs:  
RECOMMENDATIONS TO PREVENT CONTAMINATION BY PCDFs**

**First Edition**

prepared by

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Report EPS 1/CC/2  
March 1985

## COMMENTS

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## SUMMARY

The purpose of this publication is both to enhance awareness of fires implicating electrical equipment containing polychlorinated biphenyls (PCBs) and to recommend a course of action for the prevention of contamination by polychlorinated dibenzofurans (PCDFs).

Human exposure to PCDFs alone has not occurred. PCDFs are usually accompanied by PCBs and sometimes by other contaminants, such as polychlorinated dibenzo-p-dioxins (PCDDs). Although the effects observed in humans cannot be solely attributed to PCDFs, it is reasonable to assume that these compounds, like PCDDs, are extremely toxic not only in the short but also in the long term. The toxicity of various PCDF congeners depends upon the position and degree of chlorination; the tetra- and penta-chlorodibenzofurans are the most toxic.

PCDFs are generated when PCBs, chlorinated benzenes (PCBZs), or both are heated in the presence of oxygen at temperatures in the range of 250°C to 700°C. The optimal temperature for the formation of PCDFs appears to be around 500°C. The formation of PCDFs is catalyzed by the presence of certain metals (e.g. iron and copper) or their salts. The pyrolysis of PCBs differs from that of PCBZs in that PCBs do not yield PCDDs.

By far the largest quantity of PCBs still in use in Canada is inside transformers, which on the average contain 1350 kg of PCBs per unit. Compared to that, the content of PCBs in individual capacitors is very small, particularly in those capacitors that are encased in lamp ballasts used for fluorescent and high-intensity discharge lamps. However, unlike transformers and large capacitors installed usually in isolated locations, the capacitors in lamp ballasts are installed throughout buildings, often in large quantities as part of each fluorescent lighting fixture.

Fires implicating PCB-containing electrical equipment are usually caused by electrical faults or malfunction of electrical equipment. Frequently, these fires start in electrical equipment containing mineral oil and then spread to PCB-containing equipment. All fires involving PCBs are smoky and yield large amounts of black, oily soot. This soot is contaminated with PCBs, PCDFs and, if chlorobenzenes are present, PCDDs. PCBs and PCDFs adhere to the soot. Soot analysis shows that approximately 1% of the PCBs are converted to PCDFs. PCB capacitors in fire generated no PCDDs; but PCB transformers in fire did generate PCDDs. PCB transformers in fire generated 1 part of PCDD for every 10 parts of PCDF.

The following comprehensive set of recommendations addresses specifically the prevention of contamination by PCDFs resulting from fires in electrical equipment, and forms a useful basis for the development of effective measures to deal with this problem.

TABLE 1 RECOMMENDATIONS

	PREVENTATIVE MEASURES	FIRE-FIGHTING MEASURES	CLEAN-UP MEASURES
Individual Health and Safety	Information and Training	Awareness of PCBs	Information
	Identification of Equipment	Use of proper Protective Gear	Protective Procedures • area
	Protective Material	Medical Aid	• individual
	Contingency Plan	Evacuation	Medical Attention
Equipment and Facilities	Programs	Strategies	Soot Removal
	• operation	Materials	Inspection
	• maintenance/inspection		
	Safety Systems		
Environmental Concerns	PCB Management		
	Containment of:		Decontamination
	• equipment fluids		Disposal
	• contaminants		



## 1 INTRODUCTION

### 1.1 Background

Polychlorinated biphenyls (PCBs) produce under certain conditions polychlorinated dibenzofurans (PCDFs) which are more toxic than PCBs.

Environment Canada estimates that approximately 15 million kg of PCBs are still in use throughout Canada as dielectric fluid in electrical equipment, mostly in transformers and capacitors.<sup>1</sup> Most of this PCB-containing equipment is installed inside or adjacent to buildings.

When fires occur in PCB-containing electrical equipment, physico-chemical conditions are created that are conducive to the generation of PCDFs in significant quantities.<sup>2,3</sup>

A working group formed by the Interdepartmental Committee on Toxic Chemicals (ICTC) to develop a management strategy for dioxins and dibenzofurans prepared an interim report (ICTC - Report No. 1) in August 1982. One of the recommendations contained in this report reads: "That guidelines for the prevention of severe PCDF contamination from accidental fires in PCB-containing electrical equipment be developed".

The responsibility for the development of such guidelines was given to the Commercial Chemicals Branch, Environmental Protection Service, Environment Canada.

M. M. Dillon Limited, Consulting Engineers and Planners, in association with Wellington Environmental Consultants, were retained to conduct a study, under the direction of the Commercial Chemicals Branch, that would address the recommendation of the ICTC working group.

Case histories of ten fires implicating PCB-containing electrical equipment from 1977 through 1982 were reviewed. Two of those fires occurred in Canada, one in the United States of America, five in Sweden, and two in Finland.

The recommendations presented as part of this report were developed in order to limit the formation of PCDFs in electrical equipment and to prevent human exposure to these chemicals, in fire situations.

Since a thorough knowledge of the properties of the PCDFs and the conditions under which they are formed was essential for the development of these guidelines, a computer survey was performed using the Lockheed DIALOG™ data system. The literature was surveyed for the period of 1967 to 1983.

Articles relevant to this project were collected and the information derived from them is discussed in the following sections. For more detailed discussions of PCDFs in the context of their chemistry, biological/toxicological effects, and their occurrence as contaminants in industrial chemicals, the reader is referred to the following publications:

- Jones, P.A., Chlorophenols and Their Impurities in the Canadian Environment, Environmental Protection Service, Report EPS 3-EC-81-2 (March 1981).
- Chittim, B., B.S. Clegg, S. Safe and O. Hutzinger, PCDFs and PCDDs: Detection and Quantification in Electrical Equipment and Their Formation During the Incineration of PCBs, Wellington Science Associates, Prepared for Environment Canada, Contract No. 05578-00067 (1979).
- Mitchell, M.F., H.A. McLeod and J.R. Roberts, Polychlorinated Dibenzofurans: Criteria for Their Toxic Effects on Humans and the Environment, National Research Council of Canada, Report No. 28846 (1984).

## 1.2 Objectives

The principal purpose of this study is both to enhance awareness to fires implicating electrical equipment containing polychlorinated biphenyls (PCBs) and to recommend a course of action for the prevention of contamination by polychlorinated dibenzofurans (PCDFs).

More specifically, the recommendations are to relate to the conditions before, during, and after a fire. The recommendations are concerned with the aspects of individual health and safety, equipment and facilities, and environmental control.

The recommendations deal with the PCDF contamination only. PCDDs and other contaminants that are known to form during some of the fires in or near electrical equipment, are outside the scope of this report. Where references to PCDDs appear in this report, they are incidental.

## 2 POLYCHLORINATED DIBENZOFURANS (PCDFs)

### 2.1 Introduction

Polychlorinated dibenzofurans (PCDFs) have received considerable attention recently because of their severe toxicological properties and their occurrence as contaminants in widely used industrial chemicals such as the chlorinated phenols (CPs). In addition, they can be thermally and pyrolytically generated from CPs, polychlorinated biphenyls (PCBs), and chlorobenzenes (PCBZs). For this reason, they can be found in fly ash from municipal incinerators.

In Canada, considerable quantities of PCBs and PCBZs are contained in active electrical equipment (see Section 3) or in storage awaiting disposal. Other fluids substituted for PCBs in such equipment may very well be contaminated with PCBs (and PCBZs).

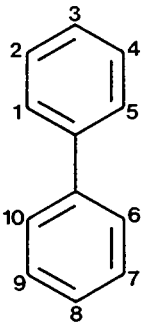
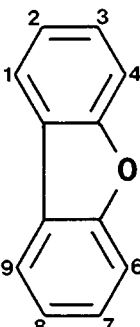
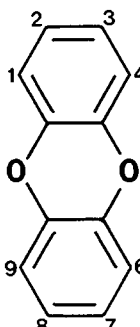
Fires implicating electrical equipment containing PCBs and PCBZs can lead to the formation of PCDFs. Failures in this equipment (e.g. electrical arcing) may produce PCDFs as well.

### 2.2 PCDFs - Properties

**2.2.1 Physical/Chemical Properties.** The PCDFs are a series of chlorinated tricyclic aromatic compounds having the same basic structure. As can be seen in Figure 1, they are very similar in structure to another series of compounds, the chlorinated dibenzo-p-dioxins (PCDDs); it has been shown that the properties of these two groups often, if not always, parallel one another.

As shown in Figure 1, substitutions with one to eight chlorine atoms lead to the formation of 135 possible PCDF congeners. They are all crystalline solids at room temperature, the individual congeners melting at temperatures ranging from ca. 100 to 250°C. At standard temperature and pressure they have no appreciable vapour pressure.<sup>4,5</sup> Like the PCBs and PCDDs, the PCDFs are extremely insoluble in water and only sparingly soluble in most organic solvents. The solubility of the individual congeners generally decreases with increasing chlorine content.<sup>4</sup>

**2.2.2 Biological/Toxicological Properties.** The PCDFs behave in the environment like most halogenated aromatic compounds; they are highly stable, tend to persist and bioaccumulate in fatty tissues. Although there have been few reports on their ecokinetic properties, it is generally assumed that movement of PCDFs in aquatic systems and in air would largely occur via their adsorption on particulate.<sup>4</sup>

Molecular Structure & Numbering Sequence		Polychlorinated Biphenyls	Polychlorinated Dibenzofurans	Polychlorinated Dibenzodioxins
				
		PCBs	PCDFs	PCDDs
Number of Isomers	Mono	3 ( 3)*	4	2
	Di-	12 ( 10)	16	10
	Tri-	24 ( 17)	28	14
	Tetra-	42 ( 27)	38	22
	Penta-	46 ( 22)	28	14
	Hexa-	42 ( 26)	16	10
	Hepta-	24 ( 18)	4	2
	Octo-	12 ( 9)	1	1
	Nona-	3 ( 1)	-	-
	Deca-	1 ( 1)	-	-
TOTAL		209 (134)	135	75

\* Numbers in parentheses indicate the number of isomers found in technical formulations.

FIGURE 1 PCBs, PCDFs, AND PCDDs

The discovery of PCDF contamination of PCBs was due in large part to the toxicity of some of the individual PCDF isomers. For example, previous research has shown that some fractions of PCBs were far more toxic to chicks than others; and that these fractions contained PCDFs.<sup>6</sup>

The toxicity of individual PCDF congeners is extremely dependent upon the position and degree of chlorination. The tetra- and penta-chlorodibenzofurans are the most toxic, in particular, the 2,3,7,8-tetra, 1,2,3,7,8-penta and 2,3,4,7,8-pentachlorodibenzofurans.<sup>7</sup> The LD<sub>50</sub> for orally consumed 2,3,7,8-TCDF in most animal species has been reported to be of the order of micrograms per kilogram.<sup>8,9</sup> Human exposure to PCDFs alone has not been reported although related incidents have been.

In Japan, over 1,000 people consumed rice oil contaminated with PCBs.<sup>10</sup> It was subsequently postulated that the toxic symptoms observed were due in part to PCDF contamination of the PCBs. In addition, exposure to PCDDs and PCDFs has been discussed in relation to malignant tumors among spraymen exposed to phenoxy acid herbicides in the 1950's and 1960's in Sweden.<sup>11</sup>

Although the effects observed in humans cannot be solely attributed to PCDFs, it is reasonable to assume that these compounds, like PCDDs, are extremely toxic not only in the short but also the long term.

## **2.3 PCDFs - Thermal/Pyrolytic Generation**

**2.3.1 Background.** PCDFs are present as contaminants in chemicals such as chlorinated phenyls (CPs) and phenoxy acid herbicides. Of major importance to this study is that PCDFs have also been detected as contaminants in PCBs and askarels (the generic name for mixtures of PCBs and PCBZs) and that they exist in fresh fluids. The total levels of PCDFs found in these unused products have been reported to range from 0.1 to 33 ppm.<sup>12</sup>

Levels of PCDFs are higher in used PCB-based fluids. For example, in PCBs used as a heat transfer medium, levels of PCDFs up to 500 ppm have been reported.<sup>12</sup> The levels of 2,3,7,8-TCDF in askarel-filled transformers have also been found to be higher in those units that have been in service for long periods of time.<sup>13</sup>

Therefore PCDFs most likely exist in active electrical equipment containing PCBs (and PCBZs). Under severe conditions, such as fire to this equipment, much higher levels of PCDFs can be formed. Laboratory research has been carried out to determine the conditions under which PCDFs are formed thermally and pyrolytically from their precursors (i.e., PCBs and PCBZs).

**2.3.2 Pyrolysis of Chlorobenzenes.** Transformer-grade askarels contain from 30 to 40 per cent (w/w) chlorobenzenes; the remaining 60% to 70% are PCBs (either Aroclor® 1254 or 1260). The chlorobenzenes used are mixtures of trichlorobenzenes (primarily the 1,2,4- and 1,2,3- isomers) and tetrachlorobenzenes (primarily the 1,2,3,4-isomer).

Studies of the pyrolysis of PCBZs have shown that in the presence of oxygen, oxygen-containing aromatic compounds (PCDDs and PCDFs) are formed, whereas in its absence (e.g. under nitrogen) oxygen-free aromatic products are produced.<sup>14,15</sup>

In 1979, Buser<sup>15</sup> reported the formation of PCDFs (and PCDDs) through pyrolytic reactions of chlorobenzenes. In this research, individual as well as combined samples of tri-, tetra- and pentachlorobenzenes were pyrolyzed in air at 620°C in quartz ampoules. The major products of the resulting mixture were chlorobenzenes, with decomposition of the lower chlorinated benzenes occurring to a greater extent than that of the higher chlorinated benzenes, i.e., more than 95% for trichlorobenzenes, approximately 90% for tetrachlorobenzenes and approximately 50% for pentachlorobenzenes in the combined sample. Other products of the pyrolyses included PCDFs, PCDDs, PCBs, CPs, chlorinated naphthalenes (PCNs) and chlorinated styrenes (PCSs).

Significant quantities (up to 10% yields) of PCDFs were formed in the pyrolyses. Generally the PCDFs formed had chlorine numbers of  $2m-2$ ,  $2m-1$ , and  $2m$ ; where  $m$  is the chlorine number of the chlorobenzene used; e.g., pyrolysis of the trichlorobenzenes gave tetra-, penta-, and hexachlorodibenzofurans.

According to Buser, the thermochemical formation of the PCDFs (and PCDDs) from the PCBZs is bimolecular, and so their formation depends on the PCBZ concentration. Buser also proposed that the CPs (present in all pyrolyzed samples) are intermediates in the formation of the PCDFs. A reaction of the CPs with PCBZs could lead to chlorinated diphenylethers (PCDPEs) which upon pyrolysis are known to yield PCDFs.

**2.3.3 Heating/Pyrolysis of PCBs.** Heating PCBs at sufficiently high temperatures results in the formation of PCDFs. Buser and his co-workers<sup>16</sup> found increased levels of PCDFs (in the ppm range) not only in a commercial PCB mixture heated at 300°C for a week in the presence of air, but also in a PCB mixture used in a heat exchange system.

Several groups have since studied the pyrolytic/thermal formation of PCDFs from PCBs in the laboratory to determine the mechanisms involved, the additional reactants necessary, and any catalysts that may enhance the formation of these compounds.

**2.3.3.1 Mechanisms.** In 1979, Buser and Rapp<sup>16</sup> studied the pyrolyses of 18 PCB congeners and determined that the formation of PCDFs in these reactions resulted from intramolecular cyclization processes. They determined that the formation of the PCDFs from PCBs follows one or more of four general reaction routes:

- a) Loss of ortho-Cl<sub>2</sub>
- b) Loss of HCl with or without a 2-3 chlorine shift
- c) Loss of ortho-HCl
- d) Loss of ortho-H<sub>2</sub>

A further mechanism for the formation of PCDFs from pyrolysis of PCBs has been proposed as part of an investigation of trace organic compounds in fly ash from municipal and industrial incinerators. Choudhry and Hutzinger<sup>17</sup> have proposed that the reaction proceeds according to the following mechanism:

- i) chlorinated diphenyl radicals are first formed from PCBs by either abstraction of ortho-hydrogen by free radical species or by scission of an ortho C-Cl bond,
- ii) reaction of these diphenyl radicals with O<sub>2</sub> to form peroxide radicals which in turn form ortho-hydroxychlorinated biphenyls, and finally,
- iii) cyclization of these chlorinated biphenyls to form PCDFs.

**2.3.3.2 Temperature.** PCB pyrolyses have been carried out in the laboratory at temperatures ranging from 200°C<sup>18</sup> to 850°C.<sup>19</sup> There is some discrepancy, however, regarding the effect temperature has on the amounts of PCDFs formed. The optimal temperatures for PCDF formation in two separate studies were reported to be 500°C<sup>20</sup> and 550°C<sup>18</sup>, whereas in yet another study the authors found that at 330°C the PCDFs formed began to decompose.<sup>21</sup>

The minimal temperature reported by Morita and his co-workers<sup>21</sup> for PCDF formation is 270°C. In their article they suggest that the PCDF levels formed are governed by the transient equilibrium of thermal formation and decomposition.

Buser *et al.*<sup>19</sup> investigated the pyrolysis of two hexachlorobiphenyls at temperatures ranging from 550°C to 850°C. PCDFs were formed at temperatures of 550°C to 650°C. However, at 700°C and above complete destruction of these PCDFs occurred.

**2.3.3.3 Time.** Only one study has reported the effect of time on the pyrolytic formation of PCDFs from PCBs.<sup>21</sup> The authors found that at 300°C the amounts of

PCDFs formed increased to a maximum at 7 days with O<sub>2</sub>, 14 days with air, and then gradually decreased.

**2.3.3.4 Atmosphere.** The structures of PCBs and PCDFs require a source of oxygen for their conversion. This was confirmed in one study where PCBs were pyrolyzed under oxygen, air and nitrogen.<sup>21</sup>

PCDFs were formed in good yields when oxygen was used, lesser amounts (ca. one tenth that of O<sub>2</sub>) in the presence of air, and very little, if any, were formed under nitrogen. (The PCDFs formed were attributed to either oxygen, water, or some other oxygen-containing contaminants in the nitrogen.)

**2.3.3.5 Catalysis.** Addition of Fe<sup>18</sup>, FeCl<sub>3</sub><sup>20</sup>, or Cu-Fe powder<sup>20</sup> has been found to increase the amounts of PCDFs formed during the pyrolysis of PCBs. The reactions are probably similar to Ullman-type catalyzed reactions<sup>17</sup>, in which case many other metals may also catalyze the reaction.

**2.3.4 Pyrolysis of Askarels.** As discussed earlier, askarels are mixtures of PCBZs and PCBs. Pyrolysis of these mixtures is therefore likely to yield PCDFs and PCDDs (the latter from the PCBZs).

To our knowledge only one study has reported on the in-lab pyrolysis of askarels.<sup>13</sup> In that study, samples of Aroclors® 1254 and 1016 and the askarels Pyranol®, Inerteen™, and Chlorextol™ were pyrolyzed under air at 500°C. The pyrolysates were analyzed for PCDFs and the tetrachlorodibenzofurans (TCDFs) quantified.

All askarels yielded significant quantities of TCDFs (ca. 40 to 500 micrograms TCDF per gram of starting material) as did Aroclor™ 1254. Aroclor™ 1016, by contrast, yielded much lower quantities of TCDFs. This difference is most likely due to the lower chlorine content of the PCBs in Aroclor™ 1016; i.e., very little penta- and hexachlorobiphenyls. PCDDs were not detected, possibly because they were formed in such low quantities that they were masked by the higher levels of PCDFs.

**2.3.5 Pyrolysis of PCB-contaminated Mineral Oil.** To date no reports of experiments investigating the heating or burning of PCB-contaminated oils of any type and the analysis of products formed have been published.

Mineral oils (also called naphthenic or white oils) used for dielectric insulation are mixtures of paraffinic (ca. 70%) and aromatic (ca. 30%) hydrocarbons.<sup>22</sup> These oils are frequently contaminated with PCBs in concentrations that often exceed 50 ppm (see Section 3).



Quantities of PCDFs formed in a fire situation implicating such oils are difficult to predict. If a 1% PCB to PCDF conversion is assumed, a 1000-L transformer filled with mineral oil containing 100 ppm PCB would yield 1 ppm PCDFs or a total of 1 gram of PCDFs.

The conversion of PCBs to PCDFs could, however, be higher or lower. For example, the temperatures reached in a mineral oil fire could be high enough so that all the PCBs and PCDFs are destroyed. By contrast, the mineral oil could act as a fuel feeding the fire over a longer period of time and potentially produce more PCDFs (PCBs or askarels, unlike mineral oils, would quench a fire).

The mineral oil components could take part chemically in the conversion of PCBs to PCDFs according to the reaction mechanism proposed by Choudhry and Hutzinger<sup>17</sup> (see 2.3.3.1).

This is one area where much more research is required.

## **2.4 General Observations and Conclusions**

From this laboratory research several conclusions can be drawn regarding the thermal/pyrolytic generation of PCDFs:

- (a) PCDFs are formed when PCBs, PCBZs, or both are heated in the presence of oxygen at temperatures greater than ca. 250°C but less than ca. 700°C.
- (b) The optimal temperature for the formation of PCDF is ca. 500°C, however lower temperatures have been reported.
- (c) Oxygen (pure O<sub>2</sub>, air, or possibly other oxygen-containing compounds) is required. The yields of PCDFs depend on the amount of oxygen present.
- (d) The formation of PCDFs is catalyzed by the presence of certain metals (e.g. iron or copper) or their salts.
- (e) Percentage yields of PCDFs (i.e., 1% or greater) have been reported when PCBs, PCBZs, and askarels have been pyrolyzed.
- (f) In addition to PCDFs, PCDDs are also formed when PCBZs are pyrolyzed.

Although the number of variables is such that it is difficult to predict accurately to what extent PCDFs are formed during a fire situation, their formation should nevertheless not be dismissed.

### **3 ELECTRICAL EQUIPMENT**

#### **3.1 General**

Fire-resistant dielectric liquids, known under the generic name of askarels, have been used in electrical equipment in Canada since the early 1930's. Transformer-grade askarels consist of polychlorinated biphenyls (PCBs) usually blended with chlorinated benzenes (PCBZs) in varying ratios.<sup>23</sup> The most common transformer-grade askarels used in Canada contain 60% to 70% PCBs and 30% to 40% PCBZs. Capacitor-grade askarels (ASTM Types 2233A, B, and D) contain no PCBZs, only PCBs.<sup>24</sup>

The main reason for using askarel equipment indoors, in preference over mineral oil equipment, is the superior fire-resistant property of askarel. The main reasons for using askarel equipment indoors, in preference over dry-type, air-cooled equipment, are:

- (i) the superior dielectric strength of askarel;
- (ii) suitability for use in areas where the ambient atmosphere is badly contaminated with dust, dirt, or corrosive fumes;
- (iii) where the ambient atmosphere is extremely damp;
- (iv) where the hazard of lightning surge is unduly high.

#### **3.2 Transformers**

The transformers, which present a potential hazard for contamination by PCDFs, fall into two categories:

- (i) those that were designed to use askarel as the dielectric and cooling medium, and
- (ii) those that were designed to use mineral oil as the dielectric and cooling medium, but contain PCBs due to an adventitious contamination of the mineral oil.

Askarel transformers were designed as sealed units complete with pressure-relief vents. Relief vents are usually designed to operate at a tank pressure in the range of 50 to 70 kPa. The tanks can bulge when pressure exceeds 70 kPa, and rupture when pressure exceeds 175 kPa.

The typical range of askarel transformers is 300 kVA to 5000 kVA, with an average transformer containing approximately 1400 kg of PCBs.

Askarel does not support or sustain combustion until it reaches its boiling point at approximately 205°C. It has a high dielectric strength, exceeding that of mineral oil.

Internal arcing faults may create conditions in which PCDF are generated. With respect to the potential for PCDF formation, the following two types of fault in the transformer windings have been considered.

In the event of a short-circuit within the transformer, the tank should remain intact, being disconnected by the primary circuit breaker or fuse protection assembly. The speed at which the transformer will be disconnected depends on the magnitude of the fault current, and the speed at which the protection mechanism operates.

An escalating high-impedance fault accompanied by arcing is more serious. This type of arcing fault may cause the current to increase over an extended period, increase the temperature of the askarel, and increase the tank pressure to a dangerous level. This can result in the opening of the relief vent whereupon askarel and gases could be expelled from the tank.

### **3.3 Capacitors**

Capacitors containing askarel are used for the following applications:

- (i) power factor correction and voltage regulation of high-voltage lines and transformer stations;
- (ii) power factor correction for indoor power distribution systems;
- (iii) fluorescent and high-intensity discharge (HID) lamp ballasts.

Capacitors containing PCBs have been manufactured since the 1930's until 1979 when askarel became no longer available.

All askarel capacitors are sealed in metal enclosures. The enclosure would have to rupture to spill askarel.

A dielectric breakdown within a capacitor could cause hot spots within the capacitor and, in turn, cause the formation of PCDF without rupturing the capacitor enclosure.

High-voltage power factor correction and voltage regulation capacitors are normally located outdoors on poles or structures, and at outdoor transformer stations.

Indoor power distribution systems may have power factor correction capacitors located at the main secondary switchboard, at motor control centres, or at individual electric motors. The degree of hazard is similar to that of small askarel transformers.

Capacitors used for power factor correction are installed either outdoors or in isolated indoor locations. Capacitors used in lamp ballasts, however, are installed throughout a building as part of fluorescent or HID lighting systems. In a large building,

the lighting system may include many thousands of PCB capacitors encased in the lamp ballasts. Therefore these lamp ballasts present a higher degree of hazard than power factor correction capacitors, in spite of the fact that a single lamp ballast unit contains a relatively small amount of PCBs.<sup>25</sup>

### **3.4 Electromagnets**

Electromagnets may be located in industrial plants, scrap metal yards, and mineral conveyor systems.

The number of units and total amount of PCB contained in electromagnets is considered to be relatively small compared to transformers and capacitors.

The degree of hazard is nevertheless similar to that of small askarel transformers.

## **4 CASE HISTORIES**

All occurrences, actions, etc., are discussed with reference to the situation before the fire, what happened during the fire, and how clean-up was handled after the fire. More detailed information is given in the Appendix.

### **4.1 General Observations**

Electrical fires in transformers and capacitors have historically been very common occurrences. Toronto Hydro has documented an average of one transformer fire per year. Only one of those fires implicated a transformer containing PCB.

There have been few documented incidents of PCB fires. Several hypotheses are advanced for this:

- (i) PCBs do not burn easily;
- (ii) awareness that PCBs and their combustion products pose extreme risks when implicated in electrical fires did not exist until after the Binghamton, N.Y., fire in 1981;
- (iii) companies that have small fires implicating PCBs probably do not report them in order to avoid expensive clean-ups and intense public concern triggered by PCB incidents.

PCB fires are a normal occurrence in U.S.A., but all, except the one at Binghamton, have been quite small with no in-depth study or analysis having been carried out. The majority of PCB fires go by without being tested for PCDFs, because of the lack of awareness concerning the hazards of PCDFs.

All documented fires in transformers in North America were caused by electrical malfunction. In all these cases the characteristics were very consistent: very small flames, accompanied by large amounts of heat, released thick, black smoke leaving residues of oily, black soot.

All documented Scandinavian incidents implicated capacitors containing PCBs. All but one of these fires were caused by an electrical malfunction in the capacitors. In all these fires the soot was contaminated with PCDFs, but not with PCDDs. The lack of PCDD formation has been explained by the absence of chlorobenzenes in those capacitors.

### **4.2 North American Fires**

Case histories of three North American fires involving PCB-contaminated electrical equipment were reviewed:

Toronto Fire	9 December 1977
Binghamton Fire	5 February 1981
Manitoba Fire	29 March 1982

#### 4.3 Scandinavian Fires

Seven PCB fires or explosions have occurred in Sweden and Finland since 1977: These are, in chronological order:

Norrtälje, Sweden*	June 1977
Danviken, Sweden	August 1981
Skovde, Sweden	March 1982
Imatra, Finland*	August 1982
Helsinki, Finland*	August 1982
Surahammar, Sweden	September 1982
Hallstahammar, Sweden*	November 1982

#### 4.4 Conclusions

The case histories discussed in this report are typical of electrical fires implicating PCB-containing transformers or capacitors.

The fires are rarely, if ever, caused by PCBs themselves. The PCB fluid is normally incidental to a fire caused by an electrical malfunction or a mineral oil fire. Fire implicating PCBs are smoky and yield large amounts of black oily soot. This soot is contaminated with PCBs, PCDFs and, if chlorobenzenes are present, PCDDs.

Testing has indicated that PCBs and PCDFs do not volatilize from soot. In all these case history studies, testing was conducted to determine the amount of PCDFs formed during the fire in relation to the amount of PCBs available. Approximately 1% of the PCBs are converted to PCDFs, and 10 times more PCDFs than PCDDs are formed.

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\* Specific details are not known.

## 5 RECOMMENDATIONS

### 5.1 General

The recommendations put forward in Table 1 define the general context from which more specific, more refined procedures are to arise. Such procedures must transcend general guidelines for fire prevention, fire-fighting, and clean-up after a fire.

The recommendations deal with additional precautions applicable to the possible formation and subsequent dissemination of PCDFs during and after a fire.

TABLE 1 RECOMMENDATIONS

	PREVENTIVE MEASURES	FIRE-FIGHTING MEASURES	CLEAN-UP MEASURES
Individual Health and Safety	Information and Training	Awareness of PCBs	Information
	Identification of Equipment	Use of proper Protective Gear	Protective Procedures
	Protective Material	Medical Aid	• area
	Contingency Plan	Evacuation	• individual Medical Attention
Equipment and Facilities	Programs	Strategies	Soot Removal
	• operation	Materials	Inspection
	• maintenance/inspection		
	Safety Systems PCB Management		
Environmental Concerns	Containment of:		Decontamination
	• equipment fluids		Disposal
	• contaminants		

## **5.2 Discussion of Recommendations - Preventative Measures**

### **INDIVIDUAL HEALTH & SAFETY**

These measures aim primarily at the benefit of personnel; they will also facilitate action by the emergency response crews.

#### **1. Information and Training**

Personnel should be informed on the procedures to follow in case of fire. This will not only prevent exposure to those taking uninformed actions during a fire, but also instill caution.

Practice, rehearsal, and training are necessary to ensure that personnel can be evacuated or appropriate precautions and countermeasures taken, pending arrival of emergency response crews.

Fire wardens should be familiarized with the additional hazards posed by PCDFs and with any special countermeasures necessary in the event of a fire implicating electrical equipment and possibly PCDFs.

#### **2. Identification of Equipment**

Each piece of electrical equipment containing PCDF precursors should be identified, properly labelled, and its location recorded on a schematic layout of the facility. This will prevent exposure to those taking uninformed actions in case of fire, and instill caution. In addition, areas to be avoided or restricted to authorized personnel can be more easily defined.

The emergency response crews (fire department, environmental protection departments) should also be informed on the identity and location of such equipment to enable them, in the event of an emergency, to use appropriate material and implement adequate countermeasures.

#### **3. Protective Material**

Fire alarms systems, fire extinguishers should be clearly labelled and readily accessible. Voice communication systems should be checked periodically. Fire exits should be free of any obstacles.

Fire extinguishers and self-contained breathing apparatus (SCBA) should be inspected periodically.



#### **4. Contingency Plan**

This plan should contain clear courses of action and various options for dealing with emergency situations. This contingency plan should also be provided to and discussed with emergency response crews. The plan should also consider evacuation needs and actions to be taken prior to arrival of emergency response crews.

## EQUIPMENT & FACILITIES

These measures aim primarily at protecting equipment and facilities.

### 1. Programs

#### (a) Of Operation

- Equipment should not be operated above design ratings.
- Undersized (overloaded) equipment is more prone to deterioration and

failure, thereby increasing the risks for fire.

#### (b) Of Maintenance and Inspection

- A good inspection program keeps operating equipment in condition and identifies defective equipment.
- Repair the equipment before it becomes hazardous.

### 2. Safety Systems

(a) A properly designed fire-extinguishing system can begin the fire control procedure even before emergency response crews are aware of the fire. Install automatic fire-extinguishing systems, and distribute small portable extinguishers at strategic locations.

(b) Shutting the power off reduces both the arcing and the production of PCB/PCBZ degradation products; it also cuts the energy input and reduces the intensity of fires. In addition, firefighting is always delayed pending equipment shut-off. A prompt intervention reduces damage to equipment and limits generation of smoke and fumes. Install alarms, shut-down systems, or both on equipment.

(c) The ventilation system is a major route by which contamination spreads. Smoke, fumes, and hot gases may be carried throughout an entire building by convective effect, resulting in massive widespread contamination from a relatively localized occurrence. Install auto-close mechanisms on the ventilation network.

### 3. PCB Management

#### (a) Do not mix PCB equipment with non-PCB equipment.

PCB transformers and capacitors should be physically separated from non-PCB equipment so that in case of a fire in a mineral oil transformer, the fire will not spread to PCB equipment.

A fire starting in PCB equipment may not be self-sustaining when the power is off, whereas a fire in a mineral oil transformer will continue to burn. If PCBs are implicated in a self-sustaining fire, the difficulty of controlling the contaminant dispersion is compounded; not only must contaminants be contained, but their containment must take place during the control of another emergency of higher priority.

- (b) Remove PCBs from equipment, and retrofill with non-PCB fluids.

Where possible, this course permits the reduction of hazard without incurring the major capital expense of replacing the equipment.

There are several caveats with this course:

- (i) the flammability with a retrofilled appliance is greater than with a PCB appliance,
- (ii) draining and retrofilling of equipment may not be practical,
- (iii) the replacement fluid will become contaminated and may contain more than 50 ppm PCBs.

## ENVIRONMENTAL CONCERNS

These measures aim primarily at minimizing dispersion into the environment.

### **Containment of Equipment Fluids**

A containment system; e.g., berms, curbs, dams, capable of holding more than the total volume of fluids contained within the equipment should be provided for each piece of equipment.

Drains in the floor must be outside the containment area.

A drain-sealing system must be in place to prevent contaminants from escaping to the sewer system.

### **Containment of Contaminants**

All surfaces (walls, ceilings, and floors) should be painted with materials impermeable to PCBs and PCDFs. This precaution will facilitate clean-up and may also avoid the necessity of removing building materials as part of the decontamination process.

### 5.3 Discussion of Recommendations – Firefighting Measures

#### INDIVIDUAL HEALTH & SAFETY

These measures highlight the additional precautions necessary to avert anticipated hazards arising from fires implicating PCBs.

##### 1. Awareness of the Presence of PCBs

Warn emergency response crews about the identity and location of PCB equipment. This will lead to the use of proper extinguishing techniques, including personal protective gear.

##### 2. Use of Proper Protective Gear

Hazards are likely to be associated with an electrical fire as well. Therefore, protective gear should guard against heat, asphyxiants, and corrosive atmospheres.

Protection against PCDFs should be based on a limit of  $1.5 \text{ ng/m}^3$  (24 hour average)\*. This means use of full protective suit and self-contained breathing apparatus.

##### 3. Medical Aid

Due to the extremely toxic effects involved, emergency medical aid should be on call. Where personnel has been exposed to gases from a fire, decontamination of both skin and protective material is required.

Medical testing is also required.

##### 4. Evacuation

All ventilation openings (inlets and outlets) in the building should be closed automatically. Otherwise evacuation of adjacent buildings must be considered whenever contamination could reach other buildings. The hazardous nature of PCDFs justifies a conservative course of action.

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\* The Ontario Ministry of Labour, in its Chlorinated Dioxins and Chlorinated Dibenzofurans Ambient Air Guidelines (Dec. 1982) has recommended an annual exposure limit for TCDD of  $30 \text{ pg/m}^3$ . PCDFs have not been specifically addressed, but the limit for mixtures of TCDD and PCDFs implies that TCDD is more toxic by a factor of 50. This would suggest an annual average limit of  $1500 \text{ pg/m}^3$ , i.e.  $1.5 \text{ ng/m}^3$ .

## EQUIPMENT & FACILITIES

These measures aim at promoting a quicker control of fire and, in turn, minimizing hazards and damage.

### 1. Firefighting Strategies

#### (a) Concerning Power

Ensure that power is off. A power-on situation complicates firefighting considerably, requiring extra precautions to avoid potentially live sources, both for personal safety and for fire control.

#### (b) Concerning Ventilation

If one of the three necessities for fire is absent - in this case the oxidant ( $O_2$ , air) - then control and extinguishment may be achieved at much less cost and result in much less damage.

Ensure that air inlets/outlets and access to a building's ventilation system are closed.

If this is not done, what should have been a localized confined contamination can become a major environmental problem, contaminating all areas accessible to the building's ventilation system.

Once a fire has been extinguished in this way, caution is required to avoid re-ignition when air is re-admitted, while ignition sources still remain.

### 2. Firefighting Materials

Carbon dioxide ( $CO_2$ ) and HALON® act by segregating the oxidant ( $O_2$ , Air) from the fuel. Although they do not have as significant a cooling effect as water does, they do not have the drawbacks that water has either.

## ENVIRONMENTAL CONCERNS

The emphasis on environmental concerns has been placed on the Preventive Measures to warrant the precedence given to firefighting measures during the emergency.

## **5.4 Discussion of Recommendations - Clean-up Measures**

### **INDIVIDUAL HEALTH & SAFETY**

These measures aim at minimizing exposure to the hazards the contaminants pose.

#### **1. Information**

Personnel must be informed of the occupational health concerns of PCBs, PCDDs, PCDFs, and the cleaning materials used.

Training of clean-up crews in recognizing the hazards of the task is a necessary adjunct to the provision of protective gear.

#### **2. Protective Procedures**

##### **(a) Area**

Monitor contamination of the area to

- (i) indicate the degree of hazard,
- (ii) provide boundaries for the clean-up,
- (iii) provide information for the use of proper protective gear,
- (iv) indicate when clean-up is satisfactory.

##### **(b) Individual**

Although fire-related hazards are not present in the clean-up phase, protection against PCDFs must be maintained at a high level. Generally, protective gear must lend itself to decontamination or discard.

Reduction in air contamination through an air-cleaning vacuum system will reduce the inhalation hazard and skin contamination from airborne particulates, thus permitting less stringent requirements for breathing apparatus.

#### **3. Medical Attention**

Prompt medical attention is essential for any case of exposure to the substances produced in a fire involving electrical equipment. Response crew members should undergo medical examination, if there has been any possibility of exposure.

Decontamination procedures must ensure that no hazardous material remain on the clean-up crew members, and that clothing and equipment has also been cleaned or disposed of.



## EQUIPMENT & FACILITIES

These measures aim at the efficient and thorough removal of contaminants.

### 1. Soot Removal

The major location of PCDF contamination is expected to be in soot deposited on surfaces. PCDFs are quite strongly adsorbed by soot, thus removing the soot also removes much of the hazard. Loose soot is best removed by vacuuming with a high-efficiency vacuum cleaner equipped with high-efficiency filtration for the exhausted air. Remaining soot adhering too well to be removed by vacuum, is removed by washing with organic solvents. Water and detergent systems, with mechanical scouring, may also be effective, particularly as a final cleaning step. Washing should be repeated until the surface contamination is reduced to 10 ng/m<sup>2</sup> PCDFs. All cleaning materials and residues must be contained for treatment or disposal.

The curtain-wall technique is effective in permitting the intensive cleaning of small sections of an area without recontaminating the area with debris or contaminants from uncleaned sections. Although installation and use of curtain-walls is expensive in terms of material and time, it does minimize the need to reclean areas.

### 2. Inspection

Ventilation inlets of all buildings in the vicinity of the fire should be closely examined. Should any soot be found at these inlets, it must be analyzed immediately, and appropriate clean-up procedures must be put into effect with respect to all contaminated areas.

## ENVIRONMENTAL CONCERNS

These measures aim at preventing the spreading of contamination.

### 1. Decontamination

Prevention of contamination spread is achievable by maintaining the contaminated area under reduced pressure. Exhausting air through a high-efficiency filtration system maximizes the benefits of decontamination.

Decontaminating workers and cleaning up equipment on site keeps contamination localized.

### 2. Disposal

Contaminated materials should be stored in labelled and numbered containers. All clean-up materials must be considered contaminated and stored until treated or disposed. This requirement includes clothing and tools; once these are decontaminated, the wash liquids must be treated as contaminated and then stored.

Contaminated materials should be disposed in an approved hazardous-waste disposal facility.

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## **APPENDIX**



## TORONTO FIRE - 9 DECEMBER 1977

### Introduction

Adelaide Street is located in downtown Toronto. The underground vault housed two transformers: one filled with mineral oil; the other, a 1500-kVA transformer, filled with 1800 litres of askarel and installed in 1965.

The accident occurred at the start of the morning rush hour.

### Event

A crack developed in the circuit breaker (2500 A low-voltage); the protective relays could not immediately clear the fault. Arcing occurred across the crack starting a small electrical fire. The crack spread to the porcelain bushing on the transformer causing 450 litres of askarel to leak onto the floor; some of the askarel vapourized across the electrical arc.

Protective relays then opened the primary feeder lines, and low-voltage fuses blew disconnecting the askarel transformer from the mineral oil transformer.

Twenty-two firemen fought the fire: at no time did they enter the vault. They were wearing self-contained breathing apparatus because of volumes of black smoke coming from the vault. Firemen filled the vault with carbon dioxide (CO<sub>2</sub>) through the ventilation gratings and extinguished the fire.

### Aftermath

Primary feeder lines supplying the mineral oil transformer were opened to de-energize the spot network completely. Toronto Hydro personnel entered the vault and found that the 450 litres of spilled askarel had been contained in a pit around the askarel transformer. Hydro personnel isolated the askarel transformer so that the mineral oil transformer could restore power to an adjacent building. Only then was it known that PCBs were definitely implicated.

An electrical maintenance company, experienced in dealing with askarel, pumped the unspilled askarel out of the transformer and removed the unit.

Some Hydro employees complained of illness after the fire; symptoms included headache, eye discharges and irritation, nausea, vomiting, and skin rashes similar to cold sores on the face and hands.

Twenty-five Hydro employees who went to the fire without proper protective gear and the 22 firemen were tested for PCB levels one week after the fire: no high

levels of PCBs were found. Firemen underwent close scrutiny for six months after the fire: they showed no ill effects.

An experienced clean-up contractor enclosed the vault with sand berms and a barricade. He decontaminated the area by first spraying No. 2 fuel oil and then detergent. Any fixtures in the vault that could not be decontaminated were removed for disposal. All contaminated equipment and clothing from the clean-up contractor, Toronto Hydro personnel, and firemen were collected.

After initial clean-up, the vault was tested for PCBs in air: results showed that PCBs were above  $30 \mu\text{g}/\text{m}^3$  (Ontario Ministry of the Environment Standards). The vault was re-scrubbed until the PCB levels were below the standard, and cleaning agents were collected.

Soot containing 10 000 ppm PCBs covered a  $70 \text{ m}^2$  area adjacent to the fire site. A second contractor was hired to decontaminate the walls of adjacent buildings.

Contaminated water, clothing, equipment that could not be cleaned were disposed at a PCB-secure landfill in Niagara Falls, N.Y.

PCDFs were found in the soot at concentrations of 5 ppm. PCDDs were also detected in test samples of air and soot taken at the fire site in late December.

Costs were estimated at \$100 000. They include value of destroyed transformer, labour to replace it; decontamination of vault, building, and surroundings; disposal of contaminated materials.



## BINGHAMPTON FIRE - 5 FEBRUARY 1981

### Introduction

The Binghampton State Office Building is the central tower of a governmental building complex completed during Spring 1973; it rises 18 storeys (about 90 metres) from street level; it has two subsurface levels.

Thirty-three state agencies employ 700 employees in the building. However, at the time of the fire (05 h 30), only a security guard and a stationary engineer occupied the building.

### Event

A loose connection or a piece of dirt possibly caused an electrical failure within the main switching equipment close to an askarel transformer in the mechanical room of the basement. The electrical failure touched off an intensely hot fire; the heat caused a porcelain bushing on the nearby transformer to crack and leak 700 litres of askarel onto the floor. The transformer contains 4000 litres of Pyranol® (65% Aroclor® 1254 and 35% chlorobenzenes).

The fire burned for 45 minutes before the power was shut off; during that time temperature at the centre of the fire had reached 1000°C. The Pyranol® vapourized and contaminated soot and ash. The drastic temperature gradient from the basement to the roof (-20°C) propelled the soot into the fire stairwell and into an airshaft contaminating all 18 storeys of the building.

Firemen waited for the power to be shut off before they started extinguishing the fire. After the power had been shut down and firemen were informed of the presence of Pyranol®, the fire was extinguished by ventilating the area and dousing the flames with water. It took 35 to 40 minutes. Firemen were wearing standard protective gear including Scott Airpaks®, full enclosure poly/canvas jackets and pants, rubber boots, gauntlet gloves.

### Aftermath

State fire investigators determined that soot rose from the basement through a door left ajar to prevent pipe freezing; it then distributed through the rest of the building with the aid of a steady stream of air escaping through two roof-top hatches, above the fire stairs, that automatically opened when the fire alarm sounded.

All firemen took a shower immediately after the fire (standard procedure). All equipment and clothing were disposed, but the water used was not contained. One

fireman developed a recurrent rash on his face; two others developed rashy burns after hot fluid had penetrated their protective gear.

Wipe samples of the soot were immediately taken and tested. A 24-hour security system was maintained to control access to the building. A trailer serving as an entry/exit module was set up at the basement loading entrance: it contained entry facilities, lockers, showers, rest rooms, and security offices.

All personnel entering the building were required to wear a full-face respirator (with both activated carbon and high-efficiency particulate filters), and protective clothing that comprised socks, underwear, sneakers, rubber boots, coveralls, an outer Tyvek® protective suit, and both cotton and rubber gloves. Personnel were required to remove all protective gear and shower on exiting the building. Respirators were cleaned; filters replaced; outer suits, gloves and used filters were disposed after use.

A week after the fire, test results indicated that the soot was contaminated with PCDFs, PCDDs, biphenylenes and naphthalenes at concentrations as high as 2.9 ppm of 2,3,7,8-TCDD and 124 ppm of 2,3,7,8-TCDF. The horizontal surfaces of the building were covered with soot contaminated with 162  $\mu\text{g}/\text{m}^2$  PCBs.

All surfaces contaminated by soot and smoke particles were cleaned initially by a high-efficiency vacuum with vacuum bags approved for use with asbestos and washed with water and an anionic detergent (Triton™ X-100). Clean-up rags were disposed of as soon as they appeared slightly blackened by soot. Exposed areas not easily cleaned (papers, carpets, drapes etc.) were put in plastic bags and stored in the sub-basement of the building.

All water discharged from the building during cleaning was deposited into 55-gallon barrels for treatment and disposal until a carbon filter treatment system, using three plastic above-ground swimming pools, was set up in the basement of the building. The contaminated water was recirculated through the carbon filtration system until it was sufficiently decontaminated (less than 1  $\mu\text{g}/\text{L}$ ) to be fit for sending to the city's sanitary sewage treatment plant.

An air-pollution control filtration system was installed to filter the air in the building so that it was clean before discharge from the building. The system created a negative pressure throughout the building to ensure that air flowed from the outside, through the building, and finally through the filters on the roof.

Preliminary cleaning reduced the levels to 1  $\mu\text{g}$  of removable PCB/ $\text{m}^2$  on glass and painted surfaces. Cleaning procedures were not successful in decontaminating porous ceramic and vinyl floor surfaces, therefore they had to be removed for disposal. Many

people suspect that the floors could have been cleaned, if the oily soot had not been left to penetrate into the porous surfaces for upwards of 6 months (during which time clean-up and safety procedures were being developed).

Clean-up personnel have been continually monitored with blood tests. No exposure symptoms other than chloracne and "rashes" have been documented. Blood tests were given on a voluntary basis to anyone who thought that he or she was exposed during and after the fire. Results of these tests were inconclusive, and the tests are currently being redone.

The preliminary clean-up required 14 months for completion.

The criterion for completion of preliminary clean-up was the removal of all loose PCDF- and PCDD-contaminated soot from the building to allow opening of the building to normal ventilation; normal ventilation is required in order to use organic-solvent-based cleansers which would further decontaminate the building.

All material that could not be decontaminated was packaged in drums and landfilled at the SECOS-secure landfill at Niagara Falls, New York.

Final clean-up is currently pending a decision by scientific authorities on how clean (i.e. how low do the levels of PCDF and PCDD contamination have to be) the building must be before it can be reopened. Final clean-up will probably include replacement of all vinyl and ceramic floor tiles as they could not be sufficiently cleaned by detergents, and repainting the walls with chemical-resistant paint.

On 31 January 1983 Governor Mario Cuomo of the State of New York stated that \$8.6 million had been spent on the Binghamton clean-up thus far and that a further \$3 million will be allocated in 1983 to complete the final clean-up.

The target date for reoccupancy is Summer 1985, by which time the costs of the clean-up may equal the original cost of the building (\$20 million).

## MANITOBA FIRE - 29 MARCH 1982

### Introduction

A vault located in the basement of the electrical engineering laboratory of the University of Manitoba in Winnipeg contained six transformers used for both experimental and operational purposes. Transformers were filled with mineral oil.

No one was at the fire site at the time of the fire (early morning).

### Event

An electrical failure caused arcing on one transformer and started a fire. The mineral oil ignited and spread fire to others.

Firemen extinguished fire with water; power must not have been shut off, because a transformer exploded spraying oily soot all around the room. Firemen wore standard gear with no specialized chemical gear, because the transformers were supposed to contain only mineral oil.

The entire laboratory was contaminated with soot, and the water was not contained.

### Aftermath

The Manitoba Department of the Environment responded to the fire and tested the oil in the damaged transformers and on the walls of the laboratory. The test results indicated that the soot was contaminated with 250 ppm PCBs. No detectable levels of PCDFs were found.

Precautions against PCB contamination were taken during the clean-up. Blood tests were taken.

Contractors were hired to clean up the high-voltage equipment with Keysolve™ and scrub the rest of the laboratory with Varsol™. An exhaust system was set up to remove Varsol™ fumes. Clean-up crews were protected with air-line respirators, rubber gloves and boots, and disposable suits impervious to chemicals.

All contaminated materials that could not be decontaminated were shipped in metal drums for storage at an authorized disposal facility.

**DANVIKEN, SWEDEN - AUGUST 1981****Event**

Electrical malfunction caused a fire that burned 18 capacitors in a transformer station.

Firemen wore no special protective equipment against PCBs.

**Aftermath**

- 1 to 3  $\mu\text{g}/\text{m}^2$  PCDFs in soot
- no PCDDs detected
- chlorinated pyrenes formed

Clean-up: high-efficiency vacuuming followed by washing with detergent.

Exposed personnel were tested by blood-sampling: no elevated PCB or PCDF levels were found. No symptoms of exposure were reported.

All contaminated wastes were stored in drums, pending decision by the Swedish government on disposal.

**SKOVDE, SWEDEN - MARCH 1982****Event**

An electrical malfunction occurred in a mineral oil capacitor serving a high-frequency oven in a casting line of a Volvo metal treatment factory.

A very hot fire ensued and spread to the capacitors: 12 broke open, 9 remained sealed. The fire burned for two hours before it was finally extinguished. Temperatures were high enough to melt a copper pipe (1100°C).

Firemen were aware of the presence of PCBs and wore protective equipment accordingly, which was disposed afterward.

**Aftermath**

- up to 900  $\mu\text{g}/\text{m}^2$  PCDFs
- no PCDDs detected

Clean-up: high-efficiency vacuuming followed by washing with detergent.

Exposed personnel were tested by blood-sampling: no elevated PCB or PCDF levels were found. No symptoms of exposure were reported.

PCDF contamination levels were at  $<10 \text{ ng}/\text{m}^2$  after the clean-up.

All contaminated wastes were stored in drums, pending decision by the Swedish government on disposal.

**SURAHAMMAR, SWEDEN - SEPTEMBER 23, 1982****Event**

An explosion in a steel kiln caused 10 tonnes of molten steel (1500°C) to spread through the steel mill. The molten steel melted a metal door sealing off the capacitor room.

A fire ensued in the 500 capacitors, 200 of which contained PCBs (ca. 2000 kg).

Firemen attempted to extinguish the fire resulting from the molten steel with water. Explosions resulted. They then decided to let the fire burn itself out.

The building was occupied at the time of the fire, but everyone was evacuated. The heat was very intense, and large amounts of hydrochloric acid were given off by the burning PCBs.

**Aftermath**

- up to 4  $\mu\text{g}/\text{m}^2$  TCDF in soot (condenser room)
- no PCDDs detected

Clean-up: high-efficiency vacuuming followed by washing with detergent. The sucked-up soot was treated by carbon filtration; the contaminated carbon was stored in steel drums for future disposal. A movable curtain wall was erected in the steel mill to prevent re-contamination of areas already cleaned.

Clean-up personnel wore disposable protective suits, rubber boots, gloves, and line respirators (air was filtered by a glass-fibre filter before breathing).

Exposed personnel were tested by blood-sampling: no elevated PCB or PCDF levels were found.

Two incidents of skin problems resulting from exposure to hydrochloric acid were reported.

PCDF contamination levels were at  $<10 \text{ ng}/\text{m}^2$  PCDFs after clean-up.

All contaminated wastes were stored in drums, pending decision by the Swedish government on disposal.