THE NEED FOR CONTINUED USE OF POLYCHLORINATED BIPHENYLS AS ELECTRICAL INSULATING LIQUIDS

January 5, 1972

by

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U.S. Department of Commerce
Washington, D.C. 20230

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Introduction

In view of the questions which have been raised about the environmental impact of PCB's, it seems appropriate to examine the reasons why these materials are employed by the electrical industry, and the public benefits associated with such use.

What are Polychlorinated Biphenyls (PCB's)?

Polychlorinated biphenyls are derivatives of the hydrocarbon, biphenyl, which has the chemical formula $C_{12}H_{10}$ consisting of mixtures of variously chlorinated isomers as seen in Table 1. They are usually identified by the weight percent of chlorine in the total mixtures, e.g. Aroclor* 1254 contains 54% chlorine. Aroclors are characterized by stability - high flash points and even higher combustion temperatures essential to safe operation.

How are PCB's used by electrical industry?

The principle use of PCB fluid in the electrical industry is in transformers and capacitors (both large and small) as an insulator and coolant.

> Transformers are devices for converting electrical power from one voltage and current level to another, and the conducting parts of these devices must be separated from each other by a suitable insulating medium.
>
> Capacitors are devices for storing electrical energy through the physical separation of charged metal surfaces by an insulating medium.

* Monsanto Registered Trademark (Monsanto is the sole U.S. producer of PCB's.)

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Table 1

Composition of Different Liquid Chlorinated Biphenyls

Components - given as % -	Monsanto Aroclors							
	1221	1232	MCS 1043	1242	MCS 1015	1248	1254	1260
Chlorine	21	32	32	42	42	48	54	60
Biphenyl	14.8		.04	.02	.02			
Mono-chlorobiphenyl	56.5		22.2	.72	.93			
Di-chlorobiphenyl	26.9	~55	74.4	15.6	19.4			
Tri-chlorobiphenyl	1.42		3.3	54.5	64.5			
Tetra-chlorobiphenyl	.06			22.5	15.0	~55		
Penta-chlorobiphenyl				6.7*	.16*		60	
Hexa-chlorobiphenyl								70

*Includes higher than penta-chlorinated isomers.

Because of the nonflammability (Table 2) of Aroclors, their vapors, and their arc-formed gaseous products, transformers filled with PCB's are free of fire and explosion hazards and may be used in locations where failures of oil-insulated transformers would present a potential danger to life and property. In addition to improving the safety aspect of capacitors the use of Aroclors also gives them the advantages of reliability, long life, and small size.

Table 2

Underwriter Laboratory Flammability Rating

Fluid	Flammability Rating
Ether	100
Gasoline	90-100
Ethyl Alcohol	60-70
Kerosene (100° F.P.)	30-40
Mineral Oil	10-20
Aroclor 1242 and MCS 1016	2- 3

The need for PCB's in Transformers

PCB's are used in transformers wherever fire protection is particularly important -- for about 5% of all transformers.

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Most of these transformers are located inside public, commercial, or industrial buildings; on the roof tops of such buildings or in close proximity to such buildings, and require no special enclosures other than what are necessary to prevent accidental hazardous mechanical or electrical contact of persons with the equipment.

The amount of Aroclor used in various types of transformers ranges from 40 to 500 gals. (516 to 6,450 lbs.) with an average of about 235 gals. (3,032 lbs.). During 1968, the last complete "normal" year for the electrical industry, the total amount of PCB's used in transformers was approximately 1.3 million gallons (8.4 thousand tons).

The only present alternatives to Aroclor-insulated transformers are mineral oil-insulated transformers or dry-type transformers (either those open to the atmosphere or those that are gas-filled and sealed).

A. Mineral oil-insulated transformers

1. If one disregards safety considerations, there are no technical reasons why mineral oil-insulated transformers could not be directly substituted for PCB-insulated transformers. The size of the unit would be unchanged; the weight and cost would be less.
2. But one cannot disregard safety considerations, which are often embodied in legal codes.

Obviating the safety hazards involves serious economic and space constraints, that would occur either by

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the use of protective vaults, or use of insulated buses (with the transformer located outdoors). Either solution, if the space is available, could cost $5,000 — $50,000 per transformer.

B. Dry-type transformers

In most locations, dry-type transformers (either those open to the atmosphere or those that are gas-filled and sealed) could not be directly substituted for PCB-insulated transformers. There are several restrictions to such a direct substitution:

1. The reliability of dry-type transformers is less than that of comparably rated liquid-insulated transformers. An EEI survey of failures in network transformer banks showed a 7% per year failure rate for dry-type units compared to 0.2% for liquid-insulated units.
2. Furthermore, liquid-insulated transformers have a much greater overload capability. Many liquid-insulated units can sustain a 100% overload for 8 hours and a 200% overload for 2 hours. These transformers are able to maintain continuity of electrical service during periods of temporary malfunction of related equipment.
3. Some dry-type transformers are larger by 10 to 30% than comparably rated liquid-insulated units, and most are more expensive.

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4. Dry-type transformers are noisier by 5-10 dB than are liquid-insulated transformers.

5. Open dry-type transformers, which are cheaper than sealed dry-type transformers, cannot be used in certain corrosive or hazardous atmospheres, e.g. on furnaces or on electrostatic precipitators near hot stacks.

Clearly there is no substitute for PCB-filled transformers where fire protection is required.

The need for PCB's in capacitors

PCB's are used in more than 90% of the electric utility (large power) type and smaller industrial type capacitors made today. They are needed for safety, reliability and long life, and to achieve sizes compatible with equipment and installation requirements.

The principal types of PCB-impregnated capacitors and their applications are high voltage power capacitors used primarily for power factor correction in the distribution of electric power; low voltage power capacitors installed in industrial plants at the load (typically large motors); ballast capacitors to improve the efficiency of lighting systems; and small industrial capacitors for power factor improvement in such equipment as air conditioning units, pumps, fans, etc. Almost 80 million such capacitors are manufactured annually, most of them for first-time use.

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Capacitors used in lighting and air conditioning applications contain 0.005 to 0.09 gals. of PCB per unit. The largest power capacitors contain about 6.7 gals. of askarel. The most popular size contains about 3.1 gallons. The National Electrical Code requires that any installation of capacitors in which any single unit contains more than 3 gallons of combustible liquid shall be in a vault like that required for transformers. During 1968, the last complete "normal" year for the electrical industry, the total amount of PCB's used in capacitors was approximately 14.4 thousand tons.

Possible alternatives to PCB-impregnated capacitors are capacitors impregnated with mineral oil, or certain other liquids.

A. Mineral Oil

1. Size

The single most important property of a liquid to be used in a capacitor is its dielectric constant (the ratio of its ability to store electrostatic energy relative to air). The dielectric constant of the capacitor-grade PCB (Aroclor 1242) is 5.85 while that of mineral oil is 2.25. (See Table 3) Reverting to an oil-paper dielectric system would increase the average capacitor volume (size) by approximately 600%, the weight by 500%

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Table 3

Alternate Insulating Fluids

Some Significant Properties of Certain Candidate Insulating Fluids to Replace Aroclor 1242

Fluid	Dielectric Constant, ϵ'_r, at 25° C	Cleveland Open Cup Flammability Flash Point - °C - Fire Point		Density	Cost, ¢ lb
Aroclor 1242	5.85	194	333	1.38	18
Aroclor MCS 1016	5.85	191	319	1.36	18
Aroclor MCS 1043	5.7	160	244	1.23	18
Mineral Oil	2.25	145	150	.9	3

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and the cost by approximately 400%. At the present levels of demand for capacitor KVAR, there would be a shortage of electrical grade paper and a shortage of capacitor factory facilities further tending to increase the cost to the utility, and ultimately to the consumer.

2. Reliability and life

PCB's are thermally and oxidatively more stable than mineral oils, and discharges, which can occur in capacitors, are less likely to generate gases from askarels than from mineral oils. The chemical stability of PCB's in the presence of capacitor tissue and plastic films and the favorable stress distributions between solid and liquid have made it possible to design low-cost capacitors with a life expectancy of more than 10 years life in lighting applications and more than 20 years in electric utility applications. In each application the first-year failure rates are less than 0.2%. This level of life and reliability had not been achieved prior to the introduction of PCB's.

3. Safety

The relative non-flammability of PCB's significantly reduces the fire hazard that might otherwise accompany those failures that result in rupture of the case.

B. Other Liquids

1. Castor Oil. The dielectric constant of castor oil is 4.5 and this material is useful as an impregnant in D.C. energy storage capacitors. However, A.C. capacitors filled with this liquid have relatively short lives and are not very stable under A.C. discharges and in the presence of water derivable from the cellulosic paper.

2. Dibutyl sebacate. This ester is especially useful in high frequency parallel plate capacitors because of its low, flat loss characteristics over a broad frequency range. In this type of construction the liquid is the sole dielectric material. When used in conjunction with paper, this ester is also unstable.

3. Silicone Fluids. These materials have a dielectric constant of 2.7 and would generally be subject to the same disadvantages as mineral oil.

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In the interest of achieving a higher degree of environmental compatibility the capacitor industry has switched during 1971 from Aroclor 1242 to Aroclor MCS 1016, from which the higher-chlorinated persistent fractions have been substantially removed.

Environmental Protection

The advantages to the public in terms of safe, reliable, and efficient electrical equipment made possible by the use of PCB's have been documented. It is also clear that there are no present or prospective substitutes for these materials and the functions they perform are essential. Thus the continuing need for PCB's in closed electrical system applications is conclusive. The electrical industry well understands, however, that continued use of these materials requires unusual protective measures. These measures were the subject of recommendations made by a previous NIPCC Sub-Council report (The Use and Disposal of Electrical Insulating Liquids, June 1971) and are judged to be well on their way toward implementation: witness the introduction of the new capacitor dielectric, the provision of facilities for the incineration of liquid and solid wastes, and the instructions to operating personnel and users regarding the need for care in waste disposal, an activity now being further formalized and strengthened by ANSI's committee C107. The annual residual leakage to the environment from the continued use in transformers and capacitors has been estimated between one part in a thousand and one in ten thousand of the existing environmental PCB burden.

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