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POLYCHLORINATED BIPHENYLS
AND THEIR USE IN CAPACITORS

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POLYCHLORINATED BIPHENYLS AND THEIR USE IN CAPACITORS

1. INTRODUCTION

This paper presents an overview of considerations involved in the use of polychlorinated biphenyls (PCBs) in the electrical industry, with particular reference to their employment in capacitors. Recently, issues have been raised with regard to public health and environmental impact. These issues are addressed, and the response of the industry to this challenge is reviewed, with the aim of providing perspective for the consideration of appropriate control measures.

A capacitor is a device that stores electrical energy. It consists of two conductive surfaces or electrodes separated by an insulating medium such as air, paper, plastic film, or oil. When a voltage is applied across the electrodes, electrostatic energy is stored in the insulating medium. The circuits in which capacitors are connected may be configured to bring about regularized storage and release of energy in ways calculated to control or modify the performance of the circuits and improve the operation of associated electrical equipment, including power transmission and distribution systems.

In typical industrial capacitors the electrode material is aluminum foil and the insulating medium (dielectric) is paper tissue and/or plastic film, impregnated with a liquid dielectric. For the past four decades, the liquid impregnant of choice has been--and continues to be--polychlorinated biphenyls.

GENP 005287

2. ADVANTAGES OF USING PCBs IN CAPACITORS

The Family of PCBs--Structure and Useful Properties

The PCBs are a class of aromatic, chemically inert, chlorinated hydrocarbons. The forms suitable for impregnating electrical equipment are mobile oily liquids, but the term also embraces some sticky or solid resins with a relatively high degree of chlorination. They are non-oxidizing, permanently thermoplastic, of low volatility and non-corrosive to metals. They are not hydrolyzed by water, alkalies or acids. They will not support combustion when heated alone. Their excellent electrical properties, fire resistance and inertness have made them useful in many applications (1) (2).

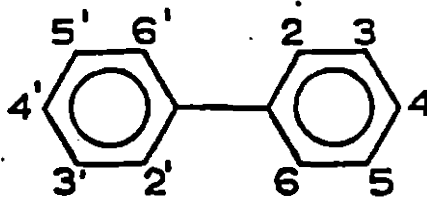
PCBs are manufactured by the chlorination of biphenyl with anhydrous chlorine using iron filings or ferric chloride as a catalyst (1). The degree of chlorination varied from 21% to 68% chlorine by weight in products manufactured in the U. S. prior to 1970.

Polychlorinated biphenyls are derivatives of the hydrocarbon, biphenyl, which has the chemical formula $C_{12}H_{10}$. From one to ten of the hydrogen atoms in a molecule of biphenyl can be replaced by chlorine atoms, and the chemical identity of the resulting compound depends both on the number of chlorine atoms that have been introduced (identifying the "homolog") and on the specific sites in the molecular structure at which the substitution has occurred (identifying the "isomer").

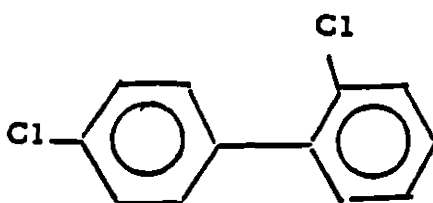
The base structure of biphenyl, showing a numbering system commonly used for positions of substitution, is the following:

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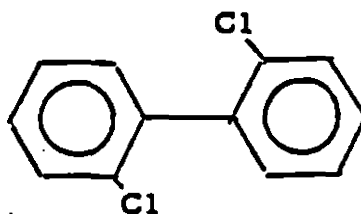
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Thus, the 2,4' isomer of the dichlor homolog may be diagrammed as:



and the 2,2' isomer of the dichlor homolog thus:



The following is the composition of the commercial grade of PCB (Aroclor 1016) used in the U.S. capacitor industry, with the principal isomers identified. (See also Appendix 2 for composition of other grades.)

<u>Homolog</u>	<u>Number of Chlorine Atoms Substituted For Hydrogen Atoms</u>	<u>Typical Composition, % (3)</u>	<u>Principal Isomers</u>
Biphenyl	0	Less than 0.1	
Monochlorobiphenyl	1	1	
Dichlorobiphenyl	2	20	2, 4'; 2, 2'
Trichlorobiphenyl	3	57	2, 2', 5'; 2, 2', 2, 2', 3'; 3, 2', 3, 2', 3'; 2, 3',
Tetrachlorobiphenyl	4	21	2, 2', 3', 5' 3, 2', 3', 6' 2, 5, 5', 4'
Pentachlorobiphenyl	5	1	
Hexachlorobiphenyl	6	Less than 0.1	
Heptachlorobiphenyl	7	None detected	
Octochlorobiphenyl	8	None detected	

Considering isomers and homologs, the term "PCB" could identify any of 210 possible (or 102 probable) (4) chemicals, each with distinctive properties. This circumstance has led to considerable confusion and unwarranted generalization about the properties and effects of PCBs.

PCBs manufactured in the United States are registered under the trade name Aroclor of the Monsanto Chemical Company. Only four Aroclors are today being manufactured for commercial applications. They are Aroclor 1221, Aroclor 1016, Aroclor 1242, and Aroclor 1254 (5). Of these, only Aroclor 1

is now used in electrical capacitors. These PCBs are marketed by the average weight percentage chlorine. The last two digits of the product number indicate the average percent chlorine, except in the case of Aroclor 1016, which has a chlorine weight content of 41%.

The properties of principal interest with regard to electrical applications include the following:

Electrical Properties (2) (3)

<u>Aroclor</u>	<u>Dielectric</u> <u>25C</u>	<u>Constant</u> <u>100 C</u>	<u>Volume Resistivity</u> <u>Ohm-cm at 100 C,</u> <u>500 Volts D. C.</u>	<u>Dielectric</u> <u>Strength</u>	<u>Power Factor</u> <u>100 C,</u> <u>1000 Hz</u>
				Greater than	Less than
1232	5.7	4.6	Above 500×10^9	35 KV	0.3%
1016	5.8	4.7 to 4.9	"	"	"
1242	5.8	4.9	"	"	"
1248	5.6	4.6	"	"	"
1254	5.0	4.3	"	"	"
1260	4.3	3.7	"	"	"
1268	2.5	--	--	--	--

Flammability Rating (4)

<u>Fluid</u>	<u>Underwriters' Laboratories</u> <u>Flammability Rating</u>
Ether	100
Gasoline	90-100
Ethyl Alcohol	60-70
Kerosene (100° F.P.)	30-40
Mineral Oil	10-20
Aroclor 1242	2-3
Aroclor 1016	2-3

Advantages of PCBs for Capacitor Design

Prior to 1930 most liquid-filled capacitors were made with mineral oil. The subsequent substitution of PCBs for mineral oil made possible significant technical improvements in the size, reliability, and life of these capacitors. In addition, designers of equipment were quick to seize upon the low flammability characteristic to apply capacitors in ways that might have been hazardous with oil-filled units.

Size

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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 capacitor-grade askarel (Aroclor 1016) is 5.85 while that of mineral oil is 2.25. When capacitor tissue is impregnated with these liquids the dielectric constant of the paper-liquid composite is 6.1 for PCB and 2.9 for mineral oil. Furthermore, because of the relatively close match between the dielectric constants of cellulose, (6.6) and PCB (5.85) it is possible to stress PCB-impregnated paper to 400-500 volts/mil., while the stresses that can be applied to comparable paper-mineral oil capacitors are limited to 300-350 volts/mil. The combined effect of these technical advantages of PCBs has been to permit a reduction of capacitor sizes to less than 14% of what they were in 1924. In 1965 a new dielectric system consisting of paper--polypropylene film--PCB was introduced with stress capability up to 900 volts/mil. overall. Besides favorable stress distributions, the ability of PCB to increase the dielectric strength of polypropylene is partly responsible for this improvement.

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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 PCBs than from mineral oils. The chemical stability of PCB in the presence of capacitor tissue and plastic films and the favorable stress distributions between solid and liquid referred to above have made it possible to design low-cost capacitors with a life expectancy of more than 10 years 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 PCBs. Furthermore, the relative non-flammability of PCBs significantly reduces the fire hazard compared to oil units.

The capacitor manufacturer has been able to "design with" the properties of PCBs and obtain significant technical improvements along with improved safety. As a result, PCBs have supplanted mineral oils in more than 90% of the power and industrial type capacitors made today.

Prior to 1952 the liquid used in PCB-impregnated capacitors was Aroclor 1254 (54% chlorine); it was then replaced by Aroclor 1242 (42% chlorine), which has better electrical properties; and, beginning in September 1971, Aroclor 1016 with improved environmental compatibility, was substituted.

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Alternatives Considered

Because of the high cost of PCBs (now more than \$4 per gallon of capacitor grade, compared to 58¢ for refined mineral oil) there has been a constant

search for a material to replace PCBs ever since their introduction. Additional impetus has been added to this quest as a result of the discovery that PCBs of some kinds have become widely dispersed in the environment (see Section 4). Several materials which have been the subject of study in the past are discussed in the report of the Interdepartmental Task Force (4). Mineral oil is unsuitable because of low power factor leading to enormous penalties in the size of capacitors and the increased demand for critical materials, and would introduce a fire hazard. Castor oil has a moderately good dielectric constant but is very unstable under A. C. discharges and in the presence of water derivable from paper dielectric. Dibutyl sebacate, useful in high-frequency parallel plate capacitors where it constitutes the dielectric material, is also incompatible with the use of paper. Silicone fluids have a low dielectric constant and would generally be subject to the same disadvantages as mineral oil.

In the period since the evaluation given by the Interdepartmental Task Force, several manufacturers have had a degree of success with designs based on dioctylphthalate as the dielectric (such as GE's Econol), introduced in 1973). Dioctylphthalate (or DOP) capacitors for general application in the "small industrial" category, match or exceed the characteristics of PCB capacitors in terms of stability with temperature changes, power factor, and effect of overvoltage on capacitor life. Within certain limits, the effect on life of overtemperature is also a match for PCB designs, but the allowable case temperature must be held down to 85 C (whereas PCB

capacitors may be used at 95 C or higher, with proper derating. DOP designs have not found any general application in the higher voltage ratings such as required in electric utility service, in part because of a propensity to undergo corona damage at lower voltages than PCB capacitors.

There exists an industry standard for non-PCB capacitors, EIA 392-1, which can be met by the use of DOP capacitors. Except for certain export applications, customer acceptance has not been good, due at least in part to concern over the higher flammability of DOP, and the unit's possibly different behavior in the presence of fire of external origin.

Several of the major chemical companies are currently offering various candidate dielectrics for evaluation by capacitor manufacturers (in addition to DOP). It is not known at this writing whether any of these will turn out to be preferred over PCBs in terms of capacitor performance parameters alone. All must go through an extensive period of proof testing for reliability and be screened in their turn for environmental effects. Then, if one of these is to come into general use, production arrangements must be made for the fluid and for the capacitors and some accommodation will have to be achieved on the question of flammability. Thus, although much has been done and is being done to qualify a substitute (or substitutes) for PCB, the best answer may well consist in resolving the controversy that has arisen over PCBs in a manner justifying their continued long range use. This possibility is further addressed in Sections 4 and 5.

3. DESCRIPTION OF THE CAPACITOR INDUSTRY

Products: Types and Applications of PCB-impregnated Capacitors

The principal types of PCB-impregnated capacitors and their applications are described in Appendix 1. Some 80 million to 100 million such capacitors are manufactured annually, most of them for first-time use.

Manufacturing plants, employment and value of shipments

The National Electrical Manufacturers Association lists six manufacturers of power capacitors, all of which use PCB dielectric systems (6):

Federal Pacific Electric Company, Cornell-Dubilier
Electronics Division, New Bedford, Massachusetts

General Electric Company, Hudson Falls, New York

McGraw-Edison Power Systems Division, Greenwood,
South Carolina

Sprague Electric Company, North Adams, Massachusetts

Westinghouse Electric Corporation, Bloomington, Indiana

In addition to the above, the following companies manufacture industrial capacitors utilizing PCBs (7):

Aerovox Industries, Inc., New Bedford, Massachusetts

Capacitor Specialists, Escondido, California

Electrical Utilities Company, LaSalle, Illinois

High Energy, Inc., Malvern, Pennsylvania

Jard Company, Inc., Bennington, Vermont

PR Mallory, Inc., Indianapolis, Indiana

Universal Manufacturing Corporation, Bridgeport,
Connecticut

York Electronics, Brooklyn, New York

In all, there are 14 manufacturers operating 16 plants in 9 states. Total direct employment in the manufacture of PCB capacitors is believed to lie in the range of 2,000 to 5,000 workers (8). (This estimate includes a number of transformer workers, but at present there are only two manufacturers listed by NEMA as producing PCB transformers.) Considering related secondary jobs and the families of workers, there are from 13,000 to 34,000 people dependent upon the PCB capacitor industry (8). If, for any reason, the entire PCB-using segment of the electrical industry should move off-shore, the unfavorable impact on balance of payments internationally would be somewhere between \$68 million and \$170 million annually (8).

The total value of U.S. PCB capacitor shipments has been estimated as ranging from \$130 to \$160 million annually (9), broken down as follows:

	<u>\$ Million</u>
Power Capacitors	50 to 60
Small Industrial Capacitors	<u>80 to 100</u>
Total	130 to 160

4. ORIGINS AND NATURE OF CONCERN

Swedish Fish and California Birds

Polychlorinated biphenyls (PCBs) were first manufactured commercially in 1929, and found increasing application to a broad spectrum of industrial uses over the ensuing forty years. Beginning in the late nineteen-sixties and early seventies, evidence began to appear that these materials had been widely dispersed throughout the environment. Because they are a man-made, rather than a natural family of chemicals, concern arose over the implications of this dispersion. Evaluation of PCBs as possible environmental pollutants has spawned, since 1970, a rapidly expanding scientific literature, with the result that a bibliography published in early 1972 contained 870 entries, mostly of recent origin (10).

During most of the history of the industrial use of PCBs, they were not generally regarded either as hazardous chemicals or as potential environmental contaminants (1). The identification of PCBs as potential food contaminants was first reported in 1966 when they were discovered in fish from Swedish waters (3) but attracted little general concern at the time (1). The growth in public concern may be said to date from the publication in a west coast newspaper, in February 1969, of a major feature about "a menacing new pollutant" found in the San Francisco Bay area.

The article was based on marine life research carried out by Dr. Robert Risebrough of the University of California. The following is Nature's synopsis of Dr. Risebrough's paper:

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Polychlorinated biphenyls are widely dispersed in the global ecosystem, and are powerful inducers of hepatic enzymes which degrade estradiol. Together with other chlorinated biocides, such as DDT, they could account for a large part of the aberration in calcium metabolism which has been observed in many species of birds since the Second World War.

The Yusho incident

Although a serious food poisoning episode attributed to PCBs occurred in Japan in 1968, it was not reported in the Japanese literature until July 1969, and remained generally unknown in the United States until 1971 (10). More than 1,000 people were made ill through ingestion of grossly contaminated rice oil. For many, recovery has been painfully slow. Their sickness was named "Yusho," or "rice oil disease," and has been fully reported in Environmental Health Perspectives (11). Strictly speaking, this episode is not a proper part of the literature on environmental occurrence and consequent human exposure, because the PCBs were introduced directly into the food through an industrial accident (leaks in a heat exchanger), and did not follow a path through the environment. Nevertheless, Yusho is important in the history of the development of concern about PCBs, contributing especially to the sentiment in Japan leading to a ban of PCBs in that country.

Without in any way discounting the tragedy of Yusho for those affected, it is nevertheless necessary to point out certain facts that limit the relevance of this episode to the problem of evaluating the appropriateness of continued use of PCBs in the electrical industry.

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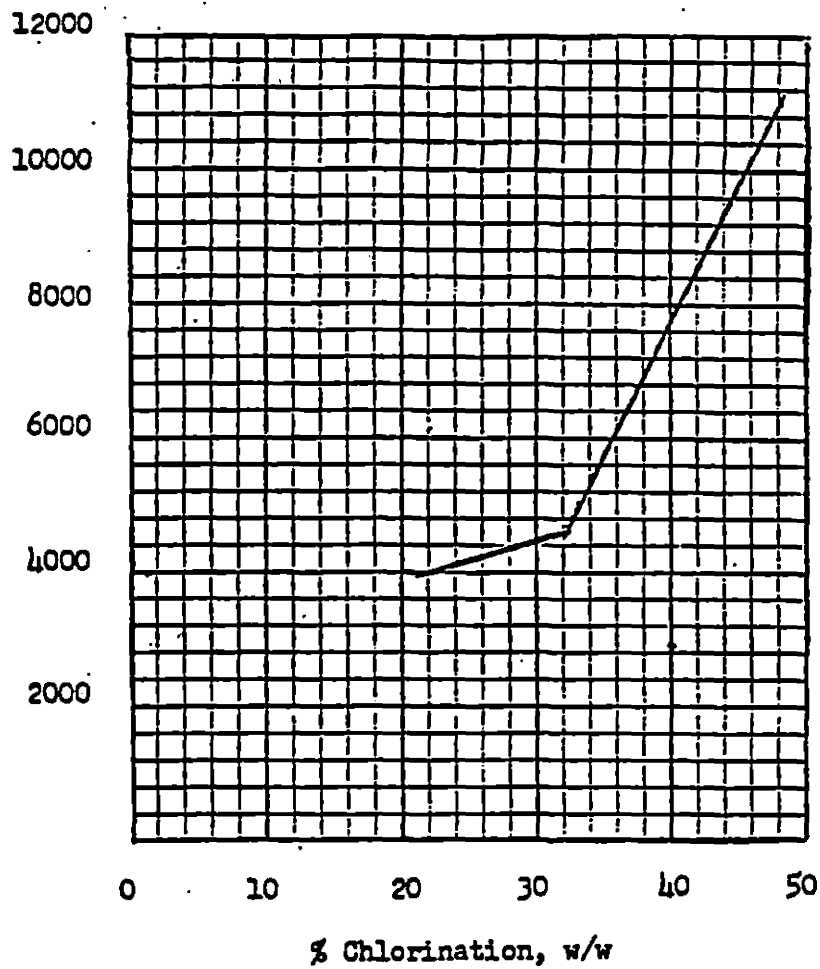
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1. As noted above, Yusho stemmed from an accident in a food plant. Transformers and capacitors were not involved; neither was transport through the natural environment.
2. The rice oil was contaminated grossly: 2 parts per thousand (not per million or per billion) (11).
3. Those made seriously ill consumed an average of 30 milligrams/day (4); and although some were reported to be seriously afflicted two years later, none appears to have died (1) (11).
4. The Japanese product figuring in the episode, Kanechlor 400, was chlorinated to about 48% by weight (compared to 41% for the U.S. capacitor grade). Tests on chickens have indicated that it may have been unusually toxic compared to American PCBs (1), possibly due to presence (not confirmed) in the formulation of the contaminant chlorin dibenzofuran, which has been identified in several foreign products. (Kanechlor has not been manufactured since 1972.)

Toxicity

The acute toxicity of commercial PCBs in experimental animals appears to be low (4) (1). Like the useful properties of PCBs, the biological properties also vary with the particular homologs and isomers present. The following graph, constructed from data in the Interdepartmental Task Force report, illustrates the variation of acute toxicity as a function of degree of chlorination of liquid PCB formulations (4)

Oral LD₅₀
mg/Kg
(Rats)



The LD_{50} is the single dose (expressed in milligrams per kilogram of the recipient's body weight) that will result in the death of half of the test population within a stated time, usually two weeks. Thus, a high number indicates low oral toxicity and a low number represents high toxicity. The term, "highly toxic" has been rigorously defined by the EPA in conjunction with the Food and Drug Administration and the Department of Transportation as an LD_{50} of 50 mg/Kg (12). From the figure on page 15, it is apparent that the LD_{50} of a 42%-chlorinated PCB is approximately 8,650, indicating that it is less toxic than the defined level by a factor of more than 170.

FDA Tolerances

Using animal tests similar to that described above, the Food and Drug Administration identified a no-effect level of 10 ppm in rats and dogs, introduced arbitrarily a safety factor of 100 to 1, and arrived at a "no effect level for man of 2.5 to 3 micrograms per kilogram of body weight. This procedure yields an allowable level of PCB ingestion of approximately 0.175 milligrams per day for a 70-Kg individual (13). This is regarded as a level that "could be exceeded" if a combination of foods containing the maximum tolerance levels is regularly ingested (14), presumably with small likelihood of harm.

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To set a maximum intake level based on human data, that should never be exceeded, FDA turned to the Yusho episode for information. Of the 1,000 or so Yusho patients, the one showing overt symptoms with the least ingestion of Kanechlor was chosen for the calculation. This was a 50-Kg

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individual who ingested 500 milligrams over a period of 50 days. The FDA employed a 10 to 1 safety factor to go from an effect level in the most sensitive individual to a permissible no-effect level, allowing an ingestion of 20 micrograms per kilogram of body weight per day. This is equivalent to 1.4 mg per day for a 70-Kg man, based on a total period of exposure of 50 days (equivalent to the Japanese incident) (13).

We have commented above on the unrepresentative nature of data based on Yusho; however, the FDA had no other place to turn for human data, as there is no other recorded instance of human disease attributed to PCBs (4).

With reference to the above calculations of allowable intake, the FDA established the following "temporary tolerances," expressed as parts per million (14):

Milk (fat basis)	2.5
Dairy products (fat basis)	2.5
Poultry (fat basis)	5.0
Eggs	0.5
Complete and finished animal feeds	0.2
Animal feed components	2.0
Fish and shellfish (edible portion)	5.0
Infant and junior food	0.2
Paper food-packaging material	10.0

There appears to be a reasonable relationship between the food limits shown and the allowable ingestion limits discussed above. For example, if a person's supply of fish is contaminated to the action limit of 5 ppm, he could eat 0.28 kilograms (or 0.6 lb.)--say, a normal serving at one meal--every day without exceeding the allowable ingestion based on the Yusho overt-symptom calculation. He could eat such a serving about once per week without exceeding the allowable intake extrapolated from animal studies. An additional level of protection is afforded by the explicit and implicit safety factors contained in the derivation of allowable ingestion limits.

EPA Limits

It is not known at this writing what basis the EPA will use finally for calculating toxic pollutant effluent standards for PCBs. However, in a draft Statement of Basis and Purpose issued early in 1975, EPA proposed to base its chronic criteria on the FDA tolerances:

"Chronic criteria are normally based upon bioassays conducted over longer periods, preferably several life cycles, and established at levels that will sustain physiological functions of aquatic organisms, i. e., reproduction, growth rate, etc. However, the PCB chronic criteria are based on bioaccumulation of PCB's by aquatic organisms and are established at levels that should protect human consumers of aquatic organisms from the ingestion of PCB's in excess of FDA tolerances." (15, page 26)

Thereupon, EPA (Op. Cit., p. 30) proceeds to compound two more "safety factors" on top of those already contained in the FDA derivation. One of these is implicit, in the choice of what some biologists feel to be an extreme bio-accumulation factor, and the other is explicit and arbitrary, i. e., 2:1.

"Based on a possible accumulation factor in freshwater organisms of 225,000 as exhibited by the fathead minnow, a maximum PCB ambient water concentration of 0.02 ug/l would be possible without exposing human consumers to levels in excess of the PCB tolerance of 5 ppm in edible portions of freshwater fish and shellfish. A chronic PCB level of 0.01 ug/l in freshwater should provide an additional 2:1 safety factor, and is therefore recommended for the protection of human consumers of freshwater aquatic life."

It is an interesting exercise to follow the same logic, but substitute different, although perhaps equally reasonable numbers: In calculating allowable ingestion from animal data, use an arbitrary safety factor for no-effect of 10 (instead of 100). Use a bio-accumulation of 3,000, as exhibited by bluegill and largemouth bass (instead of 225,000) in a well-documented study of an actual lake (23). Omit EPA's proposed 2:1 additional factor. With these numbers, one arrives at an FDA tolerance of 50 ppm and a maximum PCB ambient water concentration of 15 ug/l. The "best" answer may well reside somewhere inside this range of

1500 to 1. The need for more research, to take the guess-work out of the setting of limits, is obvious.

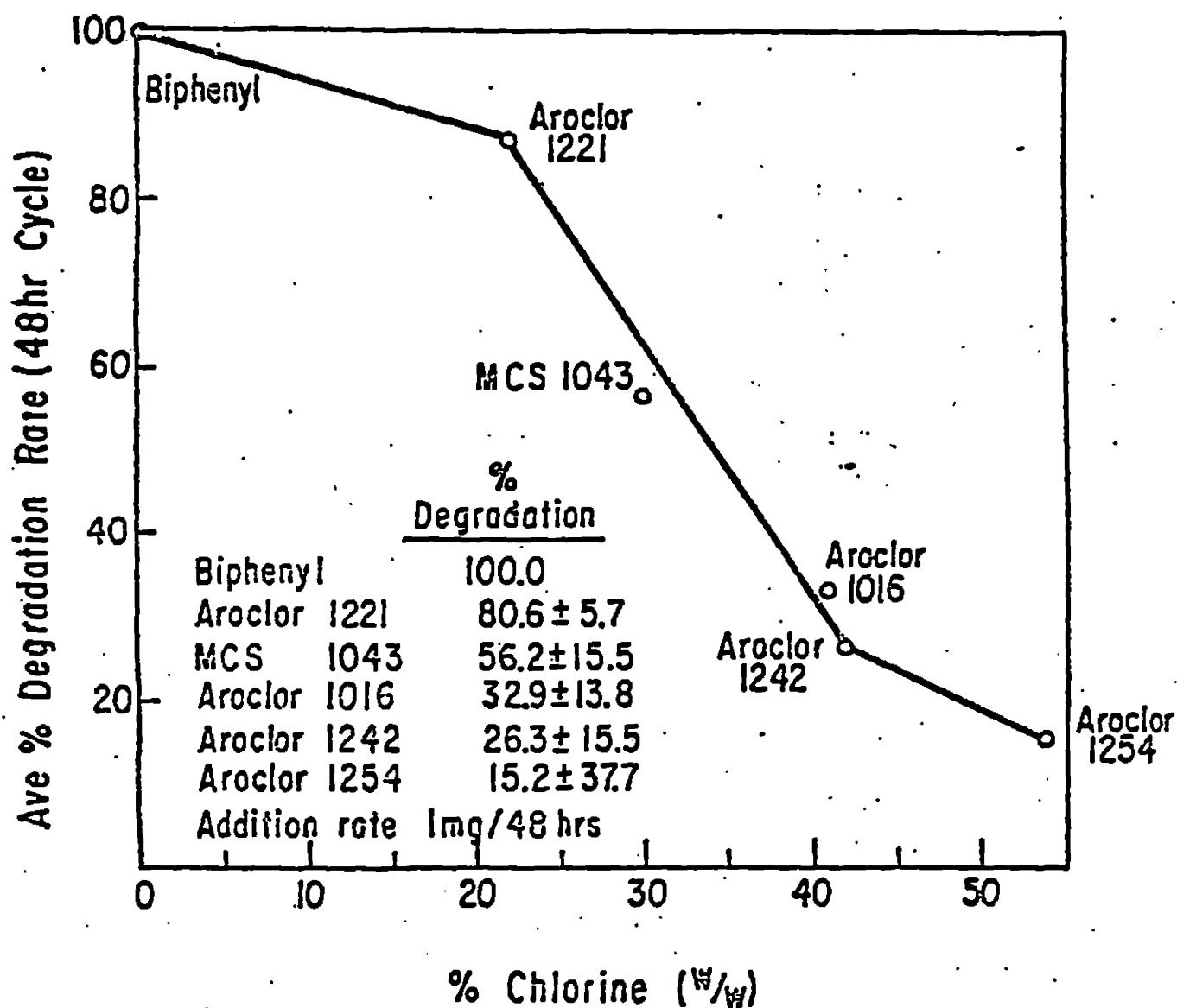
Biodegradation and Metabolism

It is particularly important when discussing biodegradation, metabolism, and environmental burdens to distinguish between grades of PCB. In an activated sludge test performed to predict the fate of various commercial grades in the environment, Aroclor 1016 (used today by the entire U.S. capacitor industry) was found to biodegrade more than twice as fast as Aroclor 1254 (the principal capacitor impregnant from the middle nineteen thirties until the early nineteen fifties). It also degrades 15% faster than Aroclor 1242 (used from the early fifties until late in 1971). The results of a key test are shown on the accompanying chart from a 1972 Monsanto presentation (3).

The more highly chlorinated species have been consistently reported in environmental residues in wildlife (4). Recent Swedish research supports the thesis that an important factor controlling the rate of metabolism is the number of chlorine atoms in the molecule. PCBs containing less than five chlorines, the study finds, are not found in human fat; the lowest chlorinated compound present in significant amounts is the 2, 4, 5, 2', 5' pentachlorobiphenyl (24).

A comparison of PCB homologs produced in the factory and those found in nature strongly indicates selective removal from the environment of low chlorinated homologs (3).

Semi-Continuous Activated Sludge Degradation of Polychlorinated Biphenyls



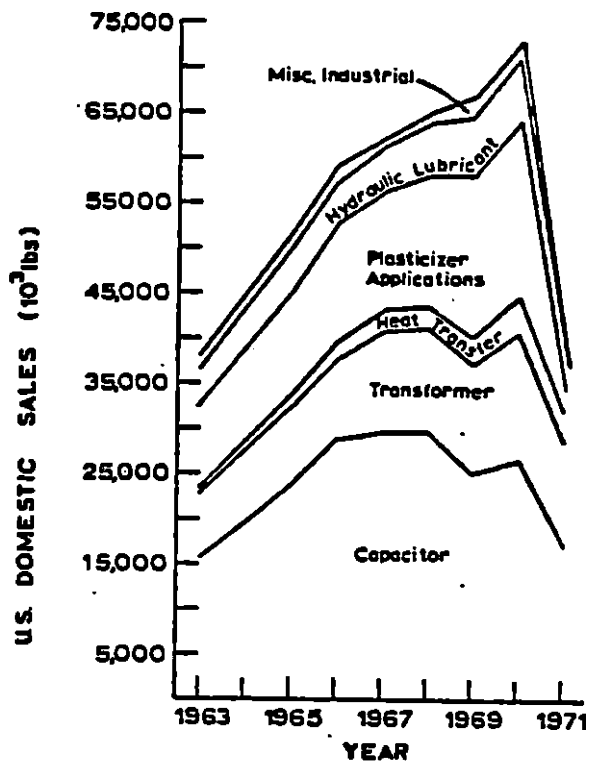
There is as yet insufficient data to list the half-life of various grades of PCBs in the natural environment, but there is abundant evidence that the substitution of a mixture that is relatively free of homologs higher than tetra (i. e., Aeroclor 1016) will play a significant role in reducing the ultimate environmental burden and levels found in the tissue of wildlife.

Environmental Burden

In 1972, Nisbet and Sarofim published a study of rates and routes of transport of PCBs into the environment, based on the situation prevailing in 1970 (16). Since that year, much has changed. In an affidavit before the EPA last year (17), a Monsanto spokesman stated:

"...the situation today is drastically different from conditions which existed only three years ago. Today about 40 million pounds per year are being carefully used in the United States by less than 50 Monsanto customers in the manufacture of sealed electrical equipment. Prior to 1971, close to 80 million pounds were used by thousands of customers."

The figure on page 23 is from Nisbet and Sarofim. The sharp downward trend in applications other than capacitors and transformers has continued to extinction, as predicted by the authors. The only remaining applications in this category stem from possible unauthorized sales of used material and from uncontrolled imports. These categories are believed to be small. The EPA has estimated that total imports in 1974 were less than 200 tons (



... U.S. domestic sales of PCBs by category.

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With improved processes and waste control, the introduction of waste PCBs into the environment from manufacturing activities has slowed to a trickle. It is estimated that only 0.014% of the approximately 79,000 pounds of PCBs used daily by the capacitor industry are discharged to water effluent; this small amount is only 10.7 pounds per day from the combined total of the 16 plants in the industry (19) and there is reason to believe that the total discharge from the transformer industry is even less. Facilities now being installed, and process changes that are continuing, will still further reduce this effluent, but already it is at a level that is totally insignificant compared to the existing burden placed in the environment mainly by the former open applications.

From published figures on past production of PCBs (4), it is possible to estimate that, since the introduction of PCBs in the 1930's, U.S. domestic usage has amounted to 4.3×10^5 tons. The electrical industry used 63% of this total, almost entirely for "closed" applications (i.e., for sealed apparatus). The remaining 37% went into "open" applications, such as paints, plasticizers, specialty inks, etc., or for semi-open applications such as heat-transfer systems and hydraulic systems. A reasonable assumption is that 10% of the electrical industry usage and 80% of the non-electrical usage may have leaked into the environment. (For a description of plausible pathways see the article by Nisbet and Serofim cited above.) Thus, if one makes no allowance for the destruction of this environmental input by natural processes such as bacterial degradation and metabolism, the estimated total burden in the United States becomes 1.5×10^5 tons.

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The following premises and conclusions will be used to calculate the increment in this burden resulting from current and projected use of PCBs.

1. Factory waste is being rapidly reduced and is already down to about 2 tons per year.
2. Procedures for the servicing and rebuilding of transformers are tight enough virtually to eliminate losses to the environment from these operations.
3. The disposal of large power capacitors is being managed in such a way, by the utilities which use them, as to prevent significant discharge to the environment.
4. The millions of small industrial capacitors used in fluorescent ballasts, air conditioning units, etc., probably will never be fully accounted for. However, as more and more communities are adopting improved waste disposal practices, it seems reasonable to assume that leakage of PCBs from failed and discarded capacitors will be cut in half in each of the next several decades.
5. The total usage of electrical energy--and consequent employment of PCB transformers and capacitors--will not exceed the classical growth rate of approximately 7% per year, i. e., doubling every ten years. Growth in use will be offset by improved waste control practices, and the resulting annual contribution to the environmental burden will remain constant and will come almost entirely from the disposal of failed capacitors.

The replacement capacitor market may be taken as a measure of annual failures, and the amount of PCBs now going into replacement capacitors is estimated as 345 tons per year. Capacitors are so constructed that approximately 80% of the impregnant is absorbed by the solid portions of the dielectric system, with only the remaining 20% free to leak out of a ruptured or eroded capacitor case. If all of this residue should reach the environment, the annual contribution would be 70 tons.

Adding in the two tons from our first premise, the maximum increase in the existing environmental burden to be expected from the continuation of electrical applications of PCB is therefore

$$\frac{72 \text{ tons}}{150,000 \text{ tons}} = 0.00048$$

That is, less than one one-thousandth of the amount presumed to be already in the environment.

Since the fall of 1971, capacitors have been made with Aroclor 1016, which only has about one-tenth the environmentally persistent higher chlorinated fractions found in the predecessor fluid. As the percentage of these new-generation capacitors among the failed population increases, the ecological significance of the industrial usage of PCB will be correspondingly reduced

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Environmental Unknowns

A complete assessment of the environmental burden includes not only quantitative analysis of the United States PCB manufacturing and using industry,

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but an estimate of other sources of PCBs, a better understanding of the fate of PCBs that reach the environment, an identification of the degradation products, and better data on the biological effects that specific formulations and their metabolites have upon specific living species in the natural environment as well as in the laboratory.

There are some other sources of PCB in the environment, that have their origin outside the PCB manufacturing industry. At one time, the degradation of DDT/DDE was suspected as a possible source of PCBs in the environment, but we are not aware that this hypothesis is being pursued any longer.

There are some chemical manufacturing operations (e. g., silicone production) that produce biphenyl and some chlorinated biphenyl as a waste byproduct that must be incinerated or otherwise destroyed. In textile mills, the biphenyl used as a dye carrier for synthetic dyes may react with chlorine gas used to control odor and effluent characteristics to form polychlorinated biphenyls (20) and it is possible that similar side reactions may occur in other processes.

The imported PCBs, mentioned previously, while small relative to domestic production, are large relative to the portion calculated to be reaching the environment. If it is true, as suggested by the EPA, that the 200 tons of imported material are going into open applications, they are more significant to the environment than the 70 tons possibly reaching the environment from discarded capacitors. The latter amount is believed to be situated largely

in contact with soil, where it is relatively immobile. The imported material probably consists in large part of material containing pentachloro homologs and above. Much of this can be kept from the environment through existing NPDES permit routines, but the EPA believes that it requires additional legislation in order to prevent remaining open applications of the type discontinued by Monsanto and its customers.

Much of the conflict surrounding the use of PCBs can be resolved only by continued private and government-supported research.. Industry sources have pointed out that most of the alarms raised about PCBs in the environment have originated in determinations of presence in the environment rather than determinations of actual harm:

"The extensive harm predicted by some theories has not been found and documented. This lack of evidence indicates that all of the PCBs do not persist in the environment as a result of factors such as...biodegradation...One characteristic which undoubtedly is of significant importance is the ability of PCBs to adsorb tenaciously to particulate matter... Presence (in the environment) should not be assumed to imply adverse effect. To our knowledge, no published report exists which conclusively relates the mortality of any wildlife species to the presence of PCBs..." (17)

It has been shown, in the preceding analysis, that the input of PCBs to the environment is now very small relative to past inputs, and it has been pointed out that little evidence exists to indicate that the present burden is doing harm. One may, however, construct a worst-case scenario that would hypothesize the desirability of trying to clean up what is out there. No technology now exists that would afford a practical approach. Dredging of water bodies would probably do more harm than good, as it would reintroduce that portion now believed to be sequestered in soil particulates. The inertness of PCBs would appear to rule out chemical treatment. The most promising possibility seems to be the augmentation of bacterial degradation. Degradation studies have been carried out on some selected PCB isomers with two species of *Achromobacter* isolated from sewage, and the susceptibility of commercial polychlorinated biphenyl mixtures to primary degradation by activated sludge microorganisms has been investigated. It is possible that the new scientific specialty of microbiological genetics have important contributions to make in this field.

A "long shot" possibility is botanical water purification. Recent work at Max Planck Institute of Limnology involving the bulrush *Scirpus lacustris* (or, *Schoenoplectus lacustris* Palla) mentions the absorption of pentachloro in connection with "surprising possibilities for the utilization of higher plants." (22)

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4. INDUSTRY ACTION LIMITING ENVIRONMENTAL IMPACT

A review of the chronology of significant events in the recognition and control of possible environmental damage from PCBs illustrates the key role played by voluntary, cooperative industry initiatives. The following chronicle lists the major industry and government actions that followed upon recognition that PCBs are widely dispersed in the environment and capable of adverse effects on various organisms:

- | | |
|------------------|--|
| February 1970 | Monsanto, the only manufacturer of PCBs in the United States, alerted its customers to the potential problem of environmental contamination. Major electrical equipment manufacturers relayed this information to end-use customers for electrical apparatus, with advice as to proper destruction of waste PCBs. |
| June-August 1970 | Heretofore, PCB formulations had been used in a wide variety of applications open to the environment, such as plasticizers for plastics, coatings, and adhesives; in semi-open applications, such as hydraulic and heat-transfer fluids; and in sealed electrical apparatus, namely transformers and capacitors (also termed condensers). During this period, Monsanto initiated the withdrawal of PCBs from all markets except the closed application in transformers and capacitors. |
| October 29, 1970 | The Pesticides Regulation Division (then in the Department of Agriculture) issued PR Notice 70-25 to the effect that "Formulators and manufacturers of economic poisons containing polychlorinated biphenyls and polychlorinated terphenyls should change their formulation to eliminate such chemicals either as active or inactive ingredients." |

- June 1971 The National Industrial Pollution Control Council (Electric and Nuclear Sub-Council) published "The Use and Disposal of Electrical Insulating Liquids" and included in their report recommendations to minimize the possibility of entry into the environment of PCBs used in capacitors and transformers. These regulations were later developed by a committee of ANSI.
- August 1971 Monsanto announced the commercial availability of Aroclor 1016, a new PCB formulation to meet the requirements of the capacitor industry. This new material is substantially free of the higher-chlorinated isomers that have been found in the environment, and has a higher rate of bio-degradation than other commercially available PCBs. The capacitor industry promptly completed conversion to the new material.
- September 1, 1971 Representatives of several agencies of the Federal Government established an Interdepartmental Task Force to coordinate the scientific efforts of the Government relative to understanding PCBs and establishing protection from actual or potential hazards.
- May 1972 The Interdepartmental Task Force on PCBs, representing five Federal Agencies, issued its final report, "Polychlorinated Biphenyls and the Environment." Among other conclusions, the report found justification for continued use of PCBs in transformers and capacitors.
- October 28, 1972 The Federal Water Pollution Control Act Amendments of 1972, PL 92-500, became law.
- December 18, 1972 The Food and Drug Administration announced (in an environmental impact statement) temporary tolerances for PCBs in food (to become part of a new "Part 122").
- February 14, 1973 The Organization for Economic Co-operation and Development (OECD) announced a decision of member countries to control the manufacture and trade of PCBs, stating: "The decision allows for production of PCBs for use in closed systems, such as condensers and transformers in large electrical equipment, which present minimal risks for the environment."

July 6, 1973	The Food and Drug Administration issued rules limiting the sources by which PCBs may contaminate animal feed, food, and food packaging materials. Transformers and condensers (capacitors) were specifically exempted from the restrictions.
1973	At various dates, several manufacturers of capacitors introduced a non-PCB dielectric based on dioctyl phthalate, capable of fulfilling a portion of the market previously served exclusively by PCBs.
December 27, 1973	The EPA proposed effluent standards for various toxic pollutants. Proposed standards for PCBs were included.
January 9, 1974	The American National Standard Guidelines for Handling and Disposal of Capacitor- and Transformer-Grade Askarels Containing Polychlorinated Biphenyl C107.1-(1974) was approved.
July 2, 1975	Culminating years-long effort, EPA announced the achievement by the capacitor industry of a daily discharge level, from the 14 companies and 16 plants comprising the industry, of less than 5 Kg, 0.014 percent of daily usage.

REFERENCES

Source of Information

1. Polychlorinated Biphenyls--Environmental Impact: A Review by the Panel on Hazardous Trace Substances, published in Environmental Research, Vol. 5, No. 3, September 1972.
2. Monsanto Application Data Bulletin No. P-115, The Aroclors, Monsanto Chemical Company.
3. Presentation to the Interdepartmental Task Force PCBs, Washington, D. C., May 15, 1972, by Monsanto Company.
4. Interdepartmental Task Force, 1972--PCB's and the Environment. National Technical Information Service, Springfield, Va. 22151
5. Polychlorinated Biphenyls. Environmental Protection Administration draft statement of basis and purpose, April 3, 1975.
6. Letter to Dr. C.H. Thompson, EPA, from Bernard H. Falk, President, National Electrical Manufacturers Association, March 25, 1974, In re: Proposed Toxic Pollutant Effluent Standards for Aldrin/Dieldrin, et al, FWPCA (307) Docket No. 1.
7. Personal communication, Tyler Nourse, Electronic Industries Association, Washington, D. C., September 24, 1975.
8. Comments of Westinghouse Electric Corporation, In re: Proposed Toxic Pollutant Effluent Standards for Aldrin/Dieldrin, et al, FWPCA (307) Docket No. 1, March 15, 1974.
9. Unpublished study by General Electric Company
10. Polychlorobiphenyls (PCBs) and Related Chlorophenyls: Effects on Health and Environment, I. Bibliography 1181-1971 ORNL-EIS-72-20, Oak Ridge National Laboratory.
11. M. Kuratsune, et al, Epidemiologic Study on Yusho, a Poisoning Caused by Ingestion of Rice Oil Contaminated with a Commercial Grade of Polychlorinated Biphenyls, Environmental Health Perspectives, Experimental Issue No. 1, April 1972.
12. Federal Register, Vol. 38, No. 173, 9-7-73.
13. Supplement to the Final Environmental Impact Statement, Rule Making on Polychlorinated Biphenyls, FDA, July 2, 1973.

REFERENCES (Continued)

Source of Information

14. Final Environmental Impact Statement, Rule Making on Polychlorinated Biphenyls, 12-18-72.
15. Polychlorinated Biphenyls, 3 April 1975, issued by EPA as a draft of a proposed Statement of Basis and Purpose.
16. Environmental Health Perspectives, Experimental Issue No. 1, April 1972.
17. W. B. Papageorge, Monsanto Industrial Chemicals Co., In Re: Proposed Toxic Pollutant Effluent Standards for Aldrin-Dieldrin, et al - FWPCA (307) - Docket No. 1, March 14, 1974.
18. Statement by Glenn E. Schweitzer, Director, Office of Toxic Substances, Environmental Protection Agency, at Hearings on PCBs, Wisconsin Department of Natural Resources, August 29, 1975.
19. Statement of Electronic Industries Association to Environmental Protection Agency, June 25, 1975.
20. Gaffney, letter to Science, February 1, 1974.
21. Biodegradation of Polychlorinated Biphenyls by Tucker, Saeger, and Hicks, Monsanto Company (paper accompanying the testimony of reference No. 17)
22. General Electric Co. Technical Information Report No. EO-75-18, April 8, 1975.
23. PCB's in Suburban Watershed, Reston, Va. by J. Martell et al, Environmental Science & Technology, September 1975.
24. M. Berlin, J. Gage, S. Holm, The Distribution and Metabolism of Polychlorinated Biphenyls, Department of Environmental Health, Lund, Sweden, 1974.

Appendix 1

Types of PCB-Insulated Capacitors

(Reprinted from The Role of Polychlorinate Biphenyls in Electrical Equipment, General Electric Company, Feb. 4, 1972)

A. High-Voltage Power

Generally AC capacitors are used to improve the power factor of a circuit. Power factor is the ratio of true power in watts to the apparent power as obtained by multiplying the current flowing to the load by the circuit voltage. The power factor correction can be made directly at the load or at utility substations. In the latter case high voltage units will be designed for 4,800 to 13,800 volt service. To the utility engineer the use of capacitors is purely a matter of economics. The main benefits that result from the use of capacitors are:

1. Reduction of losses associated with the delivery of electrical power to the point of use.
2. Reduction of the investment required in equipment for delivering electrical power to the point of use, which may be broken down into:
 - a. Reduction of current for the same kilowatt load.
 - b. Reduction of the kva rating of equipment required to handle the same kilowatt load.
 - c. Reduction of the voltage drop for a given kilowatt load.
 - d. Control of delivered voltage if the capacitor kva is varied.

Electric utilities also use capacitor banks in series with distribution circuits to improve voltage regulation. High voltage utility capacitors, low voltage power capacitors, and induction heating capacitors are manufactured at the rate of 200,000 per year, about 2 to 3% of which are for replacements; the balance are for new installations.

B. Low Voltage Power

Capacitors installed in industrial plants at the demand site (typically large motors and welders) are designed for 230-to 575-volt service. Capacitors installed near the loads are the most efficient way to supply the magnetizing current to produce the flux necessary for the operation of inductive devices. Rates for the sale of power are generally structured to encourage power factor correction at the site, eliminating the

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Appendix 1 (Continued)

need for the electric utility to transmit both power-producing current and magnetizing current all the way from the generator to the plant site.

The same considerations apply to induction heating applications, the principal difference being that capacitors for this rapidly growing application are designed for operation at 960 to 9600 Hz.

C. Lighting

Capacitors improve the efficiency of lighting systems. A fluorescent or mercury vapor lamp can be ballasted without the use of a capacitor, but the power factor of the lighting system would then be in the range of 50 to 60%. For commercial or industrial lighting with either fluorescent or high intensity discharge lamps, the use of a capacitor in the circuit provides part of the lamp ballasting and brings system power factor into the range of 90 to 95%. The current market for these applications is about 44,000,000 units annually of which about 10% are estimated to be replacement ballasts.

D. Air Conditioning

As in the lighting applications, the capacitor improves system efficiency. Air conditioners could be made to operate without capacitors, as do home refrigerators, but because of the higher capacity required for air conditioners, the resultant line current would virtually eliminate home "plug-ins" and would still further overburden a seriously threatened national power network. Almost all air conditioner pump motors are of the split-winding type on which the capacitor provides phase differential for the so-called start winding, thus delivering good starting torque. The proper size capacitor permits high (90%) power factor after start-up. The current market for this application is about 12,000,000 units annually, with about 5% of these estimated to be for replacement usage.

E. Industrial Electronics

This market category is a catchall covering many varied applications, two important ones being motor run and power supply applications. Motor run applications are for pumps, fans, and farm feed equipment, and do not differ significantly from air conditioning applications. The power supply market uses capacitors principally to provide high power factor, but through careful design the capacitor can also provide wave shaping where desired. The market is estimated at 23,000,000 units per year with no estimate as to the relative size of the replacement market.

Composition of Different Liquid Chlorinated Biphenyls

<u>Components given as %</u>	<u>Monsanto Aroclors</u>						
	<u>1221</u>	<u>1232</u> **	<u>1242</u>	<u>1016</u>	<u>1248</u> **	<u>1254</u>	<u>1260</u> **
Chlorine	21	32	42	41.3±0.5	48	54	60
Biphenyl	14.8		.02	<0.1			
Mono-chlorobiphenyl	56.5		.72	1.0			
Di-chlorobiphenyl	26.9	~55	15.6	20			
Tri-chlorobiphenyl	1.42		54.5	57			
Tetra-chlorobiphenyl	.06		22.5	21 22.5	~55		
Penta-chlorobiphenyl			6.7*	1.0		60	
Hexa-chlorobiphenyl				<0.1			70
Hepta-chlorobiphenyl				None det.			
Octo-chlorobiphenyl				None det.			

* Includes higher than penta-chlorinated isomers.

** No longer in commercial production.

Source: All data except 1016, Ref. (4)
Aroclor 1016 - Ref. (3)