RECOMMENDATIONS FOR THE PREVENTION OF PCDF CONTAMINATION FROM FIRES INVOLVING ELECTRICAL EQUIPMENT

by

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SUMMARY

The purpose of this publication is to enhance awareness through recommendations for the prevention of contamination by polychlorinated dibenzofurans (PCDFs) from fires involving electrical equipment containing polychlorinated biphenyls (PCBs).

A study was carried out by M. M. Dillon Limited, Consulting Engineers and Planners, in association with Wellington Environmental Consultants at the request of the Commercial Chemicals Branch, Environmental Protection Service, Environment Canada, following a recommendation made by the Interdepartmental Committee on Toxic Chemicals (ICTC) in August 1982.

The properties of PCDFs and the conditions under which they are formed are reviewed in Section 2 of this report. A computer survey of literature covering the period from 1967 to 1983 was carried out.

Human exposure to only PCDFs 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, both in the short and the long term. The toxicity of various PCDF congeners depends upon the position and degree of chlorination; the tetra- and penta-chlorodibenzofurans being the most toxic.

It was found that PCDFs are generated when PCBs and/or chlorinated benzenes (PCBZs) are heated in the presence of oxygen at temperatures in the range of 250°C - 700°C. The optimum 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. In addition to PCDFs, PCDDs are formed from PCBZs, but not from PCBs.

The types of electrical equipment containing PCBs which are used inside or in a close proximity to buildings, are described in Section 3. These are: transformers, capacitors and electromagnets, the latter being quantitatively insignificant as compared to the first two. By far the largest quantity of PCBs still in use are inside transformers, which on the average contain 1 400 kg of PCBs per unit. Compared to that, the per unit content of PCBs in 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 the buildings, often in large quantities as part of each fluorescent lighting fixture.

Case histories of ten fires which involved PCB-containing electrical equipment and occurred during 1977-1982 period, were reviewed. Two of those fires occurred in Canada, one in the United States of America, five in Sweden and two in Finland. A review of the ten fires is presented in Section 4 of the report and all available data on these fires are included in Appendix A.

It is concluded that fires involving 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 into PCB-containing equipment. All fires involving PCBs are smokey and yield large amounts of black oily soot. This soot is what is contaminated with PCBs, PCDFs and, if chlorobenzenes are present, PCDDs. PCBs and PCDFs are non-volatile from soot. Soot analysis shows that approximately one per cent of the PCBs are converted to PCDFs. No PCDDs were found in case of fires involving PCB capacitors. Ten times more PCDFs are formed than PCDDs in fires involving PCB transformers.

The recommendations contained in Section 5 of the report are presented in three parts:

PREVENTIVE MEASURES	-	Table 2
FIREFIGHTING MEASURES	-	Table 3
CLEAN-UP MEASURES	-	Table 4

The course of action recommended in Tables 2, 3, 4 falls into four categories - one of a general nature and three that address specific areas of concern related to:

- Individual Safety and Health
- Equipment and Facilities, and
- Environmental Concerns

It is hoped that this first attempt to produce a comprehensive set of recommendations concerned specifically with the prevention of PCDF contamination resulting from fires of electrical equipment, will form a useful basis for the development of effective measures to deal with this serious problem.

1 INTRODUCTION

1.1 Background

Polychlorinated biphenyls (PCBs) are known to produce, under certain conditions, polychlorinated dibenzofurans (PCDFs) which are more harmful than PCBs.

It is estimated that approximately 15 million kg of PCBs are still in use throughout Canada, as an integral part of electrical equipment, mostly in transformers and capacitors.[1] The majority of this PCB-containing equipment is installed inside or adjacent to buildings.

It was found that fires involving PCB-containing electrical equipment create physio-chemical conditions that are conducive to the generation of PCDFs from PCBs, in significant quantities.[2,3]

A working group formed by the Interdepartmental Committee on Toxic Chemicals (ICTC), entrusted with the development of 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 the above guidelines was placed with 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 above-mentioned recommendation of the ICTC Working Group.

1.2 Objectives

The principal purpose of this study is to develop a set of recommendations for the prevention of PCDF contamination from fires involving electrical equipment.

More specifically, the recommendations are to relate to the conditions:

- before the fire
- during the fire, and
- after the fire.

The recommendations must be concerned with the aspects of:

- health and individual 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 of 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 due to their severe toxicological properties and their presence as contaminants in widely used industrial chemicals such as the chlorinated phenols (CPs) and in fly ash from municipal incinerators. In addition, they can be thermally and pyrolitically generated from CPs, polychlorinated biphenyls (PCBs) and chlorobenzenes (PCBZs).

In Canada, there are considerable quantities of PCBs and PCBZs that are still in service in electrical equipment (see Section 3) or in storage awaiting disposal. Other fluids that are being used as substitutes for PCBs in such equipment may also be contaminated with PCBs (and PCBZs).

Fires involving electrical equipment containing PCBs and PCBZs can lead to the formation of PCDFs. It is also possible that failures in this equipment (e.g. electrical arcing) may also produce PCDFs.

The recommendations presented as part of this report were developed so that the formation of PCDFs in electrical equipment can be limited and human exposure to these chemicals minimized in fire situations involving electrical equipment.

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. For this purpose a computer survey was performed using the Lockheed DIALOG™ data system. The literature was surveyed for the period from 1967 to 1983.

Those articles relevant to this project were collected and the information contained in them is discussed in the following sections. For more detailed discussions of PCDFs, their chemistry, biological/toxicological effects and their presence 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).
- National Research Council (NRC) of Canada (a document on PCDFs is to be published in early 1984).

2.2 PCDFs - Their 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 Table 1, there are 135 possible PCDF congeners ranging from mono- to octachloro. 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.[4,5] 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.[4]

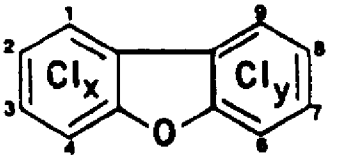
The PCDFs behave in the environment like most halogenated aromatic compounds; they are highly stable, tend to persist and bioaccumulate in fatty tissues. Although there have been few reports on their ecokinetic properties, it is generally assumed that movement of PCDFs in aquatic systems and in air would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

2.2.2 Biological/Toxicological Properties. 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 certain fractions of PCBs were far more toxic to chicks than others and that these fractions contained PCDFs.[6]

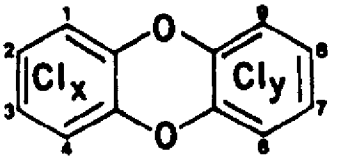
The toxicity of individual PCDF congeners is extremely dependent upon the position and degree of chlorination. It would appear that the tetra- and pentachlorodibenzofurans are the most toxic, in particular, the 2,3,7,8-tetra, 1,2,3,7,8-penta and 2,3,4,7,8-pentachlorodibenzofurans.[7] The oral LD_{50} for 2,3,7,8-TCDF in most animal species has been reported to be of the order of micrograms per kilogram.[8,9] Human exposure to only PCDFs has not occurred although related incidents have been reported.

In Japan, over 1,000 people consumed rice oil contaminated with PCBs.[10] 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

Polychlorinated dibenzofurans (PCDFs)



Polychlorinated dibenzo-p-dioxins (PCDDs):



Polychlorinated biphenyls (PCBs):

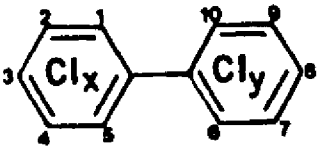


FIGURE 1 BASIC STRUCTURES

TABLE I NUMBER OF POSITIONAL PCDF ISOMERS

Chlorine Substitution	Number of Cl Atoms in Each Carbon Ring x	y	PCDFs Number of Isomers in Each Sub-Group	Total
Mono-	1	0	4	4
Di-	2	0	6	
	1	1	10	16
Tri-	3	0	4	
	2	1	24	28
Tetra-	4	0	1	
	3	1	16	
	2	2	21	38
Penta-	4	1	4	
	3	2	24	28
Hexa-	4	2	6	
	3	3	10	16
Hepta-	4	3	4	4
Octa-	4	4	1	1
				135

discussed in relation to malignant tumors among spraymen exposed to phenoxy acid herbicides in the 1950's and 1960's in Sweden.[11]

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

2.3 PCDFs - Thermal/Pyrolytic Generation

2.3.1 Background. It is well known that PCDFs are present as contaminants in chemicals such as CPs and phenoxy acid herbicides. Of major importance to this study is that PCDFs have also been detected as contaminants in PCBs and askarels and that they exist in new fluids. The total levels of PCDFs found in these unused products have been reported to range from 0.1 to 33 ppm.[12]

It has also been determined that the 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.[12] The levels of 2,3,7,8-TCDF in askarel filled transformers has also been found to be higher in those units that have been in service for long periods of time.[13]

It is therefore most likely that PCDFs already exist in the electrical equipment in service containing PCBs (and PCBZs). Under severe conditions, such as fires involving this equipment, much higher levels of PCDFs can be formed. Several incidents of this have occurred and have been well documented; these are discussed in Section 4 of the report. In addition, laboratory research has been carried out to further delineate the conditions under which PCDFs are formed thermally and pyrolytically from PCBs and PCBZs.

2.3.2 Pyrolysis of Chlorobenzenes. Transformer grade askarels, most widely used, may contain from 30 to 40 per cent (w/w) chlorobenzenes; the balance being 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.

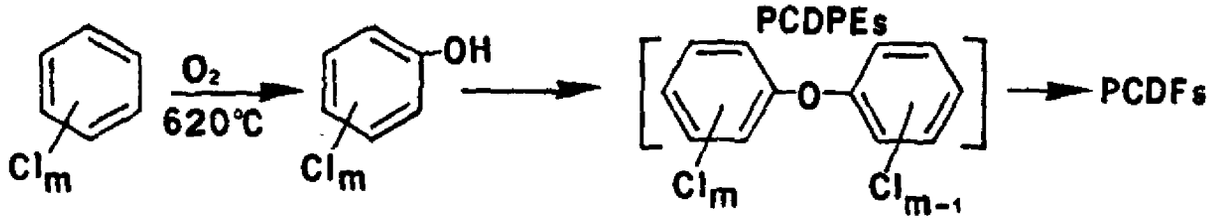
Studies involving the pyrolysis of PCBZs have shown that in the presence of oxygen, 'oxygen containing' aromatic compounds (e.g. PCDDs and PCDFs) are formed while in its absence (e.g. under nitrogen) oxygen free aromatic products are produced.[14,15]

Buser,[15] in 1979, 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 at 620°C in quartz ampoules with air present. The major components of the final mixture were chlorobenzenes, with decomposition of the lower chlorinated benzenes occurring to a greater extent than 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 (i.e. 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 is dependent on the PCBZ concentration. Buser also proposed that the CPs (present in all pyrolyzed samples) were intermediates in the formation of the PCDFs:



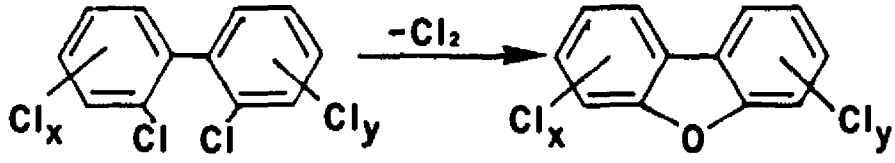
Reaction of the CPs with PCBZs could lead to chlorinated diphenylethers (PCDPEs) which upon pyrolysis are known to yield PCDFs.

2.3.3 Heating/Pyrolysis of PCBs. Investigations into the presence of PCDFs in PCBs lead to the now well-known fact that heating of PCBs at sufficiently high temperatures results in the formation of PCDFs. Buser and his co-workers[16] found increased levels of PCDFs (in the ppm range) in a commercial PCB mixture heated at 300°C for a week in the presence of air and in a PCB used in a heat exchange system.

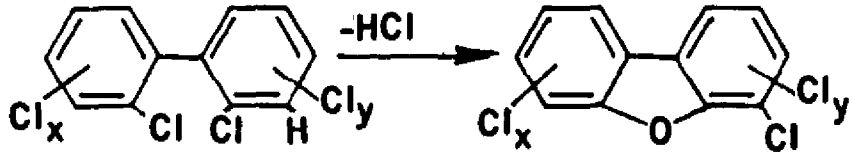
Several groups have since studied the pyrolytic/thermal formation of PCDFs from PCBs in the laboratory to determine the mechanisms involved, the additional reactants necessary and any 'catalysts' that may enhance the formation of these compounds. The results of these studies are discussed in the following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

2.3.3.1 **Mechanisms.** In 1979, Buser and Rappe[16] 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:

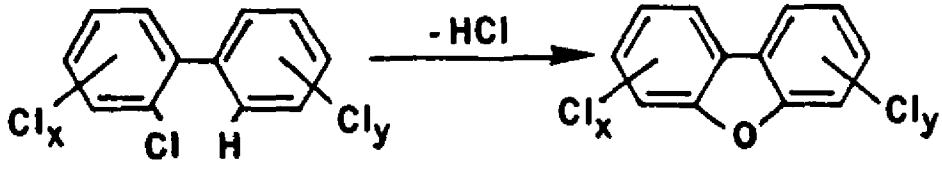
a) Loss of ortho-Cl_2



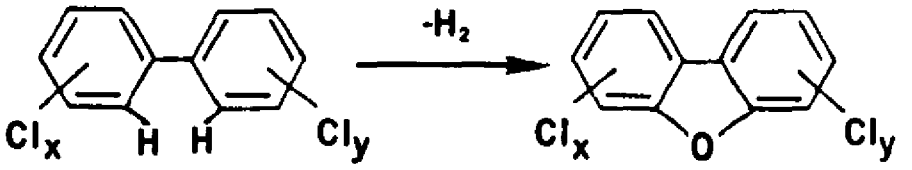
b) Loss of HCl with or without a 2-3 chlorine shift



c) Loss of ortho-HCl



d) Loss of ortho-H_2

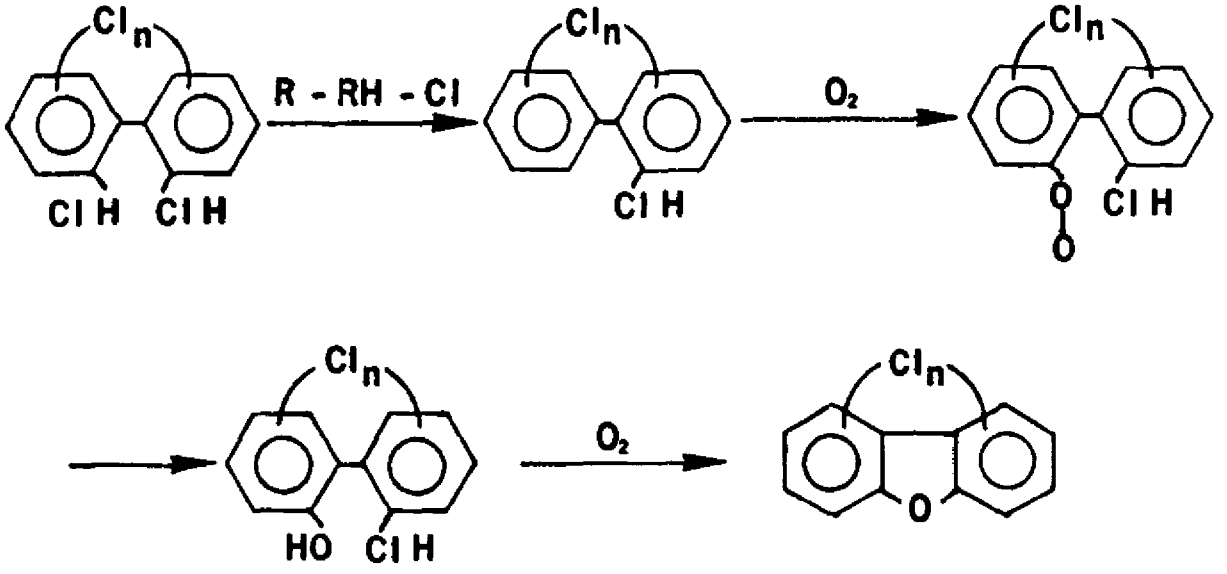


A further mechanism for the formation of PCDFs from pyrolysis of PCBs has been proposed as part of an investigation of trace organic compounds in fly ash from municipal and industrial incinerators. Choudhry and Hutzinger[17] have proposed that the reaction proceeds via the mechanism shown below, that is:

i) chlorinated diphenyl radicals are first formed from PCBs by either abstraction of ortho-hydrogen by free radical species (e.g. R*I, alkyl or aryl, Cl* orH*) or by scission of an ortho C-Cl bond,

ii) reaction of these diphenyl radicals with O_2 to form peroxide radicals which in turn form ortho-hydroxychlorinatedbiphenyls, and finally,

iii) cyclization of these chlorinated biphenyls to form PCDFs.



The intermediation of the biphenylols is supported by their detection in PCB pyrolysates.[19]

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

The minimum temperature reported for PCDF formation is 270°C by Morita and his co-workers.[21] In their article they suggested that the PCDF levels formed are governed by the transient equilibrium of thermal formation and decomposition.

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

2.3.3.3 Time. Only one study has been reported on the effect of time on the pyrolytic formation of PCDFs from PCBs.[21] In this the authors found that at 300°C the amounts of PCDFs formed increased to a maximum (7 days with O_2, 14 days with air) and then gradually decreased.

2.3.3.4 Atmosphere. It is obvious when one examines the structures of PCBs and PCDFs that a source of oxygen is needed for this conversion. This was confirmed in one report where PCBs were pyrolyzed under oxygen, air and nitrogen.[21]

PCDFs were formed in good yields when oxygen was used; lesser amounts were formed (ca. one tenth that of O_2) 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,[18] $FeCl_3$[20] or Cu-Fe powder[20] has been found to increase the amounts of PCDFs formed during the pyrolysis of PCBs. It is likely that the reactions involved are similar to Ullman type catalyzed reactions[17] 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.[13] In this 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) quantitated.

The askarels all yielded significant quantities of TCDFs (ca. 40 to 500 micrograms TCDF per gram of starting material) as did Aroclor 1254. Aroclor 1016, on the other hand, yielded much lower quantities of TCDFs. This is most likely due to the lower chlorine content of the PCBs in this mixture (i.e. very little penta- and hexachlorobiphenyls).

It is interesting to note that PCDDs were not detected. It is possible that they were formed but in such low quantities that they were not detected or were masked by the higher levels of PCDFs.

2.3.5 Pyrolysis of PCB Contaminated Mineral Oil. To date there have been no reports of experiments involving the heating or burning of PCB contaminated oils (of any type) and analysis of the products formed.

Mineral dielectric insulating oils (also called naphthenic or white oils) are mixtures of paraffinic (ca. 70%) and aromatic (ca. 30%) hydrocarbons.[22]

These oils are frequently contaminated with PCBs in concentrations that often exceed 50 ppm (see Section 3).

It is difficult to predict what quantities of PCDFs will be formed in fire situations involving such units. If a 1% PCB to PCDF conversion is assumed, a 1 000 L mineral oil filled transformer 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 involved in a mineral oil fire could be high enough so that all of the PCBs and PCDFs are destroyed. On the other hand, the mineral oil could act as a fuel continuing to burn over a longer period of time (unlike PCBs or askarels which would quench a fire) and potentially produce more PCDFs.

There is also the possibility that the mineral oil components could take part chemically in the conversion of PCBs to PCDFs as in the reaction mechanism proposed by Choudhry and Hutzinger[17] (see 2.3.3.1 above).

This is one area where much more research is required.

2.4 General Observations and Conclusions

From this laboratory research several conclusions can be made with respect to the thermal/pyrolytic generation of PCDFs:

- PCDFs are formed when PCBs and/or PCBZs are heated in the presence of oxygen at temperatures greater than ca. 250°C but less than ca. 700°C.
- The optimum temperature for the formation of PCDFs is ca. 500°C, however lower temperatures have been reported.
- Oxygen (pure O_2, air or possibly other oxygen containing compounds) is required. The yields of PCDFs are dependent on the amount of oxygen present.
- The formation of PCDFs is catalyzed by the presence of certain metals (e.g. iron or copper) or their salts.
- Percentage yields of PCDFs (i.e. 1% or greater) have been reported when PCBs, PCBZs and askarels have been pyrolyzed.
- In addition to PCDFs, PCDDs are also formed when PCBZs are pyrolyzed.

To accurately predict what will be formed in a fire situation involving electrical equipment is, however, complicated by the number of variables. This will become more evident when reading the "case histories" in Section 4 of this report.

In conclusion it must be assumed that PCDFs are formed in such situations.

3 ELECTRICAL EQUIPMENT

3.1 General

Fire resistant dielectric liquids, known under the generic name of askarels, have been used for electrical equipment in Canada since the early 1930's. Transformer askarels consist of polychlorinated biphenyls (PCBs) usually blended with chlorinated benzenes (PCBZs) in varying ratios.[23] Transformer askarels most widely used in Canada contain 60 or 70 per cent of PCBs and 40 or 30 per cent of PCBZs. Capacitor askarels (ASTM Types 2233A, B and D) contain no PCBZs only PCBs.[24] Askarel Type 2233C is a mixture of 75 per cent PCBs and 25 per cent trichlorobenzene. Most of the capacitors used in Canada contain no PCBZs.

The following electrical equipment containing askarels have been used for indoor applications:

- transformers
- capacitors
- electromagnets.

The main reason for using askarel immersed equipment indoors, in preference to oil immersed equipment, is the superior fire retardant property of askarel compared to mineral oil. The main reasons for using askarel immersed equipment indoors, in preference to dry type, air cooled equipment, are:

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

3.2 Transformers

The transformers which present a potential PCDF contamination hazard, fall into two categories:

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

Askarel transformers were designed as sealed tank type units complete with pressure relief vents. Relief vents are usually designed to operate at a tank pressure in

the range of 8 to 10 psi. The tanks could bulge when tank pressure exceeded 10 psi, and tank rupture could occur with pressures in excess of 25 psi.

The typical range of askarel immersed transformers is 300 kVA to 5 000 kVA, with an average transformer containing approximately 1 400 kg of PCBs.

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

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

- short circuit within the transformer, and
- escalating high impedance fault, accompanied by arcing.

In the first case, 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.

The second case is more serious. This type of arcing fault may cause the current to increase over an extended period of time, increase the askarel temperature, and increase the tank pressure to a dangerous level. This will result in the relief vent operating, causing askarel and gases to be expelled from the tank.

3.3 Capacitors

Capacitors containing askarel are used for the following applications:

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

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

All askarel capacitors are sealed in metal enclosures. It would be necessary for the enclosure to rupture to spill askarel.

Dielectric breakdown within a capacitor could cause hot spots within the capacitor, and 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, 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 the building as part of fluorescent or HID lighting systems. In case of a large building, the lighting system may include many thousands of PCB capacitors encased in the lamp ballast. 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 relatively small amount of PCBs.[25]

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 small compared to transformers and capacitors.

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

4 CASE HISTORIES

Case histories were collected through a combination of personal contact, telephone conversations, literature search and newspaper information services. They are given in detail in Appendix A.

All occurrences, actions, etc., are discussed with reference to the situation before the fire, what happened during the fire and how clean-up was achieved after the fire.

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 involved a transformer containing PCB.

There have been few documented incidents of PCB fires. Several hypotheses are advanced for this. The first and most common is that PCBs do not burn easily, therefore they do not become involved in fires: secondly awareness that PCBs and their combustion products act as extreme risks if involved in electrical fires did not exist until after the Binghamton, New York fire in 1981; a speculated third reason for minimal documented incidents in North America particularly, is that companies that have small fires involving PCBs do not report their involvement in order to avoid expensive clean-ups and intense public concern that coincides with PCB incidents.

PCB fires are a normal occurrence in the U.S. but all except Binghamton have been quite small with no in-depth study or analysis made into them. The majority of PCB fires go by without PCDFs being tested for, due to the lack of awareness of the hazards of PCDFs.[26]

All of the North American incidents documented involved fires in transformers due to electrical malfunction causing fire. In all of these cases the characteristics were very consistent. They involved very small amounts of flame giving off large amounts of heat and thick black smoke leaving residues of oily black soot.

All of the Scandinavian incidents documented involved capacitors containing PCB. All but one of these fires were caused by electrical malfunction in the capacitors. In all of these fires PCDFs and no PCDDs were found in the resulting soot. The lack of PCDD formation in the Scandinavian fires has been explained by the fact that chlorobenzenes were not used in the capacitors involved in these fires.

4.2 North American Fires

Case histories of three North American fires involving PCB-containing electrical equipment were reviewed. These are:

- Toronto Hydro Fire	9 December 1977
- Binghamton State Office Building Fire	5 February 1981
- University of 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:

- * Norrtalje, 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

All of these fires involved capacitors containing PCB only (no chlorobenzenes) and, with the exception of the Surahammar fire, were caused by electrical malfunction within a capacitor.

* Specific details are not shown.

4.4 Conclusions

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

In fires involving PCB equipment consistent observations can be reached. The fires are rarely, if ever, caused by the PCB itself. The PCB fluid normally acts as a bystander to a fire caused by an electrical malfunction or a mineral oil fire. Fire involving PCBs are smokey and yield large amounts of black oily soot. This soot is what is contaminated with PCBs, PCDFs and, if chlorobenzenes are present, PCDDs.

Testing has indicated that PCBs and PCDFs are non-volatile from soot. In all of 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. It was found that approximately one per cent of the PCBs are converted to PCDFs and 10 times more PCDFs than PCDDs are formed.

5 RECOMMENDATIONS

5.1 General

A review of current hazardous material regulations shows that the PCDF issue has not been specifically addressed in most cases. There is a considerable body of work on PCB fires, however, and it is this that forms most of the basis for the handling of specific aspects of PCDF incidents. The bulk of hazardous material legislation which is generally applicable to PCDFs must be applied to these materials with caution due to their extreme environmental and toxic threat.

The development of recommendations can best be pursued by subdividing the issue into 3 parts:

Preventive Measures (Table 2)

Procedures to reduce the probability of fire may eliminate the threat at the source. Planning for a fire, in terms of the measures to extinguish it and contain its products, can limit the PCDF threat to a tolerable level.

Firefighting Measures (Table 3)

Firefighting methods that result in quick control of the fire with the minimum damage to health, safety or the environment must be employed. Procedures should consider the clean-up requirements after the fire.

Clean-up Measures (Table 4)

Techniques for hazardous material spill clean-up have been well developed, and in many cases apply directly to PCB fires. Refinements to these techniques based on PCDF's special problems and the high level of cleaning necessary are, however, required.

These three phases of a PCDF contamination control program can each be addressed in terms of:

- general
- individual health and safety
- facilities and equipment
- environmental concerns

5.2 Discussion of Recommendations - Preventive Measures

GENERAL

1. Identify Equipment

Each piece of electrical equipment containing PCDF precursors should be identified, properly labelled, and its location recorded on a schematic lay-out 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 in order to, in the event of an emergency, enable them to use appropriate material and implement adequate countermeasures.

2. Inform Personnel

Personnel should be informed on the procedures to follow in case of fire.

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

3. Set Up Contingency Plan

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

This contingency plan should also be provided to and discussed with emergency response crews.

INDIVIDUAL HEALTH & SAFETY

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

1. **Ensure Training of Personnel**

This will prevent exposure to those taking uninformed actions in case of fire, and instill caution.

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

2. **Ensure Identification of Equipment**

3. **Ensure Availability of Adequate Personal Protective Material**

EQUIPMENT & FACILITIES

These measures are primarily aimed at protecting equipment and facilities; they will also protect people and lower the costs of repairs.

1. **Implement and Rigorously Follow a Preventive Maintenance and Inspection Program**

Repair of equipment before it becomes hazardous is particularly desirable in this case since the benefits of preventing fire incidents outweigh the costs.

Rebuilding of transformers is not recommended.

2. **Equipment Should Not Be Operated Above Design Ratings**

Undersized (overloaded) equipment is more prone to deterioration and failure, thereby increasing the risks for fire.

3. **Install Alarms and/or Shut-down Systems on Equipment**

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 resulting from it.

In addition, firefighting is always delayed pending equipment shut-off. During that delay, more damage to equipment can occur as well as more generation of smoke and fumes.

For transformers, a two-stage gas alarm relay installation should be considered; the first stage will trigger an alarm when the tank pressure reaches a certain level (e.g. 6 PSIG or ca 40 kPa) and the second-stage will de-energize the transformer (and possibly shut down Electrical Room ventilation, including dampers) when the tank pressure reaches a higher level (e.g. 8 PSIG or ca. 55 kPa).

4. **Install Automatic Fire Extinguishing Systems**

A properly designed fire extinguishing system can begin the fire control procedure even before emergency response crews are aware of the fire.

5. **Install an Auto-close Mechanism on Ventilation Systems**

The ventilation system is a major route of contamination. Smoke and fumes may be carried throughout an entire building by convective effect, resulting in massive widespread contamination from a relatively minor localized occurrence.

6. Do Not Mix PCB Equipment With Non-PCB Equipment
Isolate 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-filled transformer, the fire will not involve PCB equipment.

A fire starting in PCB equipment may not be self-sustaining when the power is off, whereas a fire in an oil-filled transformer will continue to burn. If PCBs are involved in a self-sustaining fire the difficulty of control of contaminant dispersion is compounded; not only must contaminants be contained, but the containment must take place during the control of another and seemingly more urgent emergency. In such a situation it is difficult both to assign environmental priorities and to carry out tasks effectively.

7. 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: the flammability with a retrofilled appliance is greater than with a PCB appliance; draining and retrofilling of equipment may not be practical; the replacement fluid may contain more than 50 ppm PCBs due to incomplete draining.

ENVIRONMENTAL CONCERNS

These measures are primarily aimed at minimizing dispersion into the environment.

1. **Ensure Containment of Fluid**

PCB equipment must be within a containment system capable of holding more than the equipment volume of fluids. Berms, dams, curbs or other barriers around the equipment should be capable of holding the equipment contents, plus any other fluid likely to be involved.

Drains in the floor must be outside the containment area.

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

2. **Ensure Containment of Contaminants**

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

TABLE 2 PREVENTIVE MEASURES

General	Individual Health and Safety	Equipment and Facilities	Environmental Concerns
1. Identify equipment	1. Ensure training of personnel	1. Implement and rigorously follow a preventive maintenance and inspection program	1. Ensure containment of fluid
2. Inform personnel	2. Ensure identification of equipment	2. Equipment should not be operated above rated capacities	2. Ensure containment of contaminants
3. Implement contingency plan	3. Ensure availability of personal protective material	3. Install alarms and/or shut-down systems on equipment	
		4. Install automatic fire extinguishing systems	
		5. Install an auto-close mechanism on ventilation systems	
		6. Do not mix PCB-containing equipment with non-PCB-containing equipment Isolate PCB-containing equipment	
		7. Replace PCBs/PCBZs with substitutes	

5.3 Discussion of Recommendations - Firefighting Measures

GENERAL

1. Inform Emergency Response Crews

Warn emergency response crews about the identity and location of equipment involved in the fire. This will enable the use of proper extinguishing techniques, including personal protective material and countermeasure precautions.

2. Consider Evacuation of Neighbouring Buildings

All ventilation openings (inlets and outlets) in the building should be closed automatically in case of a fire. Otherwise evacuation of adjacent buildings must be considered whenever there is any possibility that contamination could have reached other buildings. Considering the hazardous nature of PCDFs a conservative course must be followed in order to protect safety and health.

3. Access to Area Should be Restricted to Essential Personnel

INDIVIDUAL HEALTH & SAFETY

1. **Ensure That Emergency Response Crews Are Aware of the Identity and Location of Equipment**

2. **Protect Against All Anticipated Hazards**

Protection against PCDFs should be based on a limit of 1.5 ng/m^3 (24 hour average)[1]. This means use of full protective suit and self-contained breathing apparatus.

Note that other hazards are likely to be associated with an electrical fire as well - heat, asphyxiants and corrosive atmospheres. Protective clothing should guard against all of these.

For PCDFs, as for any unknown or highly toxic material, response personnel require:

- self-contained breathing apparatus
- fully enclosed chemical-resistant suit
- protective headgear, gloves, boots

Where personnel has been exposed to gases from a fire, decontamination of both protective material and skin is required.

Medical testing is also required.

3. **Arrange for Emergency Medical Aid**

Due to the extremely toxic effects involved, emergency medical aid should be on call.

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1 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 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 1 500 pg/m^3, i.e. 1.5 ng/m^3.

EQUIPMENT & FACILITIES

1. **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 fire control.

2. **Use Correct Firefighting Materials - DO NOT USE WATER**

Water provides a cooling effect in firefighting. It should never be used on an electrical fire. Firefighting with water has resulted in transformer explosions. Water is generally unsuitable for use with fires involving organic liquids as it causes them to spatter and to flow over a wider area without effectively cooling the fuel material.

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.

3. **Ensure That Air Inlets/Outlets Are Closed**

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 with much less damage.

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

ENVIRONMENTAL CONCERNS

1. **Ensure That Access to Building's Ventilation is 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.

TABLE 3 FIREFIGHTING MEASURES

DO NOT USE WATER			
General	Individual Health and Safety	Equipment and Facilities	Environmental Concerns
1. Inform emergency response crews	1. Ensure that emergency response crews are aware of the identity and location of equipment	1. Ensure that power is off	1. Ensure that access to building's ventilation is closed
2. Consider evacuation of neighbouring buildings	2. Protect against all anticipated hazards	2. Use correct firefighting materials DO NOT USE WATER	
3. Access to area should be restricted to essential personnel	3. Arrange for emergency medical aid	3. Ensure that air inlets/outlets are closed	

5.4 Discussion of Recommendations - Clean-up Measures

GENERAL

1. Restrict Area to Essential Personnel

2. Monitor Contamination of the Area

Determination of the extent of contamination will:

- indicate the degree of hazard, both personal and environmental
- provide boundaries for the clean-up and how much is needed
- make prompt treatment of affected personnel easier
- provide valuable information for the establishment of clean-up measures and for the need of protective equipment
- indicate when clean-up is satisfactory

3. Set up Decontamination Procedures

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.

INDIVIDUAL HEALTH & SAFETY

1. **Inform Personnel**

Personnel must be informed and trained in 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 equipment and health and safety facilities.

2. **Wear Proper Protective Material**

Although fire-related hazards are not present in the clean-up phase, protection against PCDFs must be maintained at a high level. Generally, protective equipment must feature provision for decontamination or discard as well because of the nature of clean-up work (active, hands-on scouring activities).

3. **If Clean-up is in an Enclosed Area, Set Up an Air Cleaning Vacuum System**

Reduction in air contamination will reduce the inhalation hazard and permit less stringent breathing apparatus requirements.

Skin contamination from airborne particulates and recontamination of cleaned surfaces will also be reduced.

4. **Ensure That Medical Back-up is Available**

Prompt medical attention is essential for any case of exposure to the substances produced in a fire involving electrical equipment.

Personnel feeling ill or who feel they have absorbed or contacted contaminant must see the physician immediately. Response crew members should undergo medical examination if there has been any possibility of exposure.

EQUIPMENT & FACILITIES

1. Use a Curtain Wall System to Segregate Cleaned Areas from Uncleaned Ones

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

2. Clean Up Soot Immediately

The PCDFs produced in a fire involving PCB-equipment is largely present in the carbonaceous residues. The vapour pressure of PCDF adsorbed on soot is very low so the handling and protection techniques suitable are those for fine particulate solids. PCDFs are quite strongly adsorbed, so that removing the soot will effect removal of much of the hazard.

The Site Should be Cleaned with a High Efficiency Vacuum Cleaner, Followed by a Wash with Organic Solvent and Detergent. Washing Should be Repeated Until the Surface Contamination is Reduced to 10 ng/m^2 PCDFs.

The major location of PCDF contamination is expected to be in soot deposited on surfaces. Removal of loose soot is best accomplished by vacuuming, 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. Although many solvents have sufficient solvent power, those with low vapour pressures, posing no flammability or health problems, are the best examples. Water and detergent systems, with mechanical scouring, may also be effective, particularly as a final cleaning step.

All cleaning materials and residues must be contained for treatment or disposal.

3. Inspect Ventilation Inlets of Contaminated Areas and Adjacent Buildings

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

1. **Maintain the Contaminated Area Under Negative Pressure**

Prevention of contamination spread is achievable by maintaining the contaminated area under reduced pressure. This technique is best used with high-efficiency filtration of exhausted air.

2. **Exhaust Air Through High Efficiency Filter**

To maximize the benefits of decontamination, containment must be during the clean-up phase. PCDF contamination is predominantly absorbed to carbon particles. This carbon must be removed from air before it is exhausted, to prevent spread of contamination. Contamination by PCDF vapour has not been detected so that particle removal is an effective way to reduce PCDF dispersion.

3. **Decontaminate Workers and Clean-up Equipment on Site**

This practice keeps contamination localized. In addition to decontaminating personnel, the decontamination material must be monitored and maintained contaminant-free.

4. **Store Contaminated Materials in Labelled, Numbered Containers**

Labelling containers is necessary for hazard identification. Numbering them reduces the possibility of loss and permits better control of wastes prior to storage or disposal.

All clean-up materials must be considered contaminated and must be stored until treated or disposed of. This requirement includes clothing and tools; once these are decontaminated, the wash liquids must be treated as contaminated and stored. It is advantageous to store material in numbered, identified containers, to enable quick recognition of any losses.

5. **Dispose of Contaminated Material in an Approved Hazardous Waste Disposal Facility**

Contaminated materials should be collected in labelled, numbered drums and moved to the hazardous waste facility.

TABLE 4 CLEAN-UP MEASURES

General	Individual Health and Safety	Equipment and Facilities	Environmental Concerns
1. Restrict area to essential personnel	1. Inform personnel	1. Use a curtain wall system to segregate cleaned areas from uncleaned ones	1. Maintain the contaminated area under negative pressure
2. Monitor contamination of the area	2. Wear proper protective material	2. Clean up soot immediately	2. Exhaust air through high efficiency filters
3. Set up decontamination procedures	3. If clean-up is in an enclosed area, set up an air cleaning vacuum system	3. Inspect ventilation inlets of contaminated areas and adjacent buildings	3. Decontaminate workers and material on site
	4. Ensure that medical back-up is available		4. Store contaminated material in labelled, numbered containers
			5. Dispose of contaminated material in an approved hazardous waste disposal facility

APPENDIX A
CASE HISTORIES

TORONTO HYDRO FIRE - 9 December 1977

An electrical fire in an askarel transformer located in an underground transformer vault under the sidewalk across from 60 Adelaide Street East, Toronto.

Before

A transformer vault designed for two oil insulated transformers.

In 1965 one of the oil insulated transformers had to be replaced with a 1 500 kVA askarel transformer containing 400 gallons (1 800 L) of askarel.

The askarel transformer was equipped with a 2 500 amp low voltage circuit breaker (called a network protector by Toronto Hydro).

On 9 December 1977 the transformer vault contained one oil insulated transformer and one askarel transformer.

At the start of the morning rush hour on Friday 9 December 1977 a fault (crack) developed in the network protector (circuit breaker). The crack was at a position on the protector that could not be cleared immediately by the protective relays.

During

Arcing took place across the crack starting a small electrical fire.

The crack spread to the porcelain bushing on the askarel transformer causing one hundred gallons of askarel to leak out onto the floor, some of the askarel vapourized across the electrical arc.

Protective relays in the substation opened the primary feeder.

Low voltage fuses blew disconnecting the askarel transformer from the oil transformer.

THE OIL INSULATED TRANSFORMER WAS NOT INVOLVED IN THE FIRE

22 firemen from four fire halls were at the scene.

THEY DID NOT AT ANY TIME ENTER THE VAULT.

Firemen filled the vault with CO_2 (standard practice) through the ventilation gratings and extinguished it.

Firefighters donned breathing apparatus (standard smoke breathing apparatus) because of volumes of black smoke coming from the vault.

THEY DID NOT KNOW AT THIS POINT THAT PCBs WERE INVOLVED.

The 100 gallons of askarel that spilled were contained in a pit around the transformer.

Some of the askarel that vapourized escaped through ventilation gratings in the sidewalk contaminating the front of an adjacent building and the surrounding area.

The buildings adjacent to the fire were not evacuated.

After

Primary feeder supplying the oil filled transformer was opened to completely de-energize the spot network.

Toronto Hydro personnel entered the vault and determined that askarel had spilled.

ONLY AFTER THE FIRE WAS IT KNOWN THAT PCBs WERE DEFINITELY INVOLVED.

Hydro personnel isolated the askarel unit so that power could be restored to an adjacent building.

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

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 about the face and hands.

The 22 firemen and 25 Hydro employees who went into the fire without proper protective equipment were tested for PCB levels one week after the fire occurred: no high PCB levels were found.

Firemen underwent close medical scrutiny for 6 months after the fire: men showed no ill effects.

Much controversy stemmed from the fact that firemen, Hydro employees and other personnel at the site were not told of the PCB danger until five days after the fire.

Clean-up

The area was enclosed by a sand berm and barricade.

The vault was decontaminated by spraying first with No. 2 Fuel Oil and then with detergent by an experienced contractor.

All contaminated clothing and equipment from the clean-up contractor, Toronto Hydro personnel and firemen who had been on-site, was collected.

Any fixtures in the vault that could not be decontaminated were removed for disposal.

A second contractor was hired to wash down the wall of an adjacent building that had been contaminated.

Cleaning agents and water used for cleaning were collected for disposal.

Contaminated water, clothing, equipment, fixtures etc. that could not be cleaned were disposed of at a PCB secure landfill in Niagara Falls, New York.

PCB in air levels were tested in the vault after initial clean-up and were found to be above MOE standards of 30 ug/m^3.

Vault was re-scrubbed and cleaning agents collected as in initial clean-up: it reduced PCB levels sufficiently.

Soot containing 10 000 ppm PCB covered a 700 ft^2 area adjacent to the fire site.

PCDFs were found in concentrations of 5 ppm in the soot.

Dioxin was detected in the test samples of air and soot taken at the site in late December 1977 but firefighters and Hydro personnel were not told until February 1978.

Cost

$100 000

Cost Includes:

- Decontamination of building; vault and surrounding area
- Disposal of contaminated material
- Value of transformer destroyed and labour for its replacement.

BINGHAMTON STATE OFFICE BUILDING FIRE - 5:30 a.m. Thursday, 5 February 1981

An extremely hot electrical fire in a switching mechanism. The heat caused bushings on an askarel transformer to crack and askarel to leak out. PCB contaminated soot was transported throughout the 18-storey building.

Before

Occurred at Binghamton State Office Building

Central tower within a governmental building complex
building completed Spring 1973 and rises 18 storeys (260') from street level with two subsurface levels
700 employees of 33 state agencies normally occupy building.

Building occupied by two people (a security guard and a stationary engineer) at the time of the fire.

During

An electrical failure in the building's main switching equipment within a basement mechanical room, possibly caused by a loose connection or a piece of dirt.

The electrical failure touched off an intensely hot fire.

The heat caused the porcelain bushings on a nearby transformer, containing 1 060 gallons of Pyranol (65% Aroclor 1254 and 35% chlorobenzenes), to crack and leak 180 gallons onto the floor.

The Pyranol vapourized due to the intense heat and contaminated soot and ash.

The fire burned for 45 minutes until the power was shut off; during the 45 minutes temperatures at the centre of the fire reached two thousand degrees F.

Firemen waited for power to be shut off before they tackled fire.

Fire took 35-40 minutes (total exposure time for firemen) to extinguish.

Contaminated soot was spread throughout all 18 storeys of the building.

The drastic temperature change from the warm basement to the roof (-6°F) propelled the soot into the fire stairwell and into an airshaft that ran through every floor.

State fire investigator determined that soot rose from the basement through a door that was left ajar to prevent pipe freezing and then distributed through the rest of the building with the aid of a steady stream of air that was escaping through two roof-top

escape hatches, above the fire stairs, that automatically opened when the fire alarm sounded.

Fire was quite small but very hot.

After the power was shut down and firemen were informed that they were dealing with Pyranol, the fire was extinguished by ventilating the area and dousing flames with water.

Donned Scott Airpaks* and standard full enclosure protective gear (poly/canvas jackets and pants, rubber boots and gauntlet gloves) did utmost to ensure that no skin was exposed.

The water used was not contained.

All equipment and clothing were disposed of afterwards.

All firemen took a shower immediately after fire (standard fire department procedure).

One fireman developed a recurrent rash on his face.

Two other developed "rashy burns" when the super hot fluid penetrated their gear.

After

Immediately after the fire it was known that 180 gal of PCB had spilled.

Wipe tests of the soot were immediately taken and tested for other chemicals.

A 24-hour security system was maintained to control access to the building.

A trailer that served as an entry/exit module was set up at the basement loading entrance.

The trailer contained entry facilities, locker, areas, showers, rest rooms and security offices.

All personnel entering the building were required to wear a full-face respirator and protective clothing that comprised socks, underwear, sneakers and rubber boots, coveralls, an outer "Tyvek" protective suit. and both cotton and rubber gloves.

Personnel were required to remove all protective equipment and shower on exiting the building through the module.

Respirators were cleaned and filters replaced.

The respirator weighed 4 lb and featured both activated carbon and high efficiency particulate filters.

Outer suits, gloves and respirator filters were disposed of after each use.

A week after the fire, test results indicated that the soot was also contaminated with PCDFs, PCDDs, biphenylenes and naphthalenes with concentrations as high as 2.9 ppm of 2,3,7,8-TCDD and 124 ppm of 2,3,7,8-TCDF contained in the soot found between the floors.

The horizontal surfaces of the building were covered with soot contaminated with 162 $\mu g/m^2$ PCB.

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 $\mu g/L$) to send to the city's sanitary sewage treatment plant.

An air pollution control filtration system was installed to filter the air in the building such that it was clean before discharge from the building.

The system created a negative pressure throughout the building to ensure that air flowed from outside, through the building and finally through the filters on the roof.

Preliminary cleaning has reduced the levels to 1 μg of removable PCB/m^2 on glass and painted surfaces.

Cleaning procedures were not successful decontaminating porous ceramic and vinyl floor surfaces, therefore they must 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 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 they were exposed during and after the fire.

Results of these tests were inconclusive and the tests are presently being redone.

Preliminary clean-up required 14 months for completion.

The criterion for completion of preliminary clean-up was to remove 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 drummed 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 brought) 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 this year to complete the final clean-up.

UNIVERSITY OF MANITOBA FIRE - 29 March 1982

Transformer fire in a transformer vault located in the basement of the electrical engineering laboratory of the University of Manitoba at Winnipeg.

Transformers were filled with mineral oil contaminated with 250 ppm PCB.

Before

A transformer vault contained six mineral oil transformers.

Transformers were used for both experimental and operational purposes.

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

During

An electrical failure occurred in one of the transformers causing arcing and a fire.

The mineral oil in the transformer caught fire and spread to some of the others (all six transformers were damaged by fire).

Firemen attempted to extinguish the fire with water.

Electricity must not have been shut off because the transformer exploded spraying oily soot all around the room.

Fire was extinguished with water which was not contained.

Firefighters wore standard firefighting equipment with no specialized chemical gear as the transformers were supposed to contain only mineral oil.

The entire laboratory was contaminated with PCB-containing soot.

After

The Manitoba Department of the Environment responded to the fire and tested the oil that was in the damaged transformers and sprayed on the walls to ensure that it was not contaminated with PCB.

Test results indicated that the soot that had sprayed on the walls was contaminated with 250 ppm PCBs.

They tested the soot for PCDFs but found no detectable levels.

Blood tests for PCB-exposed personnel were taken.

Precautions for PCB contamination were taken in clean-up.

Two clean-up contractors were hired to clean the laboratory, one cleaned up the high voltage equipment with Keysolve the rest of the lab was scrubbed down with Varsol.

A vacuum truck exhaust system was set up to remove Varsol fumes.

Clean-up crew were protected with air-line respirators (because of Varsol), rubber gloves and boots, and disposable chemical impervious suits.

NOTE: requirements for protective equipment would have been more stringent if PCDFs had been involved.

All solid and liquid contaminated material that could not be decontaminated was drummed in metal drums and sent to Kinetic Contaminants for storage.

DANVIKEN, SWEDEN - August 1981

A transformer station

18 PCB capacitors

During

Electrical malfunction caused a fire that burned 18 capacitors.

Firemen wore no special protective equipment against PCBs.

After

1 - 3 $\mu g/m^2$ PCDFs in soot

no PCDDs detected

chlorinated pyrenes formed

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

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

All contaminated wastes were drummed and stored, pending decision of the Swedish government on disposal.

SKOVDE, SWEDEN - March 1982

A Volvo metal treatment factory.

Fire broke out in a capacitor room containing mineral oil capacitors and 21 PCB capacitors.

During

An electrical malfunction in a mineral oil capacitor serving a high frequency oven in a casting line.

A very hot fire ensued and spread to the capacitors: 12 were broken open, 9 remained sealed.

The fire burned for two hours until it was completely extinguished.

Temperatures were high enough to melt a copper pipe (1 100°C).

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

Fire extinguishing method unknown.

After

up to 900 $\mu g/m^2$ PCDFs

no PCDDs detected

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

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

PCDF contamination levels were lowered to <10 $\mu g/m^2$ after the clean-up.

All contaminated wastes were drummed and stored, pending decision by the Swedish government on disposal.

SURAHAMMAR, SWEDEN - September 23, 1982

A steel mill

500 capacitors involved (300 mineral oil, 200 PCB)

During

An explosion in a steel kiln caused 10 tonnes of molten steel (1 500°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 PCB (ca. 2 000 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 HCℓ were given off by the burning PCB.

After

up to 4 $\mu g/m^2$ TCDF in soot (condenser room)

no PCDDs detected

Clean-up: high efficiency vacuuming followed by detergent washing. The vacuum-up soot was treated by carbon filtration and 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 and gloves. They wore air stream, helmets (air was filtered by glass fibre filter before breathing).

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

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

PCDF contamination levels were lowered to <10 $\mu g/m^2$ PCDFs after clean-up.

All contaminated wastes were drummed and stored, pending decision by the Swedish government on disposal.

APPENDIX B
REFERENCES

REFERENCES

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