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Polychlorinated Biphenyls and the Environment

Interdepartmental Task Force on PCBs

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Abstracts

This report is the product of a six month review of the chemicals known as PCBs--polychlorinated biphenyls--by five Federal agencies, with participation by other agencies. The Interdepartmental Task Force on PCBs had as its goal the coordination of the scientific efforts of the Government aimed at understanding PCBs and the strengthening of the Government's ability to protect the public from actual or potential hazards associated with them. The task force made nine findings, conclusions, and recommendations, primarily pointing out that PCBs should be restricted to essential or nonreplaceable uses which would minimize the likelihood of human exposure or leakage to the environment. Supplementing the 20-page report are eight appendices detailing current knowledge about various aspects of PCBs, including their use and replaceability; occurrence, transfer, and cycling in the environment; occurrence and sources in food; and PCBs effects on man and animals.

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*Chlorine aromatic compounds,
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PREFACE

On September 1, 1971, representatives of several agencies of the Federal Government established an interdepartmental task force to coordinate the scientific efforts of the Government aimed at understanding the family of chemical compounds known as polychlorinated biphenyls (PCBs), and to strengthen the Government's ability to protect the public from actual or potential hazards from PCBs. On September 5 it was announced that the task force would "coordinate a government-wide investigation into PCB contamination of food and other products". On September 13 the task force, made up of qualified specialists from a range of disciplines, held the first of a series of meetings. Appropriate spokesmen on various problems associated with PCBs were assigned to prepare a series of background papers, drawing on the resources of their own and other agencies.

The task force included operating units of five Executive Branch departments: Department of Agriculture; Department of Commerce (Assistant Secretary for Science and Technology and National Oceanic and Atmospheric Administration); Environmental Protection Agency; Department of Health, Education, and Welfare (Food and Drug Administration and National Institute of Environmental Health Sciences of the National Institutes of Health); and Department of the Interior (Bureau of Sport Fisheries and Wildlife).

The report which follows represents the results of the task force's review and reflects the position of the operating agencies of the Federal Government which have major responsibilities concerning such chemicals as PCBs in food and in the environment. The task force had the advantage of some additional sources of information and review on PCBs. For example, during the course of the study, the National Institute of Environmental Health Sciences sponsored an international scientific meeting on PCBs on December 20-21, 1971, at the Quail Roost Conference Center, Rougemont, North Carolina. One hundred persons--from Government, universities, industry, and the press--attended. The proceedings of this conference soon will be published by the Institute. The task force also met from time to time with a group of scientific advisors from outside the Federal Government, which was already at work prior to September 1971 examining a number of hazardous trace substances, one of which was PCBs.

The individuals who served on the task force included: Dr. John E. Spaulding and Dr. Harry W. Hays (Department of Agriculture), Dr. Robert W. Cairns and Dr. William Aron (Department of Commerce), Dr. John Buckley (Environmental Protection Agency), Dr. Lawrence Fishbein, John R. Wessel, and Dr. Albert Kolbye (Department of Health, Education, and Welfare), Dr. Lucille Stickel (Department of the Interior), Dr. Edward J. Burger, Jr. (Office of Science and Technology), and Dr. Terry Davies (Council on Environmental Quality). Many others participated in some of the meetings and lent assistance in a variety of ways including authorship of background papers published as appendices in this report. The task force is grateful for this assistance.

The task force will continue to assess new information that comes to its attention.

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FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Polychlorinated biphenyls (PCBs) have been used in the United States and elsewhere over the past 40 years, for many industrial and consumer applications. During the past three years evidence has accumulated to indicate that PCBs are widely dispersed throughout the environment and that they can have adverse ecological and toxicological effects.

The principal uses for PCB fluids are in the electrical industry. PCBs have superior cooling, insulating, and dielectric properties and hence are widely used in various electrical devices. Transformers and capacitors filled with PCBs can be used in inside locations where failures of oil-insulated equipment would present a potential danger to life and property. Because PCBs are relatively nonflammable, apparatus containing them is essentially free from the fire and explosion hazards associated with oil-insulated and oil-cooled electric devices. Stability at high temperatures is another major factor in the attractiveness of these compounds. The principal advantage of PCBs over substitutes is the relative freedom from flammability in some applications that previously had been plagued by serious fires. PCBs also give electrical equipment the critical advantages of reliability, long life, and compactness. PCB impregnated capacitors, for example, are markedly more reliable and long-lived, and 1/6 the size, 1/5 the weight, and 1/4 the cost of comparable oil impregnated capacitors. Small capacitors with PCBs have a use-life expectancy of 10 to 15 years, and large capacitors 20 to 25 years. PCBs in transformers are replaced only every 25 to 30 years.

PCBs have been discovered to have a widespread distribution in the environment, and some environmental occurrences have been associated with adverse effects on certain forms of animal life. Beginning in 1971, the Monsanto Company, the sole U. S. producer, has reported taking voluntary actions to reduce the volume of PCB production and to limit its distribution to industries concerned with the manufacture of electrical apparatus. Similar restrictions have been put into effect by statute in Sweden and voluntarily in Great Britain.

A large use of PCBs had been in carbonless duplicating paper. This use has been discontinued. The Food and Drug Administration and the food industry have increased their surveillance to assure that PCBs are not used in food, plants, products, or packaging.

The task force has reviewed all of the available scientific information on various aspects of the PCB problem. It has found much data that it regards as inadequate and many questions that remain unanswered. But on the basis of available information, the task force concurs on the following findings, conclusions, and recommendations:

1. PCBs should be restricted to essential or non-replaceable uses which involve minimal direct human exposure since they can have adverse effects on human health. There currently are no toxicological or ecological data available to indicate that the levels of PCBs currently known to be in the environment constitute a threat to human health, but additional experiments are underway to evaluate the impact of low level, long-term exposure to PCBs.

2. PCBs have been used so widely over such a long period that they are ubiquitous. Even a total cessation of manufacturing and use of PCBs would not result in the rapid disappearance of the material, and ultimate disappearance from the environment will take many years. The elimination of non-essential uses and prohibition of discharges from essential uses will result in gradual elimination from the environment.

3. PCBs were first identified as potential food contaminants in 1966. Three principal sources or routes of contamination of food have been identified. General environmental contamination has resulted in PCB residues in some fresh water fish. Prohibition of PCB discharges into water will result in the reduction of such residues. Another route occurs from the presence in food packaging materials of PCB residues, some of which migrate into packaged food. The FDA has proposed regulations for food packaging materials and foods to deal with this problem. The third route involves accidental contamination of food from leakage or spillage of PCBs into feed or directly into food. The dietary intake of PCBs is of low order and does not present an imminent health hazard. To date, all of the high levels of PCBs encountered in human or animal foods have been associated with accidents, for which Government agencies have exercised necessary regulation and control to minimize the distribution of contaminated foods.

4. The sole domestic producer of PCBs, Government agencies, and key user industries are taking appropriate steps to cut off further introduction of PCBs into the food supply and to reduce the current levels of PCBs as food and environmental contaminants. The Food and Drug Administration (FDA) has acted, under the authority of the Food, Drug, and Cosmetic Act, to preclude the accidental PCB contamination of food. It has also proposed a prohibition on the use in food packaging materials of pulp from reclaimed and salvaged fibers that contain poisonous or deleterious substances that may migrate into the food if the contamination by such substances is deliberate or avoidable. It has proposed temporary tolerances for unavoidable PCB residues in food packaging materials and in certain foods. The Department of Agriculture has acted under the Wholesome Poultry Act and other statutes to prevent accidentally contaminated foods from reaching the market.

The major gap in the regulatory system to deal with PCBs is the absence of any broad Federal authority to restrict use or distribution of the chemical, to control imports, and to collect certain types of information. The task force believes that such authority is needed. This authority would be provided by the Toxic Substances Control Act proposed by the Administration and now pending before Congress.

5. Housekeeping is particularly important in the manufacture, use, and disposal of PCBs. Under a program of limitation on the sale of PCBs, the electrical industry will continue to be the principal user of PCBs; it, as well as industries now holding inventories of PCBs, have a special responsibility for monitoring and controlling their wastes. In this connection, the Environmental Protection Agency will restrict industrial liquid discharges of PCBs from PCB users. To keep levels in fish as low as possible, and in any case below FDA's interim action level of 5 parts per million, concentrations in rivers or lakes from all sources should not exceed 0.01 parts per billion.

6. The use of PCBs should not be banned entirely. Their continued use for transformers and capacitors in the near future is considered necessary because of the significantly increased risk of fire and explosion and the disruption of electrical service which would result from a ban on PCB use. Also, continued use of PCBs in transformers and capacitors presents a minimal risk of environmental contamination. The Monsanto Company, the sole domestic producer, has reported voluntarily eliminating its distribution of PCBs to all except manufacturers of electrical transformers and capacitors.

Pending passage of the Toxic Substances Control Act, the Federal Government does not have the legal authority to impose restrictions corresponding to the actions reported by Monsanto. Although some Federal enforcement authority is available, the Federal Government does not have the authority to control PCBs at their source.

7. Most capacitors presumably have been disposed of in landfills. PCB containing material buried in soil is not expected to migrate but should remain in place. In the past, many fluids containing PCBs have been disposed of in sewers. More appropriate means of disposal such as high-temperature (at least 970°C) incineration must be used instead.

8. PCBs are manufactured in countries other than the United States. Importation of PCBs as a chemical or as a component in products remains legally possible because the Toxic Substances Control Act has not yet become law. Electrical products imported from abroad may contain PCBs. The task force looks to international agreements to bring about some multi-national understanding on the sale and use of PCBs globally. Importation of PCBs for uses other than those singled out in the present pattern of voluntary limitations should be avoided by users.

As an additional measure, the United States has asked the Organization for Economic Cooperation and Development (OECD) through its Environment Committee to make a special review of member states' national policies concerning PCBs and also to identify products moving in international trade which contain PCBs. OECD, whose membership includes all major Western industrialized states plus Japan and Australia, has been giving priority attention to the problem of PCBs over the past year.

9. More scientific information about PCBs is needed, and several Government agencies are seeking it through research. The task force recognizes that the scientific basis of much of our knowledge must be

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strengthened through research. The total exposure of a human being to a given substance from all sources--air, water, and food--must be considered, and interactions of PCBs and other substances within and outside the body must be evaluated. Similar consideration must be given to the other body organisms.

Current scientific knowledge gained from laboratory animal experiments is often inadequate to allow reliable interpretation of the data in terms of possible effects on man. The scientific basis for interpreting such tests must be improved.

The situation regarding PCBs is not significantly different from the problem of other toxic susbstances which cause concern when they come into contact with man, his food, and his environment. Continuing vigilance on the part of Government agencies, industry, universities, and many other agencies both within and outside the Government will be necessary to achieve an effective system for assessing and controlling the hazards of toxic substances, including PCBs.

The task force, by reviewing research needs and the present Federal research effort, has helped to insure that these efforts of the agencies are well planned and coordinated. Certain Government laboratories as well as a number of non-Government scientists recently have embarked on additional research on PCBs, and the results will be communicated to the scientific public completely and promptly through normal channels such as meetings and journals.

APPENDIX B

Use and Replaceability of PCBs

I. DIELECTRIC FLUIDS

Dielectric (electrically insulating) liquids are important to the electrical industry for filling agents or impregnants in transformers, capacitors, and other devices. Besides their electrical functions, the liquids may also be used for cooling and arc quenching functions. Detailed discussions of dielectric fluid applications are available (1-4).

A. CAPACITORS

Generally, industrially important capacitors use liquid impregnated cellulose paper as a dielectric. The required properties of the liquid are:

1. Non-flammability (important for preventing fires, particularly in indoor use).
2. Dielectric constant matching that of paper. A good match reduces electric field inhomogeneities, increases dielectric strength and lifetime, and allows decrease in capacitor size.
3. Low dissipation factor (reduces energy loss and destructive heating in a capacitor).
4. High dielectric strength (prevents breakdown and allows decrease in capacitor size).
5. High chemical stability (increases capacitor lifetime and stabilizes its performance).
6. Low vapor pressure (increases physical stability).
7. Inert decomposition products in an electric arc (prevents explosion or corrosion following breakdown).
8. Low toxicity of the material and its decomposition products.
9. Low cost.

1. Advantages and Disadvantages of PCB in Capacitors

The PCB capacitor liquids, commonly called askarels, are mixtures of chlorinated biphenyls and chlorinated benzenes. Several standard mixtures are specified by ASTM (5). The askarel capacitor liquids and their decomposition products are non-flammable. Thus their use in capacitors greatly reduces fire and explosion hazards. This characteristic permits economies where safety codes require fireproof enclosures for capacitors containing flammable liquids.

The dielectric constant of the askarels is high compared to other common dielectric liquids. Doubling the dielectric constant of the dielectric allows a reduction by half in the area of the capacitor electrodes, and a significant saving in the cost of construction and installation. The dielectric constant of askarels closely matches that of the capacitor paper.

The askarels are adequate with regard to dissipation factor and dielectric strength and have good chemical stability and low vapor pressure. The breakdown products, in particular HCl, have the advantage of being non-flammable, but are highly corrosive. This dictates the use of special corrosion resistant materials inside the capacitors.

The major disadvantage of the askarels is their suspected toxicity. In ordinary capacitor usage the askarels are used in closed systems to prevent contamination from moisture. This practice also prevents the askarels from reaching the environment. However, when electrical failure occurs, sealed capacitors can leak and are ordinarily discarded.

2. Replaceability of PCB in Capacitors

Capacitors can be made dry or with gas dielectrics. Dry capacitors have inferior electrical strength to liquid-filled capacitors and, for comparable performance, must be made larger.

The major disadvantage of alternative capacitor liquids is their flammability. When comparing flash point data, as in Table 1, askarel flash points comparable to those of other capacitor liquids are sometimes listed. ASTM states that these are not true flash points but are pseudo-flash points which differ noticeably from the flash obtained on combustible materials, and such a flash point is not indicative of a fire hazard (5). The requirement of non-flammability for most capacitor uses is critical, and capacitors with flammable liquids are forbidden in many cases by the National Electrical Code (6). In other cases replacement of askarel capacitors with flammable capacitors requires use of fireproof installations (6).

The fluorocarbons are one group of non-flammable liquids which are used for some dielectric applications (1). The ones listed in Table 2 have low dielectric constants and could not directly replace askarels without increasing capacitor size. The fluorocarbons have low toxicity but the decomposition products may be toxic (1). They are generally more volatile than askarels and are considerably more expensive. The fluorocarbons are a possible replacement for PCB liquids for capacitor use, but no fluorocarbon liquid is known to be available and acceptable for this purpose.

Besides the problem of flammability, possible PCB replacement liquids generally lack either a sufficiently high dielectric constant to keep capacitor size down or a sufficiently high dielectric strength. For example (see Table 1) the silicones have the disadvantage of a low dielectric constant whereas the organic esters often have poor dielectric strength. Some silicones deteriorate rapidly under electric arcing (7).

The acceptance of a PCB substitute is a complex process involving not only users but also various regulatory groups. In most of the electrical industry, regulation is non-governmental, and the primary regulatory influence comes from Underwriters Laboratories, who test products and decide on their suitability (8). In addition, control over electrical materials is exercized through companies which insure against fire, utilities which supply electrical power, and building codes.

3. Extent of Capacitor Use

Almost all industrial capacitors contain PCBs. In 1968 95 percent of the U. S. production of capacitor liquids (2.46 million gallons) were PCBs (9). Two important types of capacitors are phase correction capacitors on power lines and ballast capacitors for fluorescent lighting. Non-ballast industrial capacitors produced in 1967 had a value of $112 million (10), and fluorescent lamp ballast capacitors produced that year numbered 21.7 million units with a value of $15.5 million (10). In 1970 there were 50.9 million ballast units produced with a value of $163 million (11). These ballast units are in extensive use inside buildings where non-flammability is important.

Phase correction capacitors are necessary on power circuits to correct for the inductive loading of much electrical power equipment. The amount of phase correction capacitance is ordinarily specified in kilovolt amperes of reactive current or kvars. Most power capacitors are rated at from 1/2 to 25 kvars so that the number of capacitors is very roughly the kvar value divided by 10 (12). As examples of the extent of power capacitor use, TVA has 2-1/4 million kvars (13), and a power company serving suburban New Jersey has 3.6 million kvars on their power lines with 1/2 million kvars on order (14). The value of these capacitors is roughly $5 per kvar (14). More than 20 million kvars of power capacitors were produced in 1970 (16).

The procurement lag for these capacitors is 1-1/2 to 3 years, and estimates for redesigning new systems range from 3 to 10 years, according to power company representatives to ASTM Committee D-27 (14,15). Extensive re-designing is anticipated if distribution capacitors were required to use presently available non-PCB liquids. Askarel capacitors have been developed to the point that failures are considered negligible (13, 15).

Several private sources reported extensive efforts to find replacements for PCB capacitor fluids, but none reported having a good substitute.

B. TRANSFORMERS

Most power transformers contain a liquid to electrically insulate and remove heat from the core and windings. The properties required of these liquids are:

1. Non-flammability (required for indoor use and desirable in remote location use).
2. High dielectric strength (prevents breakdown and allows transformer size reduction).
3. Low viscosity (promotes convective heat transfer).
4. High chemical stability (allows higher temperature operation and reduces degradation of the transformer).

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5. Compatibility with other materials
6. Inert decomposition products (reduces fire danger and damage to other materials following breakdown).
7. Low toxicity of the liquid and its decomposition products.
8. Low cost.

1. Advantages and Disadvantages of PCB in Transformers

The PCB transformer liquids, commonly called askarels, are mixtures of chlorinated biphenyls and chlorinated benzenes. Several standard mixtures for transformers (differing from the capacitor askarels) are specified by ASTM (17). These liquids are used to overcome the fire and explosion hazards present with transformer oils. For most power transformer applications where occasional explosions and fires do not endanger life and property, mineral oils are still preferred. However, for distribution transformers which are located near congested areas and in buildings, askarel and dry-type transformers are required by electrical codes (6). Other advantages of the askarels include: 1. their superior chemical stability, which eliminates the sludge formation common in mineral oils, 2. a high dielectric strength, which reduces electrical failures, and 3. suitable viscosity.

The disadvantage of the transformer askarels include: 1. a poorer resistance to impulse voltages and production of highly corrosive HCl during arcing, 2. a tendency to damage common insulating solids inside the transformer, 3. probable toxicity, and 4. higher cost (about $1.80 per gallon compared to $.25 per gallon for mineral oil (15, 18).

2. Replaceability of PCB in Transformers

Askarel transformers cost about 1.3 times as much as oil transformers, and dry types cost about 1.5 times as much as oil transformers. Thus most users prefer to use the oil type where possible. This preference for oil transformers accounts for the fact that 96 percent of transformer liquids in use in 1968 were mineral oil (9). However, fire underwriters will not accept the use of oils, silicones, and other flammable liquids for indoor transformers. Dry-type transformers can be used indoors, but are generally larger in size, require more copper and iron, and are somewhat more expensive, as shown above. Dry-type transformers could possibly replace askarel transformers in many cases.

No currently available liquid which will replace askarels in existing transformers is known. Possibly, non-flammable fluorocarbons could be developed as a suitable fluid, similar in important properties to the askarels. Fluorocarbons are currently in use as convective and evaporative dielectric coolants. One main disadvantage of the fluorocarbons is their high volatility and high cost (about 40 times the cost of oil and 6 times the cost of askarels (18)).

3. Extent of Transformer Use

In 1967, 1.7 million liquid-immersed distribution transformers of 500 kva and smaller, valued at $350 million, were produced (10). These include askarel-filled transformers placed under streets to serve 1 - 4 city buildings. These transformers can fail and cause fire damage if filled with a flammable liquid. An annual report on such failures is compiled by the Edison Electric Institute (19).

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APPENDIX C

The Need For Continued Use of PCBs As Electrical Insulating Liquids

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APPENDIX C

The Need For Continued Use of PCBs As Electrical Insulating Liquids

I. HOW ARE PCBs USED BY THE ELECTRICAL INDUSTRY? (1)

The principal 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.

Because of the nonflammability (Table 1) of Aroclors (the trade name of Monsanto), their vapors, and their arc-formed gaseous products, transformers filled with PCBs are relatively 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, Aroclors also have the advantages of reliability, long life, and small size.

Table 1

Underwriters' Laboratories Flammability Ratings

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

II. THE NEED FOR PCBs IN TRANSFORMERS

PCBs are used in transformers wherever fire protection is particularly important -- for about 5 percent of all transformers.

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 necessary to prevent accidental hazardous mechanical or electrical contact of persons with the equipment. See Table 2 for some liquid chlorinated biphenyls.

TABLE 2

Composition of Different Liquid Chlorinated Biphenyls

Components - given as % -	Monsanto Aroclors 1221	1232	MCS 1043	1242	MCS 1016	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.

PLEASE READ S.I.B. FOR EXPLANATION OF THIS TABLE.

The amount of Aroclor used in various types of transformers ranges from 40 to 500 gallons (516 to 6,450 lbs.) with an average of about 235 gallons (3,032 lbs.). During 1968, the last complete "normal" year for the electrical industry, the total amount of PCBs 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 the use of protective vaults, or use of insulated buses (with the transformer located outdoors). Either solution, if 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 Edison Electric Institute survey of failures in network transformer banks showed a 7 percent per year failure rate for dry-type units compared to 0.2 percent for liquid-insulated units.

2. Furthermore, liquid-insulated transformers have a much greater overload capability. Many liquid-insulated units can sustain a 100 percent overload for 8 hours and a 200 percent 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 percent than comparably rated liquid-insulated units, and most are expensive.

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.

III. THE NEED FOR PCBs IN CAPACITORS

PCBs are used in more than 90 percent 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.

Capacitors used in lighting and air conditioning applications contain 0.005 to 0.09 gallons of PCB per unit. The largest power capacitors contain about 6.7 gallons 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 PCBs 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 volumn(size) by approximately 600 percent the weight by 500 percent, and the cost by approximately 400 percent. 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

PCBs 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 PCBs 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 percent. This level of life and reliability had not been achieved prior to the introduction of PCBs.

Table 3

Alternate Insulating Fluids

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

Fluid	Dielectric Constant, e'r, at 25° C	Cleveland Open Cup Flammability Flash Point -°C	Cleveland Open Cup Flammability Fire Point -°C	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	1.28	18 *
Mineral Oil	2.25	145	150	.9	3

* INCORRECT — NO WAY WE CAN SELL MCS #s at those prices.

3. Safety

The relative non-flammability of PCBs 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.

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

IV. ENVIRONMENTAL PROTECTION

The advantages to the public in terms of safe, reliable, and efficient electrical equipment made possible by the use of PCBs have been documented in the body of, and especially Appendix B to, this report. It is also clear that there are no present or prospective substitutes for these materials, and that the functions they perform are essential. Thus the continuing need for PCBs 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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1. The above paper was prepared by the Electric and Nuclear Sub-Council, National Industrial Pollution Control Council: Chairman, D. C. Burnham, Westinghouse Electric Corporation; Vice Chairman, Fred J. Borch, Chairman and Chief Executive Officer, General Electric Company; Members: A. P. Fontaine, President and Chairman, The Bendix Corporation; Raymond H. Giesecke,