

Last of all, since the discovery of highly-chlorinated diphenyls in the environment, the companies in question are organizing themselves in such a way that, the part which cannot be regenerated is systematically destroyed by pyrolysis.

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EXHIBIT

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*FILE
INERTEEN*

From Sharon Works, ML-017
WIN 224-4295
Date June 4, 1971
Subject I.B. 45-063-99B
Instructions for Handling
Inerteen and Installation
and Maintenance of Inerteen
Transformers.

Sharon Works, ML-381
Mr. R. L. Schwab

Sharon Works, ML-384
Mr. R. B. Pherson

South Boston Works
Mr. G. C. Wilburn

cc: Sharon Works - ML-017 - Mr. H. R. Sheppard
Sharon Works - ML-017 - Dr. T. K. Sloat

We have revised I.B. 45-063-99B to include precautions and instructions for handling Inerteen and Inerteen contaminated materials and containers. In making this revision we have completely rewritten the brochure to up-date it in all areas. A copy of the tentative revision is attached. May we have your comments, prior to making arrangements for printing.

H. A. Pearce, Jr.

ML-017 - Matls. Eng. Dept. - Fluid Insulation Section - H. A. Pearce, Jr.

/blh

Attachment

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MINUTES OF MEETING
ON

PROPOSED PCB EFFLUENT STANDARDS

February 28, 1974

Monsanto Company
St. Louis, Mo.

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Chairman: Mr. W. B. Papageorge
Manager, Product Acceptability
Monsanto Industrial Chemicals Co.

Objective:

The purpose of the meeting was to share information, experiences and impressions to help each of the participating companies in taking appropriate actions which are mutually supportive and effective in persuading the Administration of EPA to modify the proposed PCB Effluent Standard.

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PARTICIPANTS
PCB STANDARDS MEETING
February 28, 1974

CERTIFIED BALLAST MANUFACTURERS

Mr. N. R. Clark Universal Manufacturing Co.

E.I.A.

Mr. Arnold S. Doty	P. R. Mallory & Co., Inc.
Dr. E. M. Moore	Electrical Utilities Co.
Mr. Rudy Carlson	Electrical Utilities Co.

GENERAL ELECTRIC COMPANY

Mr. James S. Nelson
Mr. Stuart Richel
Dr. Edward L. Simons

JARD COMPANY, INC.

Mr. Richard Rollins

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)

Mr. A. M. Sala-

WESTINGHOUSE

Mr. H. Sheppard
Mr. W. E. Smith

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MONSANTO COMPANY

P. G. Benignus	Market Manager
H. S. Bergen	Business Director
D. B. Hosmer	Utilities and Environmental Protection Director
R. H. Munch	Senior Science Fellow
W. B. Papageorge	Manager, Product Acceptability
W. W. Withers	Attorney
C. Paton	Product Manager
W. R. Richard	Manager, Research and Development
J. R. Savage	Manager, Manufacturing
E. S. Tucker	Research Group Leader
P. L. Wright	Manager, Toxicology

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AGENDA
PCB EFFLUENT STANDARDS MEETING

February 28, 1974

- | | |
|------------|---|
| 9:00 AM | 1. Welcome - H. S. Bergen |
| 9:10 AM | 2. Introductory Remarks - W. B. Papageorge |
| | a. Brief Review of Proposed Standard |
| | b. Critical Action Dates |
| | c. Objectives of Meeting |
| | 3. Discussion Topics |
| 9:15 AM | a. PCB Characteristics - Realistic Definition
chemical, physical, biodegradation |
| 9:45 AM | b. Sampling and Analytical Methodology |
| 10:15 AM | Break |
| 10:30 AM | c. Toxicity
Acute
Chronic |
| 11:30 AM | d. Bioaccumulation - Biomagnification |
| 12:00 Noon | e. Dilution - Stream Size |
| 12:30 PM | Lunch |
| 1:15 PM | f. Proposed Effluent Standard |
| 2:00 PM | g. Control at Manufacturing
Current losses
Background |
| 2:45 PM | Break |
| 3:00 PM | h. Economic Considerations |
| 3:30 PM | i. Action Plans |
| 4:00 PM | Adjourn |

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MINUTES OF PCB EFFLUENT STANDARDS MEETING

1. Mr. Howard S. Bergen, Jr., Director, Specialty Products Business Group of Monsanto Industrial Chemicals Company, welcomed the participants.

2. Introduction - W. B. Papageorge

Mr. Papageorge summarized the timetable past and future on toxic pollutants:

- July 6, 1973 - Toxic Pollutants list published
- September 7, 1973 - Final toxic pollutants list published including PCBs and 8 other chemical classes (e.g. cyanide, mercury, DDT, cadmium, etc.)
- December 27, 1973 - Proposed Effluent Standards published
- January 18, 1974 - Filing date for status as participant at proposed EPA Hearing on Standards
- January 25, 1974 - (i) Prehearing Conference with EPA
 - (ii) NEMA, Monsanto, G.E. and Westinghouse recognized as participants.
 - (iii) A total of 38 objectors expressed an interest. They represented industry, labor associations with the exception of the Michigan Water Research Commission and two powerful environmental groups (Environmental Defense Fund and National Resources Defense Council).
 - (iv) Presiding officer said to expect that hearings will be strictly for cross-examination of participants' testimonies in affidavit form only.

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- March 15, 1974 - Written testimony by 38 objectors to be submitted in affidavit form.
- April 8, 1974 - Hearings open for cross-examination and rebuttal evidence. CN⁻/Cd/Hg - first three. PCBs are 7th (third from last).
- Mid-May, 1974 - Hearings completed. (Evenings/week-ends may be used.)
- June 25, 1974 - Final standards published - effective in one year.

It should be noted that others who are affected by these standards can still comment by March 25 to:

Dr. C. Hugh Thompson,
Chairman-Hazardous and Toxic Substances
Regulation Task Force
Office of Water Protection Agency,
Environmental Protection Agency
Washington D. C. 20460

Industry representatives still wishing to comment and who need more background information can contact any of the industry participants (see attached list) or Mr. W. B. Pageorge of Monsanto (314-694-4051).

Mr. Richel (G.E.):

- (i) Made a plea for greater industry participation. Comments can still be made up to March 25 with sound excuse for tardiness.
- (ii) EPA at January 25 prehearing Conference were reluctant to expose themselves to cross-examination. Dr. Hugh Thompson to be available for cross-examination at Hearings.
- (iii) Many objectors had common interest (e.g. environmental). EPA suggested a common counsel for this group.
- (iv) On each of first 3 pollutants, EPA would offer 2 yr

Mr. Doty (P.R. Mallory) asked about bearing of EPA on standards.

Mr. Richel (G.E.) stated:

- (i) Law is clear-economic factors are not relevant in establishing standards.
- (ii) EPA is somewhat of a split personality on this. The'

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Presiding Officer at the Prehearing Conference ruled that economics are relevant. NRDC (National Resources Defense Council) objected and was over-ruled.

- (111) Industry can and should therefore introduce relevant economic data. EPA would be wise not to expressly refer to such data in the published standard otherwise NRDC could go to court and EPA over-ruled.

Department of Commerce

It was pointed out that Sidney R. Gallier, Deputy Assistant Secretary for Environmental Affairs at the Department of Commerce wrote Monsanto on January 15 asking their views on the proposed effluent standards. Copies of Dr. Gallier's letter and Monsanto's response were circulated at the meeting. Industry should contact the Dept. of Commerce. Their legal counsel (Mr. Morland) has been active on the side of industry in other environmental hearings.

Mr. Salazar (NEMA) pointed out that the PCB Task Force had recommended a standard for PCBs of 0.01 ppb in the main body of water. (EPA was a member of that task force). ANSI C-119 proposes to use this Task Force recommendation and print this as a standard of 0.01 ppb in main body of water.

Mr. Sheppard (Westinghouse) queried if plant effluent standards could be set to meet 0.01 ppb.

Dr. Simons (G.E.) said this implied an acceptance of ANSI C-119 by industry.

There seemed to be some doubt on this.

PCB Characteristics

Dr. Tucker (Monsanto) presented hand-outs on:

- (a) Monsanto's proposed definition of PCBs .
- (b) Comments on EPA's proposed analytical methodology
- (c) Monsanto's pre-publication paper on biodegradation

(a) Definition of PCBs

1-4 chlorobiphenyls do not have long residence time. PCBs up to tetrachlorobiphenyl are no of concern on environmental persistence or biomagnification.

Dr. Tucker proposed the following definition:

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"Polychlorinated biphenyls (PCBs) means materials containing the biphenyl group which is chlorinated and which have been shown to persist and rapidly bioaccumulate in the aquatic environment. These chlorinated biphenyls are identified as those components having gas chromatographic retention times greater than 54, relative to p, p-DDE = 100, under the standard conditions recommended in the EPA PCB test method."

Mr. Sheppard (Westinghouse) said Monsanto's proposed definition was relevant to persistence but was it relevant for standards directed toward toxic materials? Are persistent materials non-toxic?

Mr. Wright (Monsanto) stated the proposed effluent standard had two parts:

- (i) acute limits directed to toxicity of materials and specifically limits PCB concentrations on that basis.
- (ii) daily load in effluent - based solely on bio-magnification (relevant to persistence).

Dr. Simons (G.E.) pointed out that section 307-A of the proposed standard refers to persistence as being a critical factor to be considered.

Dr. Tucker (Monsanto) stated we were badly hurt if all PCBs are regarded as persistent and if biomagnification factors of 200,000 are used. Researchers other than Monsanto have found bacterial degradation of PCBs and that PCBs have been found to undergo metabolism in both avian and mammalian animals.

Mr. Nelson (G.E.) asked if proposed PCB definition would exclude Aroclor 1016.

Dr. Tucker (Monsanto) Aroclor 1016 would be excluded part (90.9% is lower than pentachlorobiphenyl). Aroc would be excluded to 65% or better. Aroclor 1254 not not be excluded.

Mr. Papageorge (Monsanto) pointed out that of the list as being critical in determining which pollutants the list of 9/7/73 only biomagnification appeared relevant to PCBs.

Dr. Simons (G.E.) agreed.

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Mr. Wright (Monsanto) stated that an acute toxicological level is defined in the EPA Basis & Purpose document as ≤ 10 ppm (96 hour LC-50). He also believes that differences in toxicity among PCBs are minor until chlorinated as high as Aroclor 1260.

Mr. Nelson (G.E.) stated that words should be used in a discourse on definition to properly screen us on acute toxicity.

In reference to a comment that Aroclor 1254 would not be excluded by the proposed definition, Dr. Tucker (Monsanto) offered the opinion that transformer fluids were easier to recover than capacitors.

(b) Analytical Methodology

Dr. Tucker (Monsanto) stated the EPA's proposed method for PCB analysis was being submitted to ASTM. He thought the method was well written and capable of detection to ppt (parts per trillion) but it was untried and the quantitative accuracy is in question. The method was not submitted for round-robin testing before EPA adopted it. Monsanto has found that by spiking distilled water with 500,000 ppt or 500 ppb of PCBs we get values for PCB that vary by $\pm 55\%$. The EPA, however, claims a capability of detecting absolute values at 50 ppt. The EPA method ignores interfering substances.

Mr. Clark (Universal Manufacturing) said that with a proposed upper limit for PCB discharge of 0.0648 lb./day the sensitivity of the analytical method would vary "all over the lot" depending on the size of the water "reservoir" into which the PCBs discharge.

Mr. Sheppard (Westinghouse) commented that if the analytical techniques on determining PCB levels are so difficult, how valid are the determination of toxic values for PCBs.

Mr. Clark (Universal Manufacturing) asked if analytical techniques differentiate between different chlorine levels. Dr. Tucker (Monsanto) said it would depend on the PCB mixture. Aroclor 1242 could probably be identified quantitatively in a mixture with Aroclor 1260 but addition of Aroclor 1254 to the mixture would prevent identification because Aroclor 1254 contains PCB homologs that overlap both Aroclor 1242 and 1260.

Dr. Munch (Monsanto) said that the proposed EPA method is to use high resolution and hence handicaps identification of individual peaks.

Dr. Simons (G.E.) mentioned that after EPA set automotive emission standards (NIOX) the analytical methodology was found faulty and the standards were delayed. In this case, EPA is not setting the effluent standard on analytical methodology but

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on factors such as toxicity and persistence. The methodology is relevant in enforcement and monitoring. This then leads to the possible argument that the effluent standard is correct and justified on the basis of toxicology et al, but is not enforceable due to lack of an accurate method for absolute value determination of PCB discharge.

Mr. Richel (G.E.) pointed out that EPA won't buy an answer to that argument which seeks to raise the effluent standard to a level that can be accurately measured. Mr. Savage (Monsanto) felt strongly, however, that this dilemma needed to be in the record. Others agreed.

Dr. Tucker (Monsanto) said ASTM would hold a round-robin on the EPA method and that Monsanto would participate. He will send the name of the ASTM contact to the participants so that they can decide if they want to join the round-robin test.

Mr. Sheppard (Westinghouse) said he was not prepared to accept that the proposed EPA method for determining quantities and types of PCB in samples and animals was accurate enough so that toxic limits could be defined on the basis of PCB levels of questionable accuracy.

Toxicity

Mr. Hosmer (Monsanto) stated that the original EPA publication on Water Quality Criteria came from a publication by McKee and Wolfe for the State of California. The McKee/Wolfe volume was well done and EPA did not change much of it. There is now a new 2-volume EPA edition extracted from the work of 10 committees of the National Academy of Sciences.

The toxicity of PCBs is related to salmon egg studies and Monsanto doubts the validity of this. Monsanto has made their feelings known to Dr. Thompson of EPA but he thought the criteria were sound. Since then Russell Train has been sued by NRDC and other groups on the grounds that the toxic pollutant list is not long enough and the proposed standards are too lenient.

Mr. Wright (Monsanto) went through the rationale used by EPA arriving at a PCB discharge maximum of 0.0648 lb./day. He showed how the standard could be changed and met be consistent with published data on PCBs. Details follow.

(a) FDA set arbitrary proposed tolerances:

- 5 ppm in fish for human consumption
- 5 ppm in components for animal feed
- 0.5 ppm in complete animal feed

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- (b) Monsanto would not disagree with these tolerances.
- (c) FDA has presented - acute toxicity limits (point sources)
 - chronic toxicity limits (daily load)

Acute toxicity limits:

96 hour LC-50 studies for PCBs show:

- ~280 ppb in fresh water (bluegill)
- ~10 ppb in coastal or seawater (pink shrimp/oysters)

Published data based on materials leaving an outlet and going into a body of water. Acute limits have no direct relation to chronic limits.

Chronic toxicity limits:

The EPA equation is:

Chronic limit X water flow rate X safety factor = gm/day discharge

In Marine organisms the chronic limit is set as

$$\frac{0.5 \text{ ppm}}{30,000} = 0.0167 \text{ ppb}$$

In fresh water the chronic limit has been determined by using 0.5 ppm as toxic limit for salmon eggs and a 200,000 bio-magnification factor. This gives a chronic limit of

$$\frac{0.5}{200,000} = 0.0025 \text{ ppb}$$

The biomagnification level of 200,000 is based on unpublished data from Stalling & Meyer (Fish Pesticide Lab, U. S. Dept. of Interior, Colombia, Mo.). Dr. Simons said that in response to repeated requests by G.E. to the Columbia Lab the only reference they have been given is a Stalling & Meyer paper presented in Carolina in 1971 and which contains no mention of a 200,000 factor. Mr. Wright (Monsanto) stated he has seen only one literature reference to an accumulation factor of ~200,000 and that was in the hepato pancreas of a pink shrimp. If the PCB level was calculated on the basis of the total shrimp then the accumulation factor was only 22,000. Other references give accumulation factors of 1000-75,000 for whole tissues of various fresh water organisms. Accordingly, Mr. Wright proposes that a biomagnification factor of 30,000 and not 200,000 be used. He also proposes that we retain the chronic limit of 0.5 ppm without debating the salmon egg issue.

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This would lead to a discharge level for PCBs:

$$\frac{0.5}{30,000} \times 10,000 \times \frac{0.5}{(\text{flow rate})} \times \frac{5.4}{(\text{safety factor})} = 0.459 \text{ lb./day}$$

(conversion
into lb./
day)

This compares to the proposed standard of 0.0648 lb./day.

The safety factor comes from the EPA's Basis and Purpose document supporting the proposed effluent standards. It is supposed to take account of non-point sources of PCBs and is the same as 5 of the 9 toxic pollutants proposed for EPA standards. Monsanto's Medical Department feels this safety factor is arbitrary and confers no real toxicological benefit. If deleted, the revised Wright PCB discharge level would be 0.915 lb./day.

One of the most critical parts of the discharge equation is the water flow rate. A significant number of dielectric PCB manufacturers have plants on rivers where the flow rate is under 100 cfs or 1% of the EPA cut-off flow of 10,000 cfs. Several plants discharge into sewage plants which in turn have treated liquid flowing into rivers or streams with very low flow rates. For a river with 100 cfs flow the EPA maximum discharge would drop to 0.000648 lb./day or 0.162 lb. in a 250 work-day year. Even a revised standard of 0.915 lb./day at 10,000 cfs would only be 0.00915 lb./day at 100 cfs or ~2.3 lb. per 250 work-day year. Clearly this is a staggering target to have to meet.

Mr. Doty (Mallory) pointed out that in the present language of the EPA standards municipal sewage systems are not considered point sources.

Mr. Richel (G.E.) was of the opinion that where a plant discharged into a sewage system without treatment and hence into navigable waters the plant could have to comply with effluent standards on toxic pollutants. Mr. Papageorge (Monsanto) felt we should not be complacent and regard discharge to sewage plants being the answer to problems. Mr. Hosmer (Monsanto) stated that 10,000 cfs represents the largest flow the EPA will consider on the grounds that all industry would move to the largest river. The opposite of that argument is that it encourages small plants on every stream in the country.

Mr. Shepard (Westinghouse) raised the issue of sedimentation. Since it appears that all the experiments to establish toxic values were run without sediment effects being considered, the real-life values were questioned. PCBs attach themselves to sediment. Furthermore the sediment moves down river and so PCB would be dispersed from the point source. It was pointed out by Dr. Richard (Monsanto) that Aroclor 1254 is soluble in water up to 50 ppb and that in time partitioning between sediment and

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water could take place. Mr. Wright (Monsanto) agreed that the discharge limits were extreme cases in the absence of sediment considerations and this was worth study and incorporation into arguments against the proposed levels.

Dr. Simons (G.E.) queried whether we were correct in concentrating our attacks on the criterion of toxic effects of mammals eating fish and ignoring the possible argument that fish per se must be protected. Mr. Wright (Monsanto) said the proposed standard says both. In salt water, standards are proposed that would protect the species that eat organisms containing PCB. In fresh water, if 0.5 ppm in salmon eggs correlates with <5 ppm in salmon then we are protecting salmon. He also said that the chronic limits and biomagnification limits he was proposing would protect the species themselves. We should, however, beware of arguing for higher levels in fish because we could draw EPA and FDA into conflict. The FDA levels in food, fish etc., are temporary tolerances and any arguments against their validity could lead to a reduction in these tolerances.

Mr. Savage (Monsanto) queried whether raising the level in organisms could cause possible danger to predators.

Dr. Simons (G.E.) quoted from page 39 of the Basis & Purposes document which states that the body burdens of birds and mammals should not increase over present levels. Page 51 of the same document cites a Nat. Acad. Sci. report which gives 2.0 ppm PCB as tolerable level in flesh of whole fish. $\frac{2.0}{200,000} = 0.1 \text{ ppm PCB}$

is given as tolerable level in water divided by a safety factor of 5 to give a maximum PCB concentration in water of 0.002 ppm. Thus EPA accepted 2 ppm PCB level in fish but got to water concentration of 0.002 ppm by using a high level of 200,000 for biomagnification and an arbitrary factor of 5.

If we were to revise the proposed EPA standard by:

- (i) using 2.0 ppm as chronic limit in fresh water species instead of 0.5 ppm;
- (ii) substituting 30,000 instead of 200,000 for biomagnification factor;
- and
- (iii) ignoring safety factor of 5

then the maximum permissible discharge in lb. PCB per day would be:

$$\frac{2.0}{30,000} \times 10,000 \times 5.4 = 3.6 \text{ lb.}$$

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For the plant situation on a river with a flow of only 100 cfs the discharge would be 0.036 lb/day or 9.0 lb. per 250 work-day year. These levels are still far below the 5 lb./day given in ANSI C-107.

It is therefore apparent that other aspects of PCBs must be highlighted in order to get away from PCB discharge levels as low as even our "revised" proposals.

Aspects to concentrate on are:

- (1) Definition of PCBs that excludes biodegradable homologs.

This could exclude 90% or better of Aroclor 1016 and 65% or better of Aroclor 1242. On that basis, discharge levels would be as follows:

PCB Type	Stream Flow (cfs)	Discharge (lb. PCB equivalent/day)		
		EPA	Wright	Simons/Wright
Any PCB	10,000	0.0648	0.918	3.6
Any PCB	100	0.000648	0.00918	0.036
Aroclor 1016	10,000	0.548	9.18	35.0
Aroclor 1016	100	0.00548	0.0918	0.36
Aroclor 1242	10,000	0.194	2.75	10.8
Aroclor 1242	100	0.0019	0.027	0.10

- (2) Try to change stream flows from the present value of the flow rate in cubic feet per second (cfs) expressed as the probable low rate occurring during a consecutive day period once in 10 years at the effluent point.

If the average flow rate over a period of time (to be agreed on) was used, the lowest flow rate in the equation could conceivably be raised by a factor of 10 from 100 to 1000. In the Simons, Wright version for a standard the Aroclor 1016 discharge could be raised to 3.6 lb./day at 1000 cfs flow and Aroclor 1242 to 1.0 lb. day at 1000 cfs flow.

- (3) Magnitude of PCB Point-Sources

It is possible that EPA and environmentalists are totally misinformed on the number of plants still using PCBs. In the U.S. today there are:

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1 PCB manufacturing plant

~18 capacitor plants using PCB

~27 transformer manufacturing plants using PCB

In the past there were probably 1500-2500* plants using PCBs. Only 2-3% of these plants continue to use PCB today.

* (Subject to closer checking if necessary)

In the past ~97% of plants using PCBs purchased ~40 million pounds of PCB per year. Monsanto's PCB sales policy has therefore

- reduced number of using plants to ~2-3% of previous total.
- eliminated ~40M lbs. PCB sales per year.

The EPA standard would limit PCB discharge per plant to 0.0648 lb./day or ~3.2 lb./day across the U.S. (~50 plants). This equates to ~200 pounds in a 250-work-day year. Since fish have survived throughout the 40+ years that PCBs have been produced and widely used, the standard proposed by EPA seems far too drastic.

Turning again to the Simons/Wright proposal we can estimate the effect in terms of annual PCB discharge into water across the U.S. at 1000 cfs:

Discharge As	Discharge (lb./day)	No. Plants	US Total per 250 days (pounds)	As Persistent PCBs		
				Discharge (lb./day)	No. Plants	US Total
Any PCB	3.6	*1	900	1.2	1	300
Aroclor 1016	3.6	18	16200	0.36	18	
Aroclor 1242	1.08	4	1080	0.36	4	
Aroclor 1254	0.36	23	2070	0.36	23	
			20,250			

* Plant is on river in excess of 10,000 cfs.

Using this technique an argument can be made in favor of the ANSI C-107 proposal of 5.0 lb./day.

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Proposed Effluent Standards

Dr. Simons (G.E.) summarized the points he felt had to be dealt with in trying to change the proposed standard:

1. Higher persistence of higher PCBs versus alleged lower acute toxicity
2. Background levels of PCBs
3. Written testimony of participants and correlation

Toxicity

EPA Basis & Purpose document (page 50) states that 96 hour LC-50 to fish cannot adequately measure toxicity of PCB. Where is time demarcation between acute and chronic. Chronic effects can be either lethal or non-lethal.

Why are PCBs on the list on toxic grounds?

LD-50 for PCB is such that it is not considered toxic to humans.

For protection of aquatic life the Nat. Aca. Sci. set a 96 hour LC-50 of 10 ppm or less.

In proposing a definition for PCBs, Dr. Simons (G.E.) felt we should stress:

- (a) lack of persistence of homologs below tetra-chlorobiphenyl.
- (b) chronic toxicity does not arise for the lower homologs because they are non-persistent.
- (c) ignore acute toxicity - no real differences between Aroclor 1015, 1242 and 1260.

Participants need to consider: Do we have the best definition?

In the tentative EPA analytical method we should take note that in the table on p.3-22, the percentage of PCB was not controlled.

Mr. Carlson (E.U.C.) pointed out that in its present form the standard could saddle present PCB users with all other discontinued uses. Dr. Richard (Monsanto) pointed out that FCM and Boxboard Manufacturer's Association had agreed on a protocol that protected recycle paper users from just such a situation. Mr. Bergen (Monsanto) asked that copies be circulated to participants.

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We need to word our definitions to exclude residuals. Participants should exchange proposed drafts on wording regarding residuals by March 7.

G. E. stated we should not approach the hearing on the basis that things can't be done. Rather take the proposed standard and point out what it means in real life. In G.E.'s case they use X M lb./year and yet can't lost 0.5 drops per day. Stream flow rates make the matter worse. This is a point on which Dr. Thompson should be cross-examined.

Of the participants present, 5 plants discharge into sewers with outlets into rivers (very small except in 2 cases). Three plants discharge into small rivers.

No one at the meeting could cope with the EPA standard as it is proposed. Only Jard expressed an opinion on what level they could live with. (Jard stated 27 lb. Aroclor 1016 per day. This would be 2.7 lb. PCB by our proposed definition.)

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Participation at EPA Hearing

Definite participation: Monsanto
G. E.
Westinghouse

Undecided: Electrical Utilities
Jard
NEMA

No participation: Electronic Components
Mallory

Objectors of record could adopt non-responding company as witness.

G.E.'s testimony will fall into the following areas:

- Explanation of why PCBs are used
- Consequences of ban on customers
- Inadequacy of EPA/Nat. Acad. Sci. statements
- How standards would apply to G.E.
- Inadequacies of the Standard
 - definition
 - methodology
 - logic behind the standard

Other contributory actions:

- Involve Federal Energy Office (e.g. Aerovox letter on motor-run capacitor contribution to ease energy crisis.)
- Involve F.E.O./other agencies along lines of petrochemical producers' PEG report.
- Power Systems Group of IEEE will circulate paper on PCBs (technical aspects) to dielectric industry to Congress, EPA, F. Dept. of Commerce (target date: April)

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Action Plans

1. (W. B. Papageorge) Circulate to participants copies of FDA/Boxboard Manufacturers protocol on PCBs in recycle paper.
2. (Participants) Exchange drafts on testimony regarding PCB residuals/background levels with each other by March 7.
(Monsanto contact should be W. B. Papageorge.)
3. (Participants) Submit to W. B. Papageorge their thoughts on proposed PCB definition (to exclude 1-4 chlorine homologs).
4. (Participants) Communicate with each other on how best to handle sedimentation phenomenon (as raised by Mr. Sheppard of Westinghouse).
5. (E. S. Tucker) Send out name of ASTM contact for participation in round-robin on proposed EPA analytical method.
6. (Participants) Write to Dr. Galler of Commerce Dept. opposing EPA standards.
(See Galler letter to Monsanto and Monsanto response.)
7. (Participants) Those who have not responded to EPA can still write Dr. Thompson by March 25.
8. (A. Salazar, NEMA) (a) Get feedback from Barrage and Edison on the
(b) Determine re. affidavits/t. hearing.
9. (W. B. Papageorge) Obtain PEG report Mr. Nelson (G.E.)
10. (Participants) Involve F.B.I. in lines of AERVOX and Simon.

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MAR 29 1974



National Electrical Manufacturers Association
155 East 44th Street • New York, N.Y. 10017 • 212-682-1500

Bernard H. Falk
President

March 25, 1974

Dr. C. Hugh Thompson, Chairman
Hazardous and Toxic Substance
Regulation Task Force
Office of Water Program Operations
Environmental Protection Agency
Washington, D. C. 20460

SUBJECT: PROPOSED TOXIC POLLUTANT EFFLUENT STANDARDS - PCB'S

Dear Dr. Thompson:

I am Bernard H. Falk, President of the National Electrical Manufacturers Association. I am writing in behalf of the Power Equipment Division of NEMA, which represents companies responsible for over 95% of the domestic production of liquid-filled transformers and capacitors for both domestic and foreign use. A list of these companies is attached as EXHIBIT "A".

Our purpose in writing is to object to the proposed Toxic Pollutant Effluent Standards for Aldrin/Dieldrin et al, FWPCA (307) Docket No. 1, particularly in regard to the proposed standard for Polychlorinated Biphenyls - 40 CFP 129. This communication will serve to endorse and supplement the formal testimony already filed by individual companies before the Administrator in the current Hearings - namely, General Electric, Monsanto and Westinghouse. Copies of this letter are being sent to all objectors on the service list for the Hearings.

In the remarks which follow we shall stress our conviction that the definition of PCB's employed is too loose and that the toxicity of PCB's has been misrepresented; that previous industry efforts have brought the problem well in hand; and that important safety and economic values are threatened by the unjustified extreme proposals for effluent limitation, which would also exacerbate materials shortages and the energy crisis. We shall urge that the EPA limit its control efforts to the isomers found in the environment and establish limits attainable by industry and consistent with voluntary measures already adopted, which have been shown to be rapidly reducing the environmental burden - even in the absence of regulations.

Our first observation is that the EPA has classified a wide range of different compounds with differing potentials for environ-

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Dr. C. Hugh Thompson

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March 25, 1974

mental impact into one general definition of "PCB's". We urge that the Administrator establish a definition of PCB's consistent with the objective of protecting the environment against only those isomers found to be persistent in the environment. Excellent suggestions for accomplishing this purpose are to be found in the testimony referred to above.

We note also that a serious question remains as to the appropriateness of including any form of PCB on a list of toxic pollutants. Certainly PCB's are not "highly toxic to man" as characterized in the document promulgating the list of toxic pollutants (38FR21342). The toxicity of the industrial formulations has been shown by the report of the Interdepartmental Task Force to be many times less than the criterion referenced by EPA for such classification.

EXHIBIT "B" is a chronological history of key actions by Government and industry in response to the growing awareness in the past 4 or 5 years of the possible adverse effects of PCB's upon the environment. An analysis of this list indicates that industry was prompt in responding to this environmental concern and took steps to bring the potential pollution problem under control even prior to passage by the Congress of the Act (PL 92-500) which authorizes the suggested proposed effluent standards. The unilateral action of the Monsanto Company in withdrawing PCB's from all open and semi-open applications, such as plasticizers for paints and varnishes, carbonless carbon paper, hydraulic and heat transfer systems, etc., accomplished a major reduction in the total use of PCB's and in the total amount which could possibly reach the environment (entirely apart from any disposal control efforts). The only remaining applications countenanced by Monsanto's sales policy are in transformers and capacitors. In order to minimize any entry into the environment from the remaining applications, the electrical industry through NEMA standards for handling these materials and controlling the discharge of wastes. These standards have since been adopted as an American National Standard, ANSI C107.1-(1974).

Inasmuch as Monsanto is the sole U. S. Supplier, these voluntary actions by industry have greatly reduced the threat of serious environmental contamination.

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Another observation which can be drawn from the chronology of events is that previous studies of the values involved on the part of Government Agencies have resulted in the conclusion that continued use of PCB's in transformers and capacitors is currently warranted because of the public safety and economic importance on the one hand and the lack of serious environmental threat on the other. We cite the Interdepartmental Task Force Report and the Food and Drug Administration regulation with regard to food and food packaging materials and, on an international basis, the OECD decision.

Within the electrical industry, the development by Monsanto and the prompt adoption by the manufacturers of Aroclor 1016 as a capacitor impregnant substantially reduced the potential environmental impact. This new dielectric, it should be observed, is virtually free of the higher chlorinated isomers which alone have been found to be persistent in the environment. The resulting effect of these voluntary actions on the part of industry are already measurable in the environment. We quote from a paragraph in the Monsanto testimony:

"Thus 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 per year were used by thousands of customers."

Monsanto also quoted in their testimony the following statement by Dr. George Harvey of the Woods Hole Oceanographic Institute:

"In the summer and fall of 1972, the surface waters of the Eastern and Western North Atlantic Ocean had an average PCB concentration of 30 parts per trillion. By the summer and fall of 1973, the average PCB concentration in the same area had decreased to about 1 part per trillion."

"Since the suspended solids fall out and mixing rates of the ocean are constant, the observed reduction in surface layer concentrations indicate a reduced 'CB input.'"

Again, in its last 10 market basket surveys, the FDA has failed to find any quantifiable residues of PCB's. (See Food Chemical News, October 1, 1973). Thus entirely apart from any question as to the toxicity of PCB or appropriateness of the

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definition adopted by the proposed regulations, PCB's are diminishing significantly and rapidly in the U. S. environment.

Our member companies are concerned that the extreme nature of the proposed regulations will make it impossible for them to continue the manufacture of PCB transformers and capacitors. Should this happen, we recognize a significant increase in the risk of fire and explosion on premises where alternatives to PCB's are used. Wherever flammable liquids are substituted, there is introduced a higher risk factor. This would be of primary importance in such installations as schools, apartment houses, shopping centers and commuter mass transit vehicles. At the present time, insurance regulations and code requirements are built around the availability of PCB's. There is no substitute available with a comparable degree of protection against fire and explosion.

As pointed out in the testimony submitted by the Westinghouse Electric Corporation, any regulations which would have the effect of banning PCB's or causing major relocations within the PCB-using industry would impact on the livelihood of as many as 34,000 people (including workers and their families). The proposed regulations might well encourage off-shore manufacture of PCB's and PCB equipment, with a resulting unfavorable effect on the balance of payments amounting to as much as \$150 to \$200 million annually and the loss of jobs for U. S. workers.

As pointed out in the General Electric testimony, there will be serious consequential effects on the industries that use PCB transformers and capacitors. G. E. has estimated that an interruption in the availability of PCB transformers would cause serious delays involving "as much as \$1 billion of construction projects ...involving schools, factories, office buildings, apartment houses and commuter trains." Similarly, if PCB capacitors should be withdrawn from the market, the industry would be unable to supply the needs of electric utilities for power factor correction capacitors. "If none of these capacitors were available, the increased cost of generators and transformers and other equipment ...would amount to approximately \$1 billion per year." The G. E. testimony contains data concerning consequential energy losses amounting to many millions of barrels of oil and cites serious resulting dislocations in the lighting and air conditioning industries.

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National Electrical Manufacturers Association

Dr. C. Hugh Thompson

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March 25, 1974

As a result of the industry actions described herein, there remain only a few manufacturers who use PCB's. These manufacturers are entirely within the electrical industry and subject to the disciplines of the American National Standard C-107.1. The capacitor manufacturers are the biggest users of PCB's and have been able to switch entirely to a new formulation which is biodegradable. We can see no pressing need or urgent public necessity for the EPA to take any action with respect to PCB's beyond giving the regulatory support of the Government to the voluntary programs already established. This could be accomplished by redefining PCB's along the lines suggested above and adopting discharge limitations consistent with current best practices.

Sincerely yours,

Bennett H. Felt

BHF:dk

Atts: Exhibits "A" and "B"
Service List

CC: All Objectors on the Service List

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LIST OF CURRENT AND PAST MANUFACTURERS
OF ASKAPEL-FILLED ELECTRICAL EQUIPMENT

TRANSFORMERS

- *Allis-Chalmers Corporation
- *Central Moloney Transformer Division
Colt Industries
- *Federal Pacific Electric Co.
General Electric Company
- *I-T-E Imperial Corp.
- *McGraw-Edison Power Systems Division
- *Niagara Transformer Corp.
- *Standard Transformer Co.
Div. of American Gage and Machine Co.
- *Wagner Electric Corp.
Westinghouse Electric Corp.
- *Past manufacturers

POWER CAPACITORS

- Federal Pacific Electric Company
- General Electric Company
- McGraw-Edison Power Systems
- Sandamo Electric Company
- Sprague Electric Company
- Westinghouse Electric Co.

EXHIBIT "A"

NPC00007278

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Chronology of Events

During the years 1968 and 1969 there emerged a view, based on new scientific findings, of PCBs as widely dispersed in the environment and capable of certain adverse effects on various organisms. The following chronicle lists the major industry and government actions in response to this recognition, or having a bearing upon it.

- 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 formulations 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. The regulations were later developed by a committee of ANSI.
- August, 1971 Monsanto announced the commercial availability of Aroclor, a new PCB formulation to meet the requirements of the cap 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.
- 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.

EXHIBIT 2

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Chronology of Events

- 2 -

- 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.
- 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 Biphenyls, C107.1-(1974) was approved.

EXH

NPC00007280

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ENVIRONMENTAL PROTECTION AGENCY

BEFORE THE ADMINISTRATOR

In re:)
Proposed Toxic Pollutant)
Effluent Standards for) FWPCA (307) Docket No. 1
Aldrin/Dieldrin, et al)

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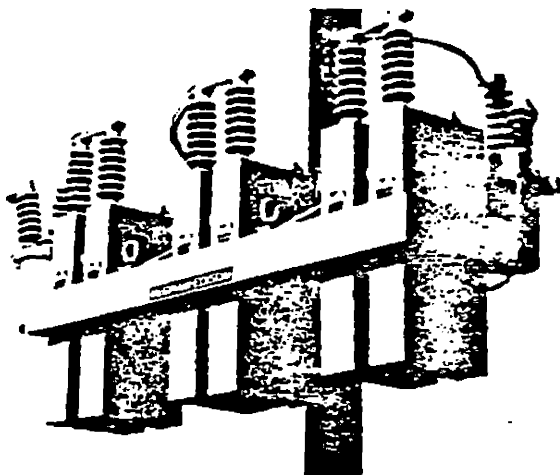
An Environmentally Acceptable Liquid Dielectric for Power Capacitors



McGRAW-EDISON COMPANY
Power Systems Division

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Operating efficiency of capacitors impregnated with the new environmentally safe insulating fluid is equal to—or better than—units using PCB. And, size is not affected.

INTRODUCTION

The history of developments in the power capacitor industry has been quite dramatic over the last 30 years. Through material and design improvements, power capacitors have had size reductions from 80 to 10 cubic inches per kvar and prices have dropped from \$5.00 per kvar to the current low of \$1.50 per kvar, making capacitors one of the best buys in the electrical industry.

A major contributor to this dramatic product improvement has been the liquid dielectric Aroclor,[®] a capacitor-grade askarel containing polychlorinated biphenyl (PCB). But today, capacitor users and manufacturers are faced with a major problem.

Table 1 is a brief account of industry and governmental activities regarding PCB liquid over the past ten years.

Table 1
Industry and Government Activities on PCBs

1966	PCB detected in the environment.
1971	Federal government establishes task force to coordinate government efforts investigating PCB liquids; FDA sets temporary PCB tolerance levels.
1972	Monsanto voluntarily restricts use of PCB liquid to electrical applications.
1972-3	EPA initiates new approach to toxic-pollutant-effluent standards.
1974	EPA develops criteria document: Clean water standards: 1 part per trillion maximum.
1975	Government task force reconvenes to consider EPA document; Michigan Department of Natural Resources meeting (attended by PCB users, chemical companies, EPA and states officials) to hear proposals on suitable replacement liquids for PCBs; EPA convenes national conference on PCBs to discuss and clarify feasibility of further steps to help reduce environmental contamination by PCBs.
1976	EPA meets with manufacturers using PCBs and equipment users to discuss technological, environmental, and cost aspects of possible substitutes.
July 1977	EPA will require zero discharge of PCBs which effectively bans their use.

It is apparent from these actions that there is a possibility that there will be a total ban on the use of PCBs in the United States in the near future. This situation is of major concern to manufacturers of power capacitors as well as major users of these electrical devices.

McGraw-Edison Recommendation

Over the past several years, McGraw-Edison has been engaged in a number of testing activities with over 30 liquids aimed at the development of a replacement dielectric fluid for power capacitors. One of these fluids, called Edisol[™] fluid by McGraw-Edison Company, was found to possess the required electrical, physical, and environmental properties specified in the testing program goals. Edisol fluid is a diphenyl oxide (DPO)-based fluid and was developed jointly with Dow Chemical Company.

HEALTH AND ENVIRONMENTAL EVALUATION

Dow Chemical Company conducted an extensive and comprehensive evaluation of the impact of Edisol fluid on the environment. Their evaluation was based on:

1. Persistence in the environment (biodegradability)
2. Toxicity in mammals.
3. Toxicity in fish.
4. Bioconcentration in fish.

Dow Chemical Company's health and environmental test procedures have evolved over the past 40 years. These procedures are based on: extensive experience in testing and marketing a wide variety of chemical products around the world; experience with governmental regulating agencies; participation on industrial standards committees; participation in academic considerations of questions of health and environmental impact.

PERSISTENCE IN THE ENVIRONMENT (BIODEGRADABILITY)

The rate of biodegradability depends on three major factors:

1. Type of water sample, i.e., sea water, river, etc.
2. Type of bacteria present, i.e., acclimated as found in chemical plant sewage or non-acclimated as found in city sewage.
3. Concentration of bacteria.

The major chemical component of Edisol fluid has shown to biodegrade at a rate 45 times faster than the major chemical component of PCB that does biodegrade. Figure 1 shows that the rate of biodegradation for the lower chlorinated fractions of PCB is extremely slow or nondetectable, which is attributed to the higher degree of chlorination of PCB. The rate of biodegradability of Edisol fluid is comparable to those of common industrial chemicals. Examples of these would be naphthalene moth balls and dichlorobenzene used to deodorize lavatories. Neither of these industrial chemicals is known to present significant environmental problems.

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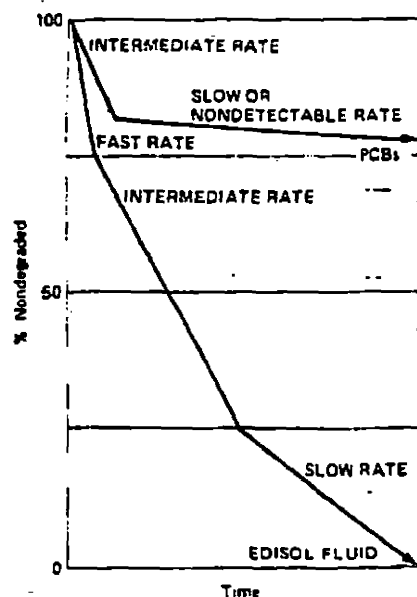


Figure 1

Guidelines available on hazardous substances such as PCBs require disposal of liquid wastes in high-temperature incinerators and solid wastes in specially designated dry landfills. The recommended disposal of Edisol fluid is by conventional incinerator or a properly designed landfill in accordance with state and local regulations. This recommendation is based on the overall interpretation of the health and environmental properties of Edisol fluid.

TOXICITY IN MAMMALS

Edisol fluid is less toxic to animals than capacitor-grade PCBs. Tests performed included toxicity from oral feeding, skin adsorption, and vapor inhalation, plus irritation to eyes and skin. Based on this information, minimal protection measures for workers handling chemicals are recommended in accordance with the Occupational Safety and Health Act of 1970. This recommendation applies to chemicals with the least potential handling hazards.

In tests regarding oral acute toxicity to mammals, results showed that the highest practical dosage of Edisol fluid did not kill rats. Evaluated during a 90-day dietary feeding study, no significant differences resulted in control rats and rats fed up to 15 mg/kg/day. In a 50-kg person (110 pounds), this dose would be equivalent to 750 mg/day or 1500 parts per million if consumed in a 1/2 kg (slightly more than a pound) daily portion of meat or fish. Accumulation studies show that Edisol fluid accumulates at least 200 times less in animal fat than capacitor-grade PCBs.

TOXICITY IN FISH

The toxicity of Edisol fluid to fish is significantly less than the toxicity of capacitor-grade PCBs. Table 2 shows the concentration of several common samples that is lethal to 50 percent of the fish (LC₅₀).

Table 2
Toxicity Classification for Fish

Toxicity	Example	LC ₅₀ (ppm)
Low	Ethyl alcohol	100
Moderate	Dry cleaning solvent	10-100
Toxic	Naphthalene (moth balls)	1-10
Extreme	DDT	1

Table 3 shows the results of the conventional static-water test on fish. In this test, fathead minnows were used to compare the toxicity of Edisol fluid with capacitor-grade PCB. Edisol fluid is moderately toxic to the fish while PCB is extremely toxic.

Table 3
Toxicity in Fish

Test	LC ₅₀ (mg/liter; ppm)	
	Edisol Fluid	PCB
96-hour static-water (EPA recommended procedure)	15	0.76

For a volumetric perspective of this contamination, the 0.76 mg/liter is equivalent to approximately 45 drops of PCB (from an eye dropper) in 1000 gallons of water. This is the amount that will kill 50 percent of the fish in 96 hours. In order to kill no fish in this period or time, the contaminated water would have to be diluted to 10,000 gallons. Further tests in this same series indicated an even greater difference in toxicity for longer exposures.

BIOCONCENTRATION IN FISH

Tests to evaluate chemical bioconcentration in rainbow trout showed that Edisol fluid has a low bioconcentration potential as opposed to a very high potential for capacitor-grade PCBs. It is this bioconcentration of PCBs in fish that is one of the most detrimental environmental effects and gives rise to the FDA limit of five parts per million in fish. For example, comparison of the two most significant components of Edisol fluid and PCB capacitor-grade fluids shows that the PCB bioconcentration potential is 30 times greater than that of Edisol fluid. Organic chemicals that have low water solubility are easily picked up and stored by fish, especially in the fat. This happens whether the chemicals are present in their food or in the water.

ENVIRONMENTAL EVALUATION SUMMARY

Table 4 summarizes the four environmental evaluation tests. Capacitor-grade PCB, transformer-grade mineral oil, and Edisol fluid are listed in a forced ranking based on their degree of environmental hazardness. To make a totally valid evaluation, these four tests must be considered collectively, not individually.

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Table 4
Relative Environmental Hazards

Chemical	Forced Ranking (1 to 5)			
	Biodegradability	Toxicity Mammal Fish	Bioconcentration	Total*
PCB	5	3	5	18
Mineral Oil	3 or 4	1	1	8 to 10
Edisol Fluid	3	1	2	8

*A total of 20 is the most hazardous ranking possible and 4 is the least hazardous ranking.

ELECTRICAL TEST PROGRAM

Since 1971, McGraw-Edison has been conducting an active electrical test program on both small and full-size capacitors using various liquid dielectrics.

Over 1000 small capacitor units were tested and over 400 of these were impregnated with Edisol. During this testing phase, units were subjected to voltage stresses at 125% to 200% of rated voltage and at temperatures ranging from -60C to +90C. Switching surge tests were performed at 150% of rated voltage for 5000 hours. During this period, 65,000 switching operations were performed at 250% rated stress.

No capacitor units failed.

During another phase of this research program which spanned a period of 2-1/2 years—100- and 200-kvar full-size capacitor units were stressed in excess of rated voltage.

1. 200-kvar units energized continuously for over one year at 130% of rated voltage.
2. 100-kvar units tested continuously for 2-1/2 years at 110% of rated voltage.
3. 100- and 200-kvar units energized intermittently for 2-1/2 years at up to 160% of rated voltage.
4. Over 20 million kvar-hours of operation logged.

And still no capacitor units failed.

Edisol fluid works satisfactorily in both paper/film and all-film capacitors. However, since it was evaluated primarily for use with an all-film dielectric as opposed to a paper/film dielectric, it is necessary to review the major electrical features of McGraw-Edison's all-film capacitor which are directly affected by the use of this new fluid.

1. Average dielectric losses under operating conditions were reduced from 0.5 (paper/film) to 0.2 (Edisol) watts per kvar. Watts losses will be reduced even further with Edisol fluid-insulated all-film capacitors than with PCB all-film capacitors (Figure 2).

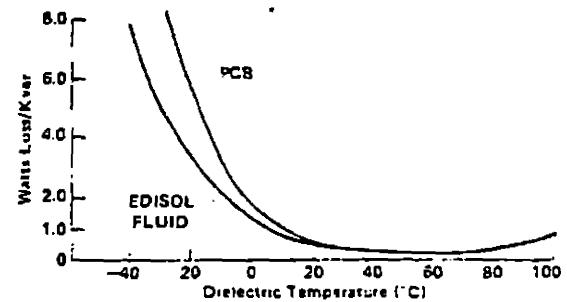


Figure 2

2. Low temperature rises during operation provide for greater kilovar stability.
3. Operating costs are reduced since less total system capacity is required plus a savings of kilowatt hours during operation.
4. Higher level of reliability due to the greater ratio of discharge inception voltage (DIV) to operating voltage thereby reducing the possibility of corona damage to the dielectric.
5. Greatly reduced tank rupture hazard due to the absence of paper in the dielectric.

DIV VERSUS TEMPERATURE

Figure 3 is a comparison of discharge inception voltage (DIV) versus temperature. Capacitor units impregnated with Edisol fluid show an appreciable advantage over those impregnated with PCB.

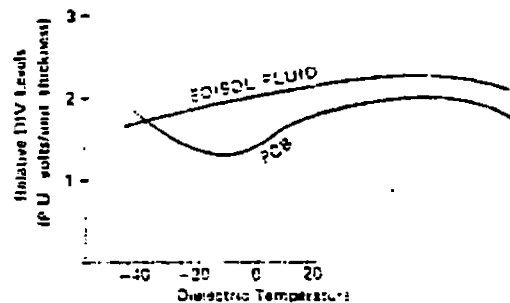


Figure 3

Figure 3 shows that, with Edisol fluid, there are no changes in DIV level over the normal temperature range. This means that the capacitor units will maintain a greater margin of safety between the operating voltage and the DIV and have better low temperature performance characteristics. This results in capacitor units with greater reliability and longer life. The results of these data show that, through the use of Edisol fluid as a dielectric, users can be assured of having capacitor units that will maintain or improve on the present available electrical ratings and physical sizes.

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FLAMMABILITY CHARACTERISTICS

It is desirable that capacitors not cause a fire hazard to the surrounding environment. This hazard exists only when a capacitor fails and its tank is ruptured. PCBs, due to their relative nonflammability, give protection against this hazard. When a wick such as paper or wood is present, however, a fire hazard could exist.

Edisol fluid is classified as flammable using a standard flammability test. By definition (Underwriters Laboratories), a nonflammable liquid will boil before the fire point is reached. Table 5 compares the flammability of three dielectric fluids. Note that Edisol fluid is not as great a fire hazard as transformer-type mineral oil.

Table 5
Flammability Characteristics

Dielectric Liquid	Flash Point (C)	Fire Point (C)
PCB	165	None to 315*
Edisol fluid	175	200
Mineral oil	155	170

*Boiled at 300 C.

Distribution transformers often operate at temperatures approaching the flash and fire points of the transformer oil, at which temperature almost any type of arc could produce a fire. Conversely, capacitors operate at temperatures well below flash or fire points of the dielectric fluid, such that a rather large arc would be required to produce a fire in the event of tank rupture. With the introduction of the all-film capacitor, paper has been removed from the active dielectric, virtually eliminating gassing, the primary cause of tank rupture. And, since the all-film capacitor operates at a lower temperature than paper or paper/film designs, the fire hazard is substantially reduced. These highly desirable characteristics are maintained with the use of the Edisol fluid, the result being a relatively safe capacitor.

TANK-RUPTURE CHARACTERISTICS

Figure 4 shows the comparison of the all-film Type S capacitor tank-rupture characteristic with that of the Type R paper/film design. There is a definite improvement in the safe zone of fusing that can be obtained by using all-film capacitors and also allows application of capacitors in higher fault-current areas. McGraw-Edison has found, through extensive testing, that virtually no internal gases are generated during an all-film capacitor failure mode. This is because of the absence of paper in the active all-film dielectric, and is in contrast to the gases which are generated during a paper/film capacitor failure mode—gases which would, in turn, rupture the tank.

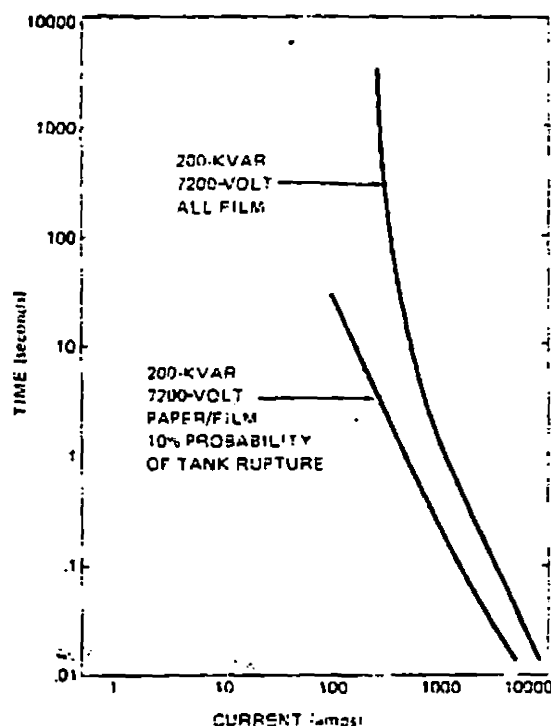


Figure 4

Comparison of all-film versus paper/film capacitor tank-rupture curves.

CONCLUSION

With Edisol fluid, McGraw-Edison brings to the capacitor industry a dielectrically suitable and environmentally acceptable alternative: capacitor-grade PCB. This new fluid is significantly less toxic and accumulative in fish and mammals and biodegrades at a much faster rate than PCB. All of the superior electrical characteristics of today's capacitors are maintained and, in some instances, improved. Physical size of the capacitors remains unchanged, completely compatible with present equipment. It is being made available at a reasonable evaluated price, especially when cost considerations for disposal of capacitors or accidental spills involving PCBs are made. The use of Edisol fluid in an all-film capacitor probably will produce no greater fire hazard than present-day PCB capacitors.

Clearly, Edisol fluid provides an excellent alternative to capacitor-grade PCB.

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MEETING WITH WESTINGHOUSE

SEPTEMBER 4, 1975

9:30 A.M.

A-303

PROPOSED AGENDA

- 1) Introductory Remarks - T. L. Gossage
- 2) Monsanto data on biodegradation and tissue residue studies MCS-1238.
- 3) Monsanto data on toxicological studies development capacitor dielectrics.
- 4) Westinghouse concern related to environmental impact of PCB replacement.
- 5) Industry status non-PCB capacitor dielectrics. (11 ... 100)
- 6) Status Westinghouse contingency planning.
- 7) Definition of future programs.
- 8) Summary.

Lunch at 12:30 P.M.

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MONSANTO TRIP

September 4, 1975

Westinghouse Personnel: R. Sawyer
K. Kelly
L. Shoaff
G. Mercier
L. Mandelcorn

Monsanto Personnel: Tom Gossage, Dir. Marketing
David Wood, Marketing Manager Dielectrics
Bill Moore, Marketing Representative
Dr. Ralph Munch, Distinguished Science Fellow
Jim Bryant, Senior Research Specialist
Dr. Jim Mieure, Group Leader Applied Science
Vic Saeger, Applied Science
Dr. George Levinskas, Medical Dept.
Representative

1238 Price and Availability

- A. Test quantities. We estimate a requirement of 500 gallons in drums over the next six months.

Price until 10/1/76 \$.71/lb. LTL Drums (8.4¢/gal. est.)

Price after 10/1/76 \$1.05/lb. TL Drums

\$1.07/lb. LTL Drums

Availability Two drums are on order. Will ship by 9/15/75.
Present capacity 2-400 gal./day.

- B. Production Quantities. We estimate 1 tank car/month (8,000 gal.) 1st year.
We estimate 2 tank cars/month (16,000 gal.) 2nd year.

To achieve production quantities in 6-9 months, temporary facilities would be required. These would be used until a new plant could be built in 18-24 months. (For 1-1½ years.)

Price first 1-1½ years of production: est. \$1.00/lb.-\$.85/lb.
In new plant: Objective price \$.65/lb. (at today's cos)

C. Monsanto's Market Position

Monsanto may terminate production of 1238. Their programs are structured on the basis that PCB will be discontinued. T. Gossage estimates that PCB will be eliminated through government edict, Monsanto decision, or utility industry decision, within six months to one year.

Monsanto is offering only 1238 as a substitute for Aroclor for the total capacitor industry. They will not offer either or both components of 1238 to the industry. Developmental costs of 1238 will be borne by Aroclor buyers. A 3¢/lb. increase across the board on Aroclor will be effective on

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on 10/1/76. Another large increase is predicted for 1977. (Settlements of law suits do not represent a portion of the 1016 cost. The amounts are "not significant".)

D. Monsanto's Decision to Invest

\$10,000,000 capital investment will be required to build a plant to produce 1238. This decision will hinge on:

- a) Continued favorable reports from the Medical Department.
- b) Acceptance by most of the industry of 1238.
They need a volume of 10-15 million lbs./year.
- c) An estimated life of 1238 of 10 years.

E. Affect on Transformer Aroclor

To achieve production within 6-9 months in temporary facilities, one of the two transformer fluids now used by Westinghouse, PDS 54201KA or 54201CM, would be discontinued.

A decision to discontinue should probably be made four months ahead of beginning production of 1238 (two months for physical changes, two months to announce to the trade).

The transformer divisions have not been advised of this possibility. Monsanto would like guidance from this division on how to go about this.

F. 1588

1588, which has been tested by R & D, will be withdrawn by Monsanto. At this time the price is raised to \$1.17/lb. LTL drums. Monsanto recommends that tests be discontinued.

G. Contracting for 1238

Monsanto expects to sell 1238 under the terms of their standard sales agreement. No indemnity agreement is planned. Such an agreement is considered undesirable since it would imply that the material is hazardous.

Because of frequent changes in railroad policy, Monsanto does not know whether or not a trip lease agreement will be required for rail shipment.

Monsanto intends to reserve the right to increase prices with 15 days written notice.

Handwritten signature
9/5/75

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Monsanto Meeting - September 4, 1975

1. Monsanto has been working with substitute fluid since 1969.
2. With pressure on PCB's, Monsanto sees very possible termination of continued use of PCB as far as Monsanto's continued supply of the material.
3. Dielectric Research Groups: Dielectrics (Munch & Bryant)
Analytical (Mieure, Seeger)
Medical (Levinskas)
4. Environmental Impact:

- a. Biodegradation
- b. Accumulation in animal tissue.

Biodegradation studies: Main emphasis in activated sludge tests.
Described details of tests.

Monsanto feels comfortable with MCS 1238 degradation because all components (hydrocarbon & sulfone portion) biodegrade even though the biodegradation rates are not significantly higher than for MCS 1016.

Accumulation studies on rats: 30 day feed + 75 day recovery period. Curve comparing 1242 and 1238 presented shows 1238 accumulation to be insignificant compared to 1242. 1016 accum. has also been measured and is about half that of 1242. Higher chlorinated types such as 1254 or 1260 accumulate more than 1242 and recovery is also much less.

5. Toxicity data (Levinskas)
Have started inhalation studies on one-month exposures on various animals and will check for liver and other organ damage. This will be complete at about the end of the year.
Acute toxicity (LD50 value) for 1238 discusses.
Skin irritation is less for 1238 than for 1016. Vapor inhalation is not strongly objectionable.
New materials 2 - stage review: (presently between 1st & 2nd stage)
(1) continued inhalation studies
(2) carcinogenic studies: now running pilot study. Complete study will be at end of 1977 or first of 1978. Reasonably confident that this material will not be carcinogenic.
(3) Acute fish toxicity to also be complete at end of 1977.

Disposal of 1238 would have to be handled similar to mineral oil. Could be incinerated as is motor oil or fuel oil.

6. Industry status of non-PCB cap. dielectric:
 - a) Monsanto has made decision to offer only 1238 to cap. industry. No other material is planned to be offered at this time, nor are the 1238 components to be offered separately.
 - b) Use of esters: reprocessing causes gradual degradation and also a hydrolysis problem exists.

7. Properties:

- a) auto ignition temp is 835°F (446°C)
 - b) refractive index: Monsanto will get.
 - c) Monsanto to check saleability of 1238 vs. temp. down to -40°C.
 - d) Will get absor. of PP and 1238.
 - e) Additives: Unox 4221 has been found to give better results than other epoxides on other hydrocarbons, but 1238 has only been tested with 4221 for ac capacitors. For dc capacitors, Monsanto has tested quinones and they enhance life on dc.
 - f) Electrical breakdown of fluid will generate no strong acid by-products (H₂S and H₂O plus some sulphorated compounds).
 - g) Life Test: Ballast capacitors impreg. by preheat for 2 hours in air oven 125°C, vacuum dry at 125°C, impreg. with de-gassed fluid heated to 95°C, cap. at 1-5μ before flooding at 125°C cap. temp. then vacuum is broken, cool to room temperature and then solder sealed. Accel. life test 90°C oven temperature, 1000 volts rms 60 Hertz on 2 sheets of .00066 (.9 den) 1238 units have run more than 1000 hours. Measure P.F. periodically (~each week).
8. No need for antioxidant with 1238 even for long time storage.
9. Avoid use of epoxy-type sealants for ballast type cap. cans.
DC S2348 (Dow Corning) - O.K.
3M EC1447 (Phenolic Type) - O.K.
10. Westinghouse to supply Monsanto with FPF units (75-50-75; for life tests (process 3 at a time) - need 100 to 200 units.

George E. Mercier

Westinghouse
Distribution Apparatus Division
Bloomington, Indiana



CAPACITOR DIELECTRICS DEVELOPMENT

B. D. McClain, Manager
Capacitor Unit Engineering

G. E. Mercier,
Senior Engineer
Capacitor Unit Engineering

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CAPACITOR DIELECTRICS DEVELOPMENT

R. D. McClain, Manager
Capacitor Unit Engineering

G. E. Mercier
Senior Engineer
Capacitor Unit Engineering

NPC00007295

1972 ELECTRIC UTILITY ENGINEERING CONFERENCE

April 9-21, 1972

SUBJECT NO. 41

CAPACITOR DIELECTRICS DEVELOPMENT

Robert D. McClain
Manager
Capacitor Unit Engineering

George E. Mercier
Senior Engineer
Capacitor Unit Engineering

INTRODUCTION

Electric utility application of capacitors will change during the 1970's because of the economics in using big capacitor units, and because of the environmental pressures to police the use and disposal of PCB's and to move distribution circuits underground.

THE SWITCH TO BIG CAPACITOR UNITS

Although 100 kvac and 150 kvac capacitors retained considerable popularity through 1971, use of 200 kvac, 300 kvac, and 400 kvac capacitors showed a marked increase. Improvements in polypropylene film, kraft paper, impregnating fluids and knowledge of processing constraints led to the introduction of the single-phase 200 kvac and the three-phase 300 kvac capacitor in 1970, followed by the three-phase 400 kvac capacitor in 1971. (See Figure 1, 2, and 3.) Field experience with the first increment of 3,000,000 kvac of three-phase units in Tri-Vac equipments vindicated the design change: failure rates were as low as for the smaller, single-phase capacitor equipments, and users benefited from lower costs.

Additional improvements in the techniques of applying the Dyna-Vac dielectric system to capacitor design have led to big unit designs with losses held to even lower levels and designed with overload capability sufficient for successful application in very small substation banks. A comparison between minimum bank sizes that may be constructed using standard 100 kvac capacitors (with rated voltages from 2400 volts to 14,400 volts and capable of sustained operation at 110% of rated voltage), and minimum bank sizes that may be constructed with 200 kvac capacitors (with rated voltages from 4160 to 19,920 volts and capable of sustained operation at 120% of rated voltage) shows the way to potential savings from reduced numbers of fuses, smaller mounting frames, reduced installation costs, reduced real estate requirements, and lower cost per kvac for the capacitor units. See Table I.

Minimum bank sizes have been established on the basis that the bank will remain in service with one blown fuse in any (or in each) parallel connected group of capacitor units. In the case of 100 kvac units, the resultant

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overvoltage permitted will be 10% of rated voltage, maximum. In the case of 200 kvac capacitors, the permitted overvoltage will be 20% of rated voltage, or less. Life expectancy, in both cases, exceeds normal commercial stated expectancies of 20 - 30 years. Only wye and grounded-wye applications have been considered. (Delta-connected banks are omitted.)

Table I shows the range of line-to-line voltages that may be served by increasing numbers of series-connected groups per phase, and compares the minimum bank rating (kvac) that may be achieved in wye and in grounded-wye applications, using 100 kvac capacitors (as stated above) and 200 kvac capacitors. Plotting this information as shown on Figure 4 reveals the broad opportunity for savings by use of big units in small banks.

Failure rates for 200 kvac capacitors, for the illustration above, may be taken to be the same as for the 100 kvac capacitors. Assuming a very pessimistic rate of 1/2% per year (a rate at least three times greater than recent experience), the probability that any given 200 kvac capacitor will experience an exposure to overvoltage due to fuse operation during the course of a year, has been plotted on Figure 5.

Because 200 kvac capacitors built for the application cited above must have very low operating losses, the user reaps another benefit in terms of better operating efficiency.

In summary, the move to big capacitors can be seen to extend over the full range of capacitor bank sizes because of greater overload capability, greater range of available voltage ratings, low failure rates and low risks of exposure. Savings in first costs and operating costs result.

USE AND DISPOSAL OF PCB'S

Discovery in the 1960's that polychlorinated biphenyls (termed "askarels" and used extensively as insulating fluids in capacitors and transformers) tended to persist in the environment, and might be factors in environmental pollution, led to a widespread effort to bring them under control. Monsanto, U.S. supplier of PCB's, has stopped sales of the material to all users, essentially, save manufacturers of transformers and capacitors. Because no suitable replacement fluid has been found with the properties of non-flammability, wide operating temperature range, excellent characteristics in the face of internal ionization, desirable dielectric constant and compatibility with other dielectric materials, and because use of PCB's is restricted to closed containers, use in capacitors and transformers is continuing.

In September, 1971, all askarel delivered to U.S. capacitor manufacturers was changed by Monsanto to be Aroclor 1216, a mix of lower-chlorinated PCB homologues and isomers deemed more biodegradable and potentially less persistent in the environment than previous askarels, in the event of their inadvertent loss. This change provided no relief from the need to exercise caution in the use and disposal of PCB's. Manufacturers have taken strong

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measures to assure against loss of PCB's to the open environment: surplus waste fluids are returned to Monsanto for special incineration at high temperature in equipment with an exhaust-gas scrubber. Saturated solids are disposed of in suitable landfills, or are held in containers for future incineration.

Standardized procedures are being developed by ANSI C-107, a national standards committee concerned with the methods for use and disposal of PCB's. Working groups, established by the principal committee, are actively producing the first drafts of procedures for use by manufacturers, users, and scrap dealers involved in the problem.

CAPACITORS FOR UNDERGROUND DISTRIBUTION

Vault application of low voltage capacitors on concentrated, urban networks has been a common practice. As suburban and rural load growth has been accompanied by increasing pressure to place the distribution circuits underground, several approaches to the capacitor installation problem have been made:

- Low profile, pad-mounted, housed equipment.
- Submersible cluster equipment for installation in subsurface, 36 inch diameter vault.
- Direct burial.

Of these, direct burial commands greatest interest at this time. Introduction of Dyna-Vac capacitors with exceedingly low losses offered the opportunity for re-investigating the possibility of direct burial on the basis that derating factors previously encountered might be avoided.

In 1969 Westinghouse joined a customer's evaluation of direct burial, supplying capacitors with a special protective finish. Connection to the terminals was through removable, submersible URD terminals. Thermocouples connected to the capacitors at top, center and on the center of one side, and thermocouples located in the surrounding earth provided thermal performance data.

The capacitors were placed in line in a trench 50 inches deep with separation of 36 inches between one capacitor and the next in line, see Figure 6. Backfill for three units consisted of tamped pea gravel to an extent of approximately 4 inches on each side of each unit. The other three units were backfilled with native soil from which large stones and major debris was removed and then well packed and tamped, see Figure 6.

In a subsequent installation, units were installed with a special finish applied by the utility, in a trench approximately 60 inches deep.

In both installations, the capacitors were switched "on" from 8:00 a.m. to 4:00 p.m. daily, for at least one season. Then banks were operated 12 hours

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"on", 12 hours "off" for one season; and finally they were placed on continuous operating duty.

Although the test program is not complete, status of the program has been reported. Continuous operation of 150 kvac capacitor units produced no case temperatures above 43°C with ambient soil temperatures of 25°C. (A limiting case temperature was considered to be 70°C for the designs under test.)

Because the field tests involved test sites receiving 30 inches of rainfall or more, per year, a comparable test program was initiated at the Distribution Apparatus Division, where moisture conditions could be controlled and the ambient kept close to 25°C, year-around. Again, these tests are incomplete, but tend to support the conclusions being reached by those conducting the field test cited above. Surprisingly, capacitors backfilled with pea gravel have tended to run at higher temperatures under the dry conditions of the laboratory test, than have capacitors backfilled with native clay.

In summary, tests conducted so far support the feasibility of direct burial of Dyna-Vac capacitors, without requiring serious derating.

CONCLUSION

Dyna-Vac capacitor designs can meet the need for economical capacitor installations in the 1970's, and the versatility of the dielectric system will support any move to underground distribution. Any threat of environmental contamination posed by the new Arcolor 1016 can be controlled by careful observance of the procedures for use and disposal of PCB's now being prepared by ANSI C-107.

REFERENCES

1. "Direct-Buried Capacitor Tests Show Promise", A. D. Gorski, Transmission and Distribution, pp. 30-33 (November 1971).

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NPC00007299

769938

POWER CAPACITORS - A MANUFACTURING OUTLOOK

**R. D. McClain
Westinghouse Electric Corporation
Bloomington, Indiana**

**Presented to the P.C.E.A. Engineering and
San Francisco, California**

March 18, 1976

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POWER CAPACITORS - A MANUFACTURING OUTLOOK

R. D. McClain
Westinghouse Electric Corporation

Over the past 50 years, the American capacitor industry has more than matched the technological progress of almost any other comparable endeavor. In constant dollars, the overall cost trend, dollars-per-kva, has been downward. Wide ranges in ratings have been made available and containers have diminished in size and weight. Along the way, flammability was brought under control, along with a host of materials contamination problems. Energy losses were drastically reduced.

If anything, the recent rate of technical change has accelerated rather than diminished. "Progress" has posed serious problems at times when technology introduced the capability to produce, with existing facilities, at a rate substantially greater than the growth of demand. During the past 5 years, pressures have been compounded by growing concern over the possible adverse effects of persistence of the dielectric fluid, polychlorinated biphenyl, in the environment. Manufacturers have responded by use of a more biodegradable fluid and by working, strenuously, toward control of PCB's in manufacturing plant water effluents to extremely low levels. In the midst of this, there appears an increasing concern over what is considered to be an excessive failure rate for capacitors of manufacture during the past several years. We address this last concern today.

The "industry problem" - if indeed there is one (as opposed to several concurrent, individual problems) -- is not yet clearly defined, nor localized as to total magnitude, kind of application, design, user(s),

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rating(s), vintage, or manufacturer(s). An effort in this direction is being launched by the IEEE Capacitor Subcommittee.

Some potential factors in the expressed concerns are --

- 1) A change in fluid, from Aroclor 1242 to Aroclor 1016, in 1971.
- 2) A change in the polypropylene resin for capacitor grade film in 1973.
- 3) Phase out of manufacture of insulating pressboard by the major source in 1974.
- 4) Changes in ownership and possible changes in operation by the companies supplying capacitor paper to the industry.
- 5) Appearance of new capacitor designs with somewhat higher voltage between winding electrodes.
- 6) Pressure by the E.P.A. and other agencies to achieve stringently low levels of PCB effluent, resulting in major changes in manufacturing processes and procedures.

With all due respect, and in view of what is known to date, almost none of these appear to be the cause for what is reported to be happening:

- a) The switch to Aroclor 1016 was well investigated and substantiated before production. At most, the change, from a dielectric standpoint, was minor, involving elimination of the small fraction of higher chlorinated (less biodegradable) compounds from Aroclor 1242. Large numbers of capacitors are in successful operation with Aroclor 1016.
- b) Essentially the same can be said of the improvement in the base resin for the film: removal of trace contaminants enhanced performance.

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- c) Alternative sources for pressboard, or use of alternative materials, posed no identifiable problem.
- d) Capacitor grade paper continues to meet the stringent requirements developed over the years, and suppliers have acted responsibly in completely checking out results of minor modifications of process.
- e) Design changes are always most suspect--and, for that reason, are always most carefully checked out. Proof of the adequacy of such investigations lies in broad, large scale, successful field operation, particularly for designs of highest stress and highest voltage, foil-to-foil.
- f) Response of the several manufacturers to E.P.A. pressures to reduce PCB plant effluent cannot be measured, as this is considered proprietary information. It is suggested that any change which produced capacitors with inherently different individual histories could overshadow misplaced trust in tests based on sampling procedures or based on advance "type" tests.

Two actions by the
reports of high failure rate

- 1) IEEE survey of experience (mentioned above)
- 2) Review of industry standard (IEEE - ANSI)

Comments in these two areas are offered:

- a) To be effective in identifying "a" problem, or "the" problem, details of field performance and application surrounding an occasion of high failure rate must be supplied to the manufacturer as soon as possible: type of application,

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protection, and attendant transient phenomena are valuable data. Complete nameplate data from each failed unit makes it possible to match performance data to design, manufacturing records, and even to source materials records. When data are available to the manufacturer from more than one user--and the experiences are comparable, or entirely different, the time frame can be identified and the list of variables to be researched narrowed to only one or two, for most cases.

b) Standards now contain the essential requirements for verification and application. However, a consensus has not been reached in several important areas. Perhaps the difficulty in achieving consensus can be given by three illustrations:

- 1) Accelerated life testing by application of high temperature and high voltage, within discrete limits, has produced several procedures and accompanying analyses with their various devotees. Consider the consternation when such tests predict very long life (type test), but production units fail at low temperatures and voltages within a few months. (An incident occurred, abroad, and the ensuing investigation resulted in a simple, delicate adjustment in chemistry.)
- 2) Great strides in detecting internal partial discharges have been made. But full sized capacitors have been reported with failures showing all the earmarks of partial discharge damage, when none could be detected beforehand. Manufacturing controls--rather than direct test--was the only assurance of quality.
- 3) Case rupture probability test methods are not standardized.

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Preparation of test samples inevitably leads to differences from field conditions. Another important aspect of field performance in this area lies with different application practices in the industry: Using even the most daring (optimistic) curves it is difficult -- if possible -- to properly coordinate group fuses for large distribution banks having isolated neutrals.

Where does all this leave the perplexed user who has both a continuing need to apply leading vars to his system and who has a recent history of bad capacitor performance?

- 1) Gather data on failures, in detail, and feed the information back to the manufacturer. There is strong reason to believe the failures will be found to be specific to a single situation -- not part of an "industry problem". Fast feedback shortens the time to make a fix.
- 2) Do not fall prey to easy generalizations. Examples:
 - a) 1500 volts, foil-to-foil is said to be better than 2400 volts foil-to-foil. Check this against the extensive history of successful operation for ...
 - b) High d.c. overpotential test ($6.25V_{\text{rated}}$) on capacitor gives better performance than ($4.3V_{\text{rated}}$) test. While the higher test gives greater dielectric strength margin and may be desirable if restriking breakers, etc., are involved, actual field failures will not be reduced if the basic problem is factory processing, or a deficient chemistry. Either test level has limited effectiveness in ferreting out defects of very small area in only one of the two sheets of film between foils.

The overall objectives appear to be to get reliable performance while continuing to be able to supply vars at low cost. These objectives can be served when the user knows his requirements and specifies to them, when field performance data is fed back, when tests relate both to manufacturing procedure and to operational requirements, and when judgements are based on a broad base of information.

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PLANT FACT SHEET ON PCB'S THAT ARE COMMON KNOWLEDGE IN OUR PLANT

Our plant uses PCB liquid in the manufacture of capacitors. It is called Inerteen because it does not burn.

Capacitors are an electrical device that store electric energy.

The PCB liquid is in a sealed or closed container.

All residue, wastes (even the sawdust on the floor) and solids that have PCB on or in them are shipped out of Indiana to two special areas that are equipped to handle PCB disposal.

The sewage leaving this plant contains less than one part per million of PCB. Over 90% of PCB's used for capacitors are biodegradable. There is no disgrace or problem with W actions. However, since PCB are and their effect on the environment are the subject of political discussions and technical debate among specialized scientists, it is a difficult subject to understand completely. Mr. Britain and Mr. McClain are in a position to get complete and accurate facts. All requests for information should be channeled to Mr. Britain's office. This will avoid rumor and conflicting reports.

We have no knowledge of any health or environmental problems caused by the use of PCB's in W capacitors.

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1 1 2 CIGRE paper
obtained for review
CIGRE Not to be released until
May 1976

International Conference on Large High Voltage Electric Systems

112, boulevard Haussmann - 75008 Paris

1976 Session -

August

NOVEL SINGLE AND MIXED LIQUIDS FOR
HIGH VOLTAGE DIELECTRICS

by

K. W. PLESSNER and E. H. REYNOLDS

(Paper presented in the name of Study Committee No. 15,
Insulating Materials)

(U.K.)

SUMMARY

This paper reviews the recent changes in some material supply conditions and the constraints arising from ecological considerations to their effects upon the existing range of liquids for high voltage equipment.

Over many decades, liquids for the impregnation of high voltage dielectrics of transformers, capacitors and cables have followed well defined lines of development leading to the establishment of International Codes of Practice and Specifications. Chlorinated biphenyls have been very successfully developed for transformers and capacitors, while natural mineral oils

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and certain synthetic hydrocarbons have been evolved to very high standards of performance and reliability for all types of electrical equipment.

Two recent changes have altered some of the accepted criteria on which choice of liquids can be based. Firstly, the discovery that polychlorobiphenyls were causing cumulative and persistent contamination of the environment, giving rise to fears of a toxic hazard. Secondly, the dislocation in the world supply of familiar crude petroleum oils, led to unavailability of certain types traditionally produced by rigorously controlled processes for standardised insulating hydrocarbons. Increased research has been stimulated into the evaluation or evolution of alternatives for both polychlorobiphenyls, and natural insulating oils, especially of naphthenic character.

The search for technologically and ecologically acceptable alternatives to PCB's has posed the greater problems, more so for power capacitors requiring liquids of permittivities in the range of 3-10, than for transformers, where hydrocarbons could be re-adopted. Thus the stimuli provided by the foregoing constraints have promoted re-assessment of all classes of liquids, carbons, natural and synthetic esters and mixtures of stabilisers and diluents, the provision of non-toxic, biodegradable hydrocarbons and a reappraisal of the practicability and range of wider applications of polysiloxanes and fluorocarbons for all types of High Voltage equipment.

Liquids, Dielectric, Novel forms for Cables, Capacitors, Transformers.
Switchgear.

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REPORT

I. GENERAL INTRODUCTORY SURVEY

In evolving more efficient, economic and compact High Voltage equipment, great importance has to be placed upon ensuring long, fault-free service, usually between 20-40 years.

The establishment of existing designs has not only been based upon lengthy research and development in the laboratory, but also upon extensive field trials and operations with continuous feed-back of data. A change in even a minor material or component cannot be assumed to be satisfactory without full and rigorous assessment. Changes, therefore, in a major component, such as the impregnating fluid, carry onerous liabilities, much more so than in most other heavy industries. Despite the title of this paper, which may be slightly inappropriate, novelty in insulating liquids may have vanished by the time bulk commercial utilisation is realised. Nevertheless, the drive for novelty must persist, though it is notable that over the last few years two unusual constraints have emerged to stimulate research. They have arisen from two entirely disconnected sources, but their repercussions is timely, if not crucial to the maintenance and improvement of existing or future standards of design, operation and reliability.

First, the widespread reliance upon the use of polychlorobiphenyls ("Askarels" or PCB's) in transformers and capacitors as non-inflammable saturants for paper-based insulation, first introduced in the middle 1930's, and more recently in the 1960's for mixed paper/plastic film dielectrics for

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H.V. unit capacitors, has been questioned on ecological and environmental grounds. This situation was first revealed in 1966 by Jensen, who published analytical results showing that chlorinated biphenyls could be detected in fish and birds and in certain natural waters. Other studies have produced similar evidence, and recently in the official Journal of the European Community⁽¹⁾ it was stated that, recognising the risks to the environment of continued dispersal of PCB's in the lithosphere special legislation constraining their use might have to be introduced.

Since polychlorobiphenyls are molecules of high chemical stability (one reason why they make excellent dielectric liquids), having a mild similarity in this respect with certain insecticides (notably DDT) it has been tacitly concluded that they were equally objectionable towards the environment. Greater control of the manufacture, use, handling and disposal of waste PCB's has very largely eliminated risks derived from their use in H.V. Electrical Equipment, and if the provisions incorporated in the CIGRE "Code of Practice"⁽²⁾ are observed, future hazards would be negligible.

Nevertheless, the publication of such information amid much ill-informed speculation has forced a closer examination of the possibility of utilising alternative liquids, which can give equivalent performance in all respects, but which cannot become a persistent source of pollution if dispersed in the environment, nor attract condemnation as having specific toxic effects detrimental to man.

Secondly, the recent interruption in the free availability of some natural mineral oils, resulting in certain cases in the complete removal

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from the market of specific types of crude oil, has stimulated research into and evaluation of hydrocarbons, both natural and synthetic, having an internal balance of molecular species very different from that which has been customary, and on which continuity of manufacture and standardisation of performance of H. V. plant has been based. International Publications such as "IEC No. 422"^(a) are typical collections of the accumulated technical experience and knowledge which is essentially based upon deriving complex products for long service duty and also upon the continuing availability of a specific class of raw material of well defined composition, refined and incorporated into the final artefact by an established, repetitive series of production processes. Alternative products, of competitive price and similar technical reliability, meeting the same specifications and tests, despite radically different chemical composition, may be difficult and expensive to establish, while failing to preserve technical continuity.

The changes reviewed in this paper mostly affect the availability and choice of liquids for impregnating, cables, capacitors and transformers. However, since a given liquid depending upon its range of properties might be used in one or more of these classes of H. V. apparatus, it appears to be more appropriate to consider new possibilities or alternatives under the generic chemical classifications, and to summarise each class with an indication of where any changes may most successfully be made, in regard to their employment in any particular type of high voltage apparatus. It is, of course, well understood that, having indicated the possible applications for a new single liquid or mixture, extensive compatibility trials would have to be made, encompassing all the other constructional and insulating materials.

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II. GENERAL TECHNICAL REQUIREMENTS

All dielectric liquids for high voltage equipment should display certain characteristics to an advanced degree, in addition to high electric strength, high electrical resistivity and very low 50 Hz loss tangent. Those other physical and chemical properties, common to all applications, may be summarised as follows:-

Low cost and easy availability

High purity (or easily purified)

Stability to oxidation and hydrolysis

High Flash point

Low pour point

Resistance to discharges

Hydrogen (Gas) absorbing under discharges

Non-inflammable

Low toxicity and easy disposal.

Not many liquids currently in use meet all the requirements to the full. It is evident that all hydrocarbons, while fulfilling tests, comply with the remainder, except for non-inflammability. In regard to this property the Askarels (or Polychlorobiphenyls) probably come closest to the ideal dielectric liquid. Like all halogenated hydrocarbons, they have high flash points and auto-ignition temperatures, and readily meet the other (especially electrical) requirements, save for their tendency to form hydrochloric acid under electrical discharges, despite constitutional aromatic unsaturation and gas absorption capability. In fact, it could briefly be

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observed that if the flammability of the hydrocarbons could be decreased without detriment to their electrical properties, while maintaining stability towards oxidation and hydrolysis, eminently suitable uses in transformers and cables would ensue. On the other hand, for power capacitors, if the marked biological persistence of the polychlorobiphenyls could be reduced, without impairing chemical stability and non-inflammability, while preserving all the other properties especially electrical, much benefit would follow.

The foregoing considerations broadly determine the pattern of research into and evolution of new dielectric liquids in respect of primary characteristics. It is just as important to preserve or improve the safety of electrical operations and reduce any fire hazard, as it is to evolve liquids of equal reliability of performance coupled with reduced disposal and quasi-toxic problems.

The greatest research and development activity has so far been concentrated upon the provision of non-halogenated, non-toxic liquids to replace Askarels, especially for power capacitors. Thus there have been numerous novel liquids proposed in the higher permittivity range which have already seen limited commercial service (cf. Section V).

III. HYDROCARBONS

Although there has been an increasing tendency to replace natural hydrocarbon insulating oils by synthetic products, a considerable proportion (varying from one country to another) of the natural product is still very widely used. The principal change in the natural crude oils available has

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been the reduction in supply of those of essentially naphthenic character, with associated aromaticity and asphaltenes, to the more plentiful paraffinic categories often of high wax content, low unsaturates and high sulphur containing compounds.

The derivation of insulating oils for transformer and cable applications from sweet naphthenic based crudes (such as Peruvian or Ecuadorian), having sufficient natural oxidation stability combined with low pour points (for low temperature outdoor applications) and good gas (hydrogen) absorption characteristics under internal discharges, was a supreme example of the refining art. Their replacement at economically and technically acceptable levels by paraffinic oils or synthetics has presented different problems concerned with securing comparable oxidation resistance (especially in the presence of copper) with positive gas absorption and low pour points. But for the cost factor the synthetics, such as alkyl benzenes or polybutenes, suitably compounded as required, may have a more promising future. Examination of recent reported data is instructive.

(1) Natural Mineral Oils

The range of hydrocarbon liquids available for capacitors, transformers and switchgear has been extensively reviewed in the past⁽¹⁾⁽²⁾⁽³⁾ and there is little to add except to direct attention to the comparison of individual properties with selected synthetics as given in Table I. The virtual removal of traditional naphthenic crudes from the world market, has forced refiners to meet existing specifications from paraffinic

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crudes, which pose three specific difficulties:-

- (a) Cheap removal of wax to achieve low pour points.
- (b) Introduction of sufficient unsaturated molecules to provide "gas absorption".
- (c) Preservation of adequate oxidation stability, without recourse to the use of added anti-oxidants.

The success with which suitable grades of refined oils have been provided, especially for H. V. transformers, varies from one country to another. Some users seem content to rely upon mineral oil derivatives to existing specifications; others apparently perturbed by the hiatus in continuity of source and composition, see the perpetuation of this uncertainty in the future and would seek to replace all petroleum-based mineral oils by synthetics, in order to re-establish complete technical control over the origin, manufacture and operation of the newer materials.

(ii) Synthetics

Dodecyl benzene⁽¹⁾ was first reported as an oil-soluble cable impregnant with several advantages claimed over the available petroleum oils. This was followed by the use of nonylbenzene⁽²⁾ of lower viscosity, giving improved oil flow over longer lengths of cable. Some attention is now being

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given to these hydrocarbons because of their excellent hydrogen absorption properties up to 120°C, and higher solubility of water, for use in large transformers, though it has been reported that these two alkyl benzenes, while meeting the oxidation stability test in the usual cable oil specifications, do not do so when subjected to the more onerous test required for transformer oil. Perhaps this offers a chance to develop antioxidants for alkyl benzenes, since successful operational improvements have been reported by the use of DBPC et alia (ditertiary butyl para-cresol) with many hydrocarbon dielectric liquids.

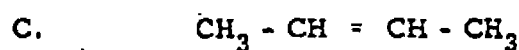
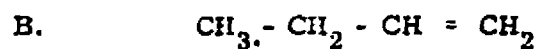
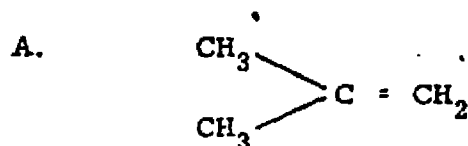
Near relatives of the alkyl benzenes, developed specially for capacitors and transformers are diaryl alkane (Table I) and alkyl naphthalene. The former has a comparatively low permittivity for this application ($k = 2.5$), but its electrical properties are otherwise excellent, it displays good gas absorption and oxidation resistance and a toxicity no greater than the general level associated with mineral insulating oils. Naturally it is inflammable, with a flash point of 164°C (compared with values of 110°C for 3 cS cable oil, 135°C for a standard naphthenic transformer oil (BSS. 143 1972) and 154°C for trichlorodiphenyl for capacitors. This liquid is reported as being used in commercial capacitors in Japan in place of PCB, for the impregnation of mixed paper/polymer film dielectrics.

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Polybutenes are now widely used and are derived from the polymerisation of olefines from natural gases or cracked petroleum fractions, consisting essentially of iso-butenes (A), with small quantities of normal butenes (B and C) and some iso-paraffins.



They are available as water white liquids having a very wide range of viscosities, with molecular weights ranging from: 325 to 2500. They have excellent electrical properties, low permittivities (2.1) and due to the residual olefinic unsaturation, are normally found to be gas absorbing in the usual test apparatus over the temperature range of 40 to 130°C. They have two minor disadvantages; first they are as inflammable as other hydrocarbons, secondly; owing to their rather low flash points their use is restricted to those grades of low molecular weights which yield viscosities over 40 cS. The latter limits their usefulness to pipe-type cables, and as additives for mineral-based oil-filled cable oil.⁽⁹⁾ Applications to capacitors are not attractive due to low permittivity, and used alone they do not seem to have excited the interest

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of transformer manufacturers. However, it is conceivable that they could be used with alkyl benzenes (v.i.) to produce lower viscosity mixtures of acceptable flash point and oxidation stability, where their excellent electrical properties could be valuable.

TABLE I

Property Hydrocarbon	Specific Gravity 25°C	Pour Point	Flash Point °C	Viscosity cS, 20°C	Permittivity 25°C	Loss Tangent 25°C	Resistivity 25°C Ω cm	Comments
Hollow Core Cable Oil	0.855	-45	105	8.0	2.2	0.0001	2.5×10^{14}	Naphthenic Oil Gas absorbing.
Capacitor Oil	0.866	-	-	32.0	2.22	0.00001	$> 10^{16}$	Paraffinic Oil Gas evolving.
Transformer Oil	0.878	-40	135	29.0	2.23	0.00001	8.5×10^{15}	Naphthenic Oil
Dodecylbenzene JN	0.870	-60	130	8.1	2.23	0.00013	4.3×10^{15}	'Hard' type Detergent base
Nonylbenzene	0.867	<-58	127	4.9	2.21	0.0001	-	
Polybutene 0/3A	-	-	107	3.7	2.1 (90°C)	0.0005	5.4×10^{12}	
Diaryl Alkane	0.988	-47.5	154	6.5 (30°C)	2.32 (80°C)	0.0003 (80°C)	3.9×10^{15} (80°C)	Proprietary. See Ref. (9)
Oil Blend with Alkyl Benzene	0.879	-32.5	136	11.2 (30°C)	2.22 (80°C)	0.0002 (80°C)	1.7×10^{15} (60°C)	Proprietary formula. See Ref. (9).

NOTE: All the Hydrocarbons in this Table are inflammable

(3) Mixed Petroleum and Synthetic Hydrocarbons

Though this kind of mixture has been known for many years, the longest usage has been in the form of semi-solid impregnants for non-draining paper cables, where synthetic waxes (Fischer Tropsch) have been used with micro-crystalline waxes dissolved in high viscosity

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mineral oils to produce compounds with drop points in the range of 85-105°C. Other attempts to produce mixed liquids have been less evident and persistent, but paraffinic type mineral oils with synthetic olefines (octadecane) have been used in polymer film capacitors and polybutenes with mineral oil for low viscosity (6 cS at 20°C) for oil-filled cable oils.⁽⁶⁾

Recently, a blend of mineral insulating oil with alkyl benzene^(a) has been developed as a universal impregnant for paper high voltage dielectrics, and is recommended as suitable for capacitors, transformers, cables, switchgear and reactors. Though the permittivity at 2.22 is rather low for the capacitor application, the high specific resistivity and low loss tangent make it suitable for all the other applications. The flash point of 136°C is of the usual value for hydrocarbon insulating liquids, but lower than for polychlorobiphenyls, hence it may be said to carry a case if used in High Voltage Transformers.

The assessment of the seriousness of fire in High Voltage equipment, especially in enclosed buildings or cable ducts, has led to the widespread use of PCB's in distribution transformers. A recent development shows possibilities of improving the fire resistance and inflammability of cables especially, by replacing the conventional

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low viscosity mineral oil with either a polychlorobiphenyl (di or tri-chloro)^(c) or other suitably halogenated hydrocarbon mixtures using trichlorobenzene.

An alternative approach to the reduction of inflammability of hydrocarbon oils (whether natural or synthetic) was suggested by the work of Nettleton, by adding small quantities by volume (up to 20%) of dielectrically acceptable halogenated liquids. This could be of greater interest to manufacturers of capacitors, transformers and switchgear than to cables. The latter have to be jointed in the field with free liquid constantly flowing in the welding zone and decomposition of halogenated liquids or additives would pose a serious health hazard, as would the use of PCB's or their mixture with TCB described above. There also remains the latent objections of toxicity and environmental pollution hazards already levelled at the polychlorobiphenyls as a whole, especially in field installation activities.

IV. POLYCHLOROBIPHENYLS ("ASKARLITE")

These chlorinated aromatic hydrocarbon liquids have reached a high level of reliability and economy as impregnants for paper and paper/polymer film insulation for transformers and unit capacitors. Since they consist of mixtures of about 70-80 different isomers, the bulk properties are

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necessarily average values, as are the nominal chlorine contents. For transformers, largely to secure low pour points, mixtures of the PCB with trichlorobenzene are preferred, while for most capacitors, the trichlorodiphenyl is widely used.

In addition to the excellent electrical properties and higher permittivities displayed by this class of fluids compared with hydrocarbons, their use has enabled a new level of safety in operation to be achieved, especially high chemical stability, resistance to oxidation and hydrolysis and particularly non-inflammability. The latter is a safety feature which is frequently taken for granted, since absence of serious fires in high voltage equipment sited in buildings becomes to be regarded as an inevitability rather than a valuable "sine qua non" to be preserved. Table II gives a summary of the properties of PCB's against which to judge the alternatives.

TABLE II

PCB Fluids Properties	Transformer Askarel	Trichloro- biphenyl *	Capacitor Askarel *	Pentachloro- diphenyl's	
Pour Point °C	-32° max.	-14° max.	-	13 max.	
Density 55°C	1.357 20°C	1.337/47	1.363 25°C	1.434	
Viscosity cS	29 25°C	7.9 55°C	14.9 39°C	577	
Flash Point °C	None to D. pt.	154 min.	160°	204 min.	
Thermal stability ppm	-	0.4 max.			ASTM D 1163
Loss tangent (100°C)	-	0.01 max.	0.3225	3.930 max.	
Permittivity (100°C)	-	4.8/5.0	5.9 25°C	4.15/35	
Resistivity (100°C) Ohm-cm	35×10^{12}	1.0×10^{12}	1.5×10^{12}	1.0×10^{12}	Minimum values.
Auto-ignition T°C	-	-	640°	-	

NOTES:

- * This is the well known variety with 42% chlorine.
- * This contains 42% chlorine with reduced pentachloro derivatives

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The chlorinated hydrocarbons as a whole tend to be very stable chemically, even at elevated temperatures, and this has led to their use in many applications outside the High Voltage field, often in consumer goods such as plasticisers for plastics, printing inks, certain varnishes, and especially in heat transfer fluids. The latter application is closest to the electrical use, since it particularly takes advantage of their better thermal conductivity ~~(which is approximately double that of hydrocarbon oils)~~.

The PCB's naturally possess some minor disadvantages, mainly that they are decomposed to give hydrochloric acid under electrical discharges, and are not only persistent but biostable under normal environmental conditions. The latter only poses a problem to the electrical engineer if the handling and disposal of obsolete equipment is improperly conducted, though this need not occur.⁽²⁾ It is perhaps relevant to note that in PCB's, the higher the chlorine content (pentachloro and above) the more stable and persistent are the molecules. The lower chlorine contents (dichlorodiphenyl) are less stable and less persistent, therefore more reactive and likely to be rather more objectionable, besides showing lower fire resistance.

During the last few years, manufacturers of PCB's have not only conducted a great deal of research into the discovery of adequate alternatives (See Section V), but have also attempted to produce bio-degradable chlorinated derivatives, which will display the same electrical performance, resistance to oxidation and hydrolysis while preserving the same degree of non-inflammability. Much progress has been made, but before a total commercial solution can be claimed, there will have to be universal agreement on what is

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duty, the universally used PCB's. As a class, the available commercial esters, developed as relatively cheap plasticisers, may contain too high a proportion of other chemical species and impurities to render their bulk purification for dielectric purposes either simple or economically competitive and these disadvantages would only disappear if there were to be any constraints placed upon the use of existing liquids.

As a class, esters are not particularly well suited to dielectric duties, for although they cover the range of permittivities requires (3.0 - 10.0) they tend to be of rather high viscosity and are susceptible to hydrolysis and oxidation. Even when carefully purified by extensive earth treatment (attapulgitus clay or activated alumina) it is rare to find values above 1.0×10^{-13} in the useful range of permittivities above 3.0. Table 3 presents some typical dielectric and physical properties, on which further development work has been concentrated.

TABLE 3

Ester	Specific Gravity	Pour Point °C	Flash Point °C	Boiling Point °C	Viscosity cS 30°C	Permittivity 25°C	Loss Tangent 25°C	Notes
Castor Oil	0.96	-15	235 ¹	318	1030	4.65	0.002 25°C	Closed cup.
Di-n Butyl phthalate	1.04	-35	171	340	16.3	6.30	0.0019 25°C	
Di-n Heptyl phthalate	0.98	-40	224	-	32.5	5.2	0.002 25°C	
Di-iso Octyl phthalate	0.984	-46	221 ¹	-	53.0	3.3	0.0065 25°C	Closed cup
Di-10 Decyl phthalate	0.985	-55	215	355	95	5.3	0.0099 25°C	
Di-iso Nonyl phthalate		-45	222	252	93	4.66	0.0065 25°C	Ref. (11)
Di-2 Ethyl nonyl sebacate	0.928	-	139	-	22.2	4.0	0.001	
"Di-Alkanyl" phthalate	0.96	-	215 ²	250 - 5 bar	6.6 80°C	5.23	0.016	² Purity 99% Esters of C ₇ -C ₉ alcohols.
Di-iso Decyl phthalate	0.97	-	210 ²	-5 bar	2.3 80°C	4.56	0.002	² Purity 99.9%

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Of the uncompounded esters listed (and many more have been evaluated), only di-isononyl phthalate has so far been recommended for a.c. capacitors.⁽¹⁴⁾ Among the remainder, promising results have been achieved on paper and mixed paper/polymer film capacitors with di-n butyl phthalate, and indeed it is the derivatives of phthalic acid which till now have attracted most attention.

The dielectric loss tangents of most esters, even if below 0.001 at 25°C, tend to rise steeply with increasing temperature and to be susceptible to chemical deterioration upon prolonged duty at elevated temperatures. Also they are all inflammable, and when ignited may burn fiercely. Nevertheless, most phthalate esters⁽¹⁵⁾ possess the attraction of providing a negligible environmental hazard, since they are initially of low or zero toxicity and are swiftly decomposed by common chemical or biological agents.

Even though traces of the widely used phthalate esters (no more derived from compounded PVC) have been found in concentrations up to 3.2 mg/g in fresh water fish⁽¹⁶⁾ (compared with reported figures of 1.3 mg/g for PCB's), the TL 50 value (tolerance limit concentration for 50% survival) for many species of fish, is well above 0.7 mg/litre of water, which is at least 40 times better than that for DDT. Little is known of the toxicity of the esters of other organic acids such as benzoic or triacetic, but their electrical properties are not attractive. Phosphate esters display some useful properties, but they vary very widely in potential toxicity. For example, 2-ethyl hexyl diphenyl phosphate can be used as a plasticiser in packaging materials which come in contact with foodstuffs; but triethyl or triisobutyl phosphates are neuro-

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toxic despite having relatively low LD 50 figures.⁽¹³⁾ These figures may be compared with those reported for polybutenes, which are reported as "practically non-toxic" (LD 50 value greater than 15.4 mg/g), while "soft" dodecyl benzene is thought of as non-toxic.

The general indication is that very few, if any, esters by themselves provide a useful a. c. dielectric liquids, and the few referred to above as having some potential, should be compounded with stabilisers, such as the epoxy derivatives of Bisphenol A. Furthermore, greater promise is shown by compounding with other easily obtainable and purifiable liquids, using the ester as a solvent, as described in the next section.

VI. ESTER BASED MIXTURES

The compounding of a selected ester (such as di-n butyl phthalate) with other dielectric liquids or organic compounds has been explored quite extensively, as an alternative to the use of a single purified chemical species. In pursuing such a concept, other combinations of organic liquids besides esters, have been scrutinised and most of the reported results emphasise the need to incorporate a specific stabiliser, following the well-established practice of protecting trichlorobiphenyl with an epoxy compound (diglycidyl ethers and derivatives of ethylene oxide) which rapidly absorbs any hydrochloric acid liberated by internal discharges under a. c. operation. Different stabilisers, usually quinones, have been used for d. c. applications. It cannot be assumed that the rates of reaction established for the various epoxies with the breakdown products of PCB's, will apply to their interaction with other

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organic compounds, and indeed it has been found that even with a substantial excess of epoxide groups to react with each phthalic acid molecule, the reaction rates could be several hundred times slower than with the hydrochloric acid released by electrical discharges in standard trichlorodiphenyl. Perhaps the best example of an epoxy stabilised phthalate ester is provided by the liquid known under its proprietary trade name "Econol",⁽⁶⁾ which consists essentially of di-2 ethyl hexyl phthalate stabilised with a diglycidyl ether of Bisphenol A (DGEBA), one of a large number of diglycidyl ethers proposed as stabilisers for capacitor applications.⁽⁷⁾ A selection of mixed ester and other organic liquids suggested as possible capacitor impregnants are given in Table 4. Most of these have been considered for use with paper windings, but some tests have been carried out on mixed paper/plastic and even all plastic film windings, where an important additional requirement is the interaction between the liquid phase and the polymer film. This may become critical where the absorption of two liquids by, for example, polypropylene is different. In such a case, the liquid possessing the higher absorbance will be sequestered preferentially in the polymer, and the carefully selected initial concentration distributions will not remain constant, especially under thermal cycling.

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TABLE 4

Properties Liquid	Density	Pour Point °C	Flash Point °C	Boiling Point °C	Viscosity cS	Permittivity	Loss Tangent	Notes
DnBP/DGEBA	1.05	-45	>165	340	2.5/3.0	6.6 25°C	0.013 100°C	Experimental
Di-3 ethyl hexyl Phthalate - DGEBA	0.99	-45	218	230 5mm	6.9 80°C	4.6 75°C	0.003 100°C	Proprietary under "Econol" Ref. (16)
DnBP/DOB 50/50	0.95	-43	>170	-	14/15 20°C	4.25 25°C	<0.01 100°C	Experimental
DOP/Polybutene 50/50	0.915	-	-	-	-	3.13	0.04 90°C	Proprietary Ref. (17)
Ester, Sulphone/Epoxyde	0.928	-	220	-	4.30 100°C	6.2 25°C	0.022 100°C	MCS 1475 Ref. (18)
Hydrocarbon Sulphone/ Epoxide	1.03	-	170	-	1.96 100°C	5.1 100°C	0.10 100°C	MCS 1528 Ref. (20)
DnBP/Nitrobenzene 80/20 .*	-	-	-	-	-	11.8	-	Experimental Ref. (13)
DnBP/Polypropylene Carbonate 50/50	-	-	-	-	-	20.6	-	Experimental Ref. (13)

It is only practicable to present a few typical examples of mixed liquids, based upon esters, which have either attracted attention experimentally, or which have revealed sufficiently important data to merit serious commercial consideration. Evolution of mixtures has followed two general approaches:-

- (1) Admixture of the ester with a suitable hydrocarbon, in relative proportions determined by the values of permittivity and physical properties to be secured.
- (2) Dissolution in the ester of another organic compound or polymer of suitably high permittivity and dielectric acceptability.

Examples of the first approach given in Table 4 involve the use of dodecylbenzene or a polybutene with respectively dioctyl phthalate or di-n butyl phthalate. The former approach, still in the experimental stage, indicates a

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general result which might characterise mixtures of an ester with a range of alkyl benzenes. The latter development, the subject of numerous pending patent applications, yields mixtures at the low end of the permittivity range, which might prove less advantageous, especially for paper/film windings, unless the total combination permits very high working stresses.

Many investigators have experimented with liquids of high permittivity, such as the nitro-aromatics and particularly nitro-benzene ($K = 36$), facing the extreme difficulty of achieving and maintaining high purity by using molecular sieves and, latterly, electrodialysis⁽¹⁶⁾ which has given useful results in the laboratory. The same workers also examined solutions of propylene carbonate ($K = 69$) in dibutyl phthalate though the resulting permittivities of the solutions may still be rather high for commercial purposes. A balance must be struck between the complexity and cost of purification, and the limited advantage of higher permittivity. Perhaps the more rewarding engineering route is to choose modest values of liquid permittivity (2.0 - 3.0), and rely upon good a. c. strength with chemical and thermal stability, to permit realisation of reliable high stressed dielectrics of good thermal conductivity.

Other recently reported mixtures⁽¹⁷⁾ include an aromatic ester blended with tolyl sulphone and stabilised with an epoxy, such as 0.1 to 3.0 per cent by weight of 3-4 epoxy cyclohexyl-methyl 3-4 epoxy cyclohexene carbonate. Diaryl sulphones, with various substituents have generated considerable interest as dielectric components, though they tend to possess a rather incompatible selection of other properties. However, by prolonged refining it has been demonstrated that a blend of a substituted diaryl sulphone and

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hydrocarbons such as alkyl benzenes, naphthalenes and biphenyls,⁽²⁰⁾ can produce a non-halogenated capacitor impregnant for paper, paper/polymer film and all film constructions including also designs incorporating metallised electrodes. A further useful claim for such a mixture, is a lower pour point than PCB's. Unlike the latter, however, they are inflammable.

VII. SILICONES

This group comprises a related series of polydimethyl siloxanes or polymethyl phenyl siloxane, in the form of clear liquids having a wide range of molecular weights and viscosities varying from 0.65 cS to 12 500 cS at room temperature (see Table 6.). They are well known for the extreme versatility of their commercial and industrial application, based upon excellent thermal stability and resistance to oxidation coupled with non-inflammability and general chemical inertness. For dielectric applications they display low loss tangents and good electrical strength, with an operational temperature range from -80°C to +250°C. With permittivities in the region of 2.2 to 2.9 they could be used for cable and transformer applications, though for capacitors the more recently developed fluoro-silicone has a more attractive dielectric constant.

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TABLE 5

Properties Polysiloxane	Specific Gravity 25°C	Pour Point °C	Flash Point °C	Viscosity cS 25°C	Permittivity 25°C	Loss Tangent 25°C	Notes
Dimethyl silicone	0.953	-73	232	70	2.68	<0.0001	Standard commercial liquid
Dimethyl silicone	0.974	-50	318	1000	2.76	<0.0001	- ditto -
Phenyl methyl silicone	0.99	-	290	50	2.70	-	- ditto -
Phenyl methyl silicone	1.102	-	362	500	2.90	-	- ditto -
Fluoro-silicone	1.12	-	>260	300	5.23	-	Commercially available
Chloro-propyl methyl polysiloxane	-	-	-	-	6.84	3.8×10^{-3}	Experimental

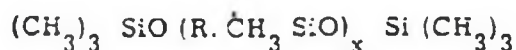
Above 400°C the polysiloxanes will begin to depolymerise, and under internal discharges the methyl derivatives display considerable gassing, which is much reduced or reversed in the methyl phenyl derivatives. Internal arcing, as in switchgear, would cause complete degradation, though unlike PCB's, evolution of corrosive molecules cannot occur. For very high voltages, the polysiloxane liquids have given promising results in experimental cables, though with cellulose their non-wetting properties generate problems of stress control at the liquid/fibre interfaces, complicating the design of joints and sealing ends. Silicones, and mixtures of them with hydrocarbons have been proposed for the impregnation of solid, extruded crosslinked polyethylene cables,⁽²¹⁾ it being claimed that higher impulse breakdown stresses and improved levels of internal corona inception stress levels can be obtained by filling the residual voids in the solid polymeric insulation.

More vigorous exploitation of polysiloxanes has been inhibited only by cost. They are produced by intrinsically high energy consumption syntheses, and compared with other liquids, this will hardly diminish in the future.

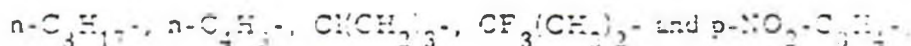
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Their use could be justified in very high voltage equipment where the cost of the liquid component is a small fraction of the total installed cost. Apart from certain embarrassing physical features arising from their strong hydrophobic character, they offer little threat to the environment and are not known to display unacceptable biological toxicity. From this aspect, introduction of halogen atoms into the molecule would be disadvantageous. A wide study of substituted polysiloxanes has been reported⁽²⁴⁾ in which the substituent "R" in the general formula:-



has taken many varied forms including:-



giving derivatives with permittivities between 2.38 and 19.3, and volume resistivities from 1.5×10^{15} to 7.2×10^{12} . Study of these liquids provides valuable information on the relationship between chemical structure and electrical properties, but not a direct contribution towards the provision of new liquids for High Voltage dielectrics. It seems that electrical applications (except for cables) must remain in the realm of specialised applications for space or electronics.

VIII. FLUOROCARBONS

The introduction of Fluorine into the hydrocarbon structure introduces many useful changes in properties, due mainly to a great increase in stability (especially resistance to oxidation and inflammability), while retaining or even

improving the electrical properties. They have been introduced as electrical coolants and insulants, heat exchange and hydraulic fluids wherever the duty is sufficiently onerous to preclude other classes of liquid, and justifies their high cost. The latter reflects the high energy absorption and cost of all fluorine chemical syntheses, and is unlikely to be much changed in the future.

The fluorocarbons of most interest as potential dielectric liquids are derived from benzene or naphthalene analogues such as:- perfluoromethyl cyclohexane, perfluorodimethyl cyclohexane and perfluorodecalin. Despite attractive electrical properties and inertness, excessive volatility is a problem, and attention has more recently been focussed upon fluorinated ethers, alcohols and amines, which are even more costly than the simple fluorocarbons. A few examples from the range of liquids examined are summarised in Table 6.

TABLE 6

Properties Fluorocarbons	Specific Gravity 25°C	Pour Point °C	Boiling Point °C	Viscosity 25°C	Permit- tivity 25°C	Loss Tangent 25°C	Notes
Hexafluorobenzene	1.81	5.2	80	0.56	2.07	-	
Perfluorodecalin	1.95	-12	142	2.65	1.95	<0.0001	
Perfluorodimethylamine	1.37	-59	178	2.95	1.66	<0.0003	
Perfluorodimethyl ether	1.81	-90	172	2.11	1.95	<0.0005	
Perfluorocyclo-octanol	1.77	-100	193	0.81	1.85	<0.0005	

Under the present searching re-examination of the toxicity or persistence of pollution caused by dispersal of synthetic chemicals of all kinds, coupled with recent statements of the likely-cumulative detrimental effect upon

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the atmospheric ozone layer of widespread use of aerosol sprays containing mixed fluoro-chloro hydrocarbon gases, it is barely conceivable that fluorinated synthetic compounds would be deliberately considered as replacements for existing dielectric liquids, except for highly specialised purposes. However, their extremely low pour points in conjunction with their remaining properties, might fit them for H. V. duties in arctic conditions, as well as in outer space.

IX. CONCLUSIONS

In a review of this nature it is impossible to do more than direct attention to those aspects which typify both advantages and disadvantages in the selection and use of novel dielectric liquids.

Efforts are being directed towards finding more stable liquids for large H. V. transformers, to establish less inflammable hydrocarbons, to improve gas absorption under internal discharges, and to optimise thermal conductivity. Alternatives to PCB's for smaller transformers, especially for distribution, are being sought as a safeguard against any unjustified limitation in use on ecological grounds. So far all possible candidates on technical/ economic grounds carry the serious objection of inflammability and explosion risks.

For cables there appears to be a wide choice of alternatives, though the gradual evolution of new, solid, taped insulations (plastic/paper laminates) pose problems of incompatibility between liquid and polymer.

There is a wider field of choice for capacitor impregnants in the requisite permittivity range, since non-inflammability poses less of a hazard

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in sealed H.V. tank designs. It must be said, however, that the various tri-chlorodiphenyls available now, and the promise of acceptable biodegradable types in the near future, provides an adequate base from which to develop units of larger kVAR. without sacrifice of safety either in operation or in disposal.

The requirements for switchgear, reactors and miscellaneous duties appear to raise rather less onerous problems, and perhaps the usual processes of selection and field trial on the full-scale will yield any necessary new or modified liquids.

Finally, there does seem to be increasing opportunity to consider a wider range of mixtures of different molecular species, rather than rely upon single classes or homologues as in the past, in order to optimise the liquid for particular requirements.

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