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Edited by

G. Addis
J. Marks
Electrical Systems Division

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
G. Addis

Transmission Substations Program

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ABSTRACT

The EPRI PCB seminar, held in Dallas, Texas, on December 1 to 3, 1981, was the first comprehensive seminar covering PCB problems and solutions of interest to the electric utilities. The purpose of the meeting, attended by 300 participants, was to present emerging technologies and ideas for PCB analysis and removal. The major areas covered were: background and history of the problem, analytic techniques, spill cleanup, destruction of askarels, treatment of capacitors, and decontamination of oil. Both EPRI-sponsored and independently developed projects are included. In addition to the ongoing research on new technologies, some presentations cover processes ready or almost ready for commercialization. Supplementing the proceedings, a videotape of author interviews was prepared and is available for purchase from EPRI (415/855-2286).

FOREWORD

The EPRI Interdivisional Task Force on PCBs was formed in November 1980 to identify projects, provide inputs to program plans, review progress, and coordinate information to and from utilities and others. Since then a comprehensive program to find answers to the PCB problems of utilities was assembled and funded by EPRI and continues to grow. In addition, a much larger research effort is building up as a result of independently funded research and early commercial endeavors. EPRI's 1981 PCB Seminar in Dallas was the most important such gathering to date; the information presented should help utilities to manage the PCB problem. Almost all of the talks given at the seminar are documented in these proceedings.

Gil Addis, Project Manager
Electrical Systems Division

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EPRI Staff	Others
M. Charlson	C. Brenner - Georgia Power
J. Gillies (Consultant)	E. Faeder - Southern California Edison Co.
R. Komai	C. Manger - Baltimore Gas & Electric
E. Norton	E. Morrison - Los Angeles Department of Water & Power
W. Shula	H. Onishi - Commonwealth Edison Co.
R. Tackaberry	W. Utic - Pacific Gas & Electric Company
V. Tahiliani	

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Section 1

BACKGROUND

PCBs - THE FEDERAL VIEW

N. Dyer
Environmental Protection Agency

PCBs - The Federal View

Norman Dyer
Environmental Protection Agency
Dallas, Texas

Beginning in the mid-1960's PCBs have been found widely distributed in low concentrations throughout the United States. From the late sixties until the early seventies, there was a fragmented federal approach to the PCB problem. The U.S. Department of the Interior Bureau of Mines (BOM), responsible for water pollution, and the Department of Health, Education and Welfare (DHEW), responsible for human health, undertook some PCB research, but no programs to control PCB release or exposure were initiated. In 1969 the Council on Environmental Quality (CEQ) was formed, and in 1970 the Environmental Protection Agency (EPA) was created. Both began work on the PCB problem. CEQ was the catalyst in the formation of a federal interagency task force to coordinate the federal PCB effort. In May 1972, the task force issued a report concluding that PCB contamination was ubiquitous and represented an unquantified but undisputable hazard, and that the use of PCBs should be restricted to essential ones which involve minimal direct human exposure.[1]

Once this report was issued, programs addressing the PCB problem were begun. In 1971 Monsanto, the sole domestic commercial producer of PCBs, voluntarily restricted sales of PCBs to "closed system uses," thereby limiting sales to manufacturers of transformers and capacitors.[2] In February 1973, the Organization for European Community Development (OECD) issued a directive which recommended limiting the worldwide usage of PCBS. In 1973, the Food and Drug Administration (FDA) published regulations prohibiting the use of PCBs in food and feed facilities, except for transformers and capacitors, and establishing temporary tolerances for PCB levels in many food and feed items.[3] In February 1977, EPA banned PCB discharges into waterways by capacitor and transformer manufacturers, and finally, the Toxic Substances Control Act (TSCA) (PL 94-469) was passed by Congress, requiring the regulation of PCBS.

EPA REGULATION OF PCBs UNDER TSCA

TSCA Requirements

On October 11, 1976, TSCA was passed. TSCA is a law to protect human health and the environment by reducing the risk posed by certain chemical substances. The Act specifically designates, by name, one class of chemicals, and one only, for regulation. This class of chemicals is PCBs.

Section 6(e) of TSCA specifically requires EPA to regulate the marking, disposal, manufacture (including inportation), processing, distribution in commerce, and use of materials

containing PCBs. These mandates were implemented in a phased manner, with the marking and disposal rules to be promulgated first. Accordingly, in February 1978, EPA regulated the disposal and marking of PCBs (40 CFR §761), (43 Fed. Reg. 7150). This rule required the marking of many PCB items still in service, and set up a system for the proper disposal of PCBs. On May 31, 1979, EPA instituted a ban on the manufacture, processing distribution in commerce, and use of PCBs. (44 Fed. Reg. 31514) There are five "exceptions" to the bans instituted May 31, 1979. The first three are very broad; the remaining two apply only to specific situations. First, TSCA applies, by statute, only to those uses of PCB that are not considered "totally enclosed." EPA, in the May 31, 1979 regulation, considered the following uses "totally enclosed": use (except servicing) of intact, non-leaking PCB Transformers, PCB-Contaminated Transformers, and PCB electromagnets and use of intact, non-leaking PCB Capacitors and PCB Equipment containing an intact, non-leaking PCB Capacitor. Second, EPA set a concentration cutoff of 50 ppm below which, in general, PCBs are not regulated. Third, TSCA provides that PCBs sold for purposes other than resale prior to July 1, 1979, are not subject to the ban on distribution in commerce. Fourth, TSCA provided for EPA to grant authorizations for non-totally enclosed uses that did not present an unreasonable risk to human health or the environment. Among the authorizations granted on May 31, 1979, are: servicing of transformers and electromagnets; use in and servicing of railroad transformers and mining equipment; and use in heat transfer systems, hydraulic systems, microscopy, carbonless copy paper, and research and development. Finally, TSCA provided that persons whose manufacturing, processing or distribution in commerce activities had been banned could petition EPA to grant "exemptions" to allow those activities to continue. To grant an exemption, EPA must find that two criteria set by Congress have been met:

1. an unreasonable risk of injury to health or the environment would not result, and

2. good faith efforts have been made to develop a chemical substance which does not present an unreasonable risk of injury to health or the environment and which may be substituted for such polychlorinated biphenyl.

Activities Since Promulgation

Exemptions

Over 400 petitions for exemptions from the prohibitions of TSCA §6(e)(3)(A) have been filed. Approximately 40 of these seek exemptions for the manufacture of PCBs at concentrations greater than 50 ppm; nearly all of these involve processes where PCBs are produced as a byproduct in the manufacture of other materials. The remaining exemption petitions are for the processing or distribution in commerce of PCBs. In the case of manufacturing

exemption petitions filed for activities which were ongoing as of January 1, 1979, and processing and distribution petitions filed for activities which were ongoing as of July 1, 1979, the activities for which exemptions are sought may be continued until EPA rules on the petitions. For late petitions, those submitted after the filing deadlines, EPA will decide on a case by case basis whether or not to accept them for consideration. The late petitioner must make a showing of good cause as to why the petition is being submitted after the filing deadline. Of those petitions accepted, only those activities which EPA determines were underway prior to the dates the bans went into effect will be allowed to continued until EPA rules on the pending petitions. Therefore, persons who wish to begin a PCB manufacturing, processing, or distribution in commerce activity which was not underway at the time the bans went into effect may not initiate the activity until EPA rules on the exemption request.[4]

EPA will probably not take final action on any of the exemption petitions until sometime in 1982, because of current efforts which are underway to rewrite portions of the PCB rule.

Open Border Policy

The Ban Rule also established an Open Border Policy which permitted the import and export of PCB wastes for purposes of disposal for a period of one year. On May 1, 1980, EPA announced that it was ending the Open Border Policy and closing all U.S. borders to shipments of PCB wastes. This decision was taken because it had become apparent that few other nations were actively seeking to develop adequate disposal facilities of their own. EPA announced that it would re-open U.S. borders to shipments of wastes to and from any nation which enters into a bilateral agreement with the U.S. based on comparable standards for disposal of PCBs. Such an agreement is presently being discussed with Canada. No other nation has sought an agreement.

Exports of PCBs for use in other nations are permitted only if the activity was ongoing as of July 1, 1979, a petition for a distribution exemption is on file, and an export notice is submitted, as required by §12(b) of TSCA. If the activity was not ongoing as of July 1, 1979, an exporter must obtain an exemption from EPA before he may initiate exporting.

Food and Feed Amendment

On May 9, 1980, EPA proposed to amend the Ban Rule to prohibit the use of PCB Items (including PCB Large High and Low Voltage Capacitors, PCB Transformers, PCB-Contaminated Transformers, PCB Heat Transfer Systems, and PCB Hydraulic Systems) in facilities manufacturing, processing, or storing fertilizers or agricultural pesticides. EPA issued this proposed rule under the authority of §6(a)(5) of TSCA. FDA and USDA published similar proposals, with each Agency's proposal covering

its area of legal responsibility in order to cover the entire food, feed, and agricultural chemical industry.

On May 6, 1981, EPA published a FEDERAL REGISTER notice placing the proposal in abeyance. This decision was made in part because of the October 30, 1980, decision of the U.S. Court of Appeals for the D.C. Circuit, which is discussed later in this paper.

ENVIRONMENTAL DEFENSE FUND CHALLENGE

Shortly after the Final PCB Ban Rule was published in the FEDERAL REGISTER, the Environmental Defense Fund (EDF) challenged the validity of the Ban Rule in a petition for review to the U.S. Court of Appeals for the D.C. Circuit. EDF sought review of the Final Ban Rule on three points: 1) EDF challenged the determination by EPA that certain commercial uses of PCBs are totally enclosed," a designation that exempts those uses from regulation under the act. 2) EDF claimed that the EPA acted contrary to law when it limited the applicability of the regulation to materials containing concentrations of PCBs greater than 50 ppm. 3) EDF challenged the decision by EPA to authorize the continued use of 11 non-totally enclosed uses of PCBs.

In its October 30, 1980 decision, the Court found no substantial evidence in the record to support EPA's classification of electrical transformers, capacitors and electromagnets as "totally enclosed" uses, or to support EPA's establishment of the 50 ppm cutoff. The Court therefore remanded these portions of the regulations to EPA for further proceedings. However, the COurt upheld EPA's authorizations of the 11 non-totally enclosed uses of PCBs.

Because the Court's invalidation of these parts of the Ban Rule would have brought into full effect the absolute prohibitions of TSCA against manufacture, distribution in commerce, processing, and use of PCBs. EPA and other parties to the litigation requested that the Court stay its mandate until new regulations could be promulgated. In two orders, issued February 12, and April 13, 1981, the court granted that request, subject to certain conditions.

Totally Enclosed Issues

The February order dealt with the use of PCBs in electrical equipment and the 50 ppm cutoff as it applied to use in electrical equipment. The Court stayed, for a period of eighteen months, the effectiveness of its decision to remand that portion of the regulations subject to several conditions. First, the stay applies only to those persons who comply with prescribed inspection and maintenance procedures known as the Interim Measures Program. Second, the Edison Electric Institute (EEI) is to conduct a study to provide EPA with information it will need for further rulemaking regarding uses of PCBs in electrical

equipment. Third, EPA must announce its new rulemaking in an Advance Notice of Proposed Rulemaking (ANPR) and must promulgate a final rule within six months of receipt of the EEI study. Finally, the parties were required to make a progress report to the court on October 1, 1981. The ANPR was published March 10, 1981, and the progress report was submitted on time.

The Interim Measures Program requires weekly inspection for leaks of all transformers with a PCB concentration over 50 ppm posing an exposure risk to food or feed products. All other transformers with a PCB concentration of 500 ppm or greater must be inspected for leaks once per quarter.

Corrective action must be initiated within two days for all moderate leaks detected. These leaks must be reported to EPA if the transformer posed an exposure risk to food or feed products. Records must be kept documenting the inspections, the leaks observed, and any servicing performed.

EPA's strategy for enforcing the Interim Measures Program augments our overall PCB strategy by adding checks for compliance with the new program while conducting regular PCB inspections. A more intensive monitoring effort is directed at utilities and food and feed facilities through a review of randomly selected records by the Interim Measures Program.

"Fifty Parts Per Million" Issue

The Court's April order dealt with the "50 ppm" issue, as that cutoff affected everything except use in electrical equipment. The court stayed its mandate with respect to this portion of its decision for 10 months and ordered EPA to undertake two parallel activities during the period of the stay.

The first activity applies to chemical manufacturing processes which generate PCBs, but release no PCBs. It also includes chemical manufacturing process which release PCBs only as constituents of wastes which are incinerated or disposed of in EPA-approved landfills, or held for such disposal. On May 20, 1981, EPA published an ANPR relating to the possible exclusion of manufacture of PCBs in these processes from the prohibitions of TSCA §6(e)(3)(A). EPA must promulgate a final rule with respect to this potential exclusion within the 18-month period of the stay or advise the Court of its reasons for not promulgating a final rule along with plans and a schedule for any further action.

The second activity applies to manufacturing, processing, distribution in commerce, and use of PCBs in concentrations less than 50 ppm (other than the creation of PCBs in those processes described above). EPA also published an ANPR regarding this activity on May 20 1981. By March 13, 1982, the Agency must advise the court of its plans for further action and its schedule for such action.

DISPOSAL

Incinerators and Boilers

The key to success for EPA's program of regulatory control of PCBs is the availability of adequate disposal facilities. Much of EPA's efforts have been directed toward approval of incinerators and encouraging verification burns in high efficiency boilers. The evaluation of data from test burns in incinerators and boilers is handled by the ten EPA Regional Offices. Public opposition to PCB incineration, and the question of toxic byproduct formation has resulted in slow, cautious, progress.

In January 1981, EPA approved the first two commercial incinerators; one in Deer Park, Texas owned by Rollins Environmental Services, and the other in El Dorado, Arkansas owned by the Energy Systems Co. (ENSCO). EPA has a plan to very thoroughly monitor operations at these two facilities.

EPA anticipates the testing of the incinerator ship Vulcanus before the end of the year. Should this incinerator be approved for use in the United States, a major portion of the high concentration liquid PCBs that are in storage could be incinerated in just a few trips.

EPA allows the disposal of low concentration (50-500 ppm) liquid PCB waste, usually transformer mineral oil, in boilers meeting certain technical criteria. These boilers, known as high efficiency boilers, operate with good combustion characteristics and have been shown in repeated tests to achieve very high destruction efficiencies for PCBs without emitting toxic combustion byproducts. Seven boilers in the U.S. have disposed of contaminated mineral oil.

Alternative Disposal Techniques

In promulgating the disposal regulations, EPA allowed persons who are required to incinerate PCBs and who can demonstrate that an alternative method for destroying PCB exists and is effective to be granted approval. The alternative method must achieve a level of performance equivalent to incineration or destruction in a high efficiency boiler, and the applicant must show that the method of destroying PCBs will not present an unreasonable risk of injury to health or the environment.

A large number of researchers and entepreneurs have sought solutions to the problem of PCB disposal using a wide range of techniques including chemical destruction, catalytic decomposition, and a variety of thermal destruction methods other than conventional incineration.

To date, one company using new technology has obtained EPA approval and a second company has tested a full scale commercial unit. Sunohio, based in Canton, Ohio has constructed a mobile PCB chemical destruction unit (PCBX) and demonstrated that their system is capable of reducing the PCB concentration in contaminated mineral oil to a nondetectable level. Due to the mobility of the PCBX system, Sunohio is seeking the approval of all ten Regional Administrators so they can offer their disposal services nationwide. Thus far, Sunohio has received approvals for PCBX in Regions I, IV, VII.

Acurex Corporation has also constructed a mobile PCB destruction system and demonstrated it for EPA. Analyses conducted by Acurex the day of the demonstration showed no detectable PCBs in the treated oil. EPA collected duplicate samples for verification of this result.

These chemical disposal systems have some interesting features. They do not produce air emissions. They are portable, allowing for on site treatment, thereby eliminating some handling and transportation of the wastes. In its present state of development, chemical destruction of PCBs is not the answer to all aspects of the disposal problem, but it does illustrate the potential which exists in the area of emerging technology.

ADDITIONAL INFORMATION

The EPA has an Office of Industry Assistance which distributes publications and answers questions to help people understand the Toxic Substance Regulations. They may be reached by calling the toll-free number 800-424-9065 during Washington business hours, or the local number, 554-1404.

Discussion

Q. Five States now have TSCA enforcement pilot programs. Will the States eventually take over enforcement responsibility?

A. The act does not allow total delegation of responsibility. Parts of the program can be delegated, but the pilot program must be evaluated before any action takes place.

Q. I understand Sacramento Municipal Utility District is negotiating with EPA on reportable limits for PCB spills. What is EPA's position?

A. EPA is reviewing the limits and there will be policy changes.

Q. What is the possibility of EPA lowering the limit?

A. No speculation on the changes.

NEW PCB RULEMAKING

A REPEAT OF HISTORY OR FINAL CONCLUSIONS ?

BY

W. Corey Trench
ASSOCIATE ENVIRONMENTAL SCIENTIST
EDISON ELECTRIC INSTITUTE

PCB SEMINAR
ELECTRIC POWER RESEARCH INSTITUTE
DALLAS, TEXAS

DECEMBER 1-3, 1981

ABSTRACT

A decision in the case EDF v. EPA, and the new rulemakings that follow, will affect the continued operation of electrical equipment bearing PCBs throughout this country.

On October 30th of 1980 the United State Court of Appeals, D. C. Circuit, ruled that EPA's classification of certain electrical equipment as totally-enclosed uses and establishment of a regulatory cutoff at 50 ppm were insufficiently supported by data. Both determinations were made previously in the so-called PCB Ban Regulations (44 Fed. Reg. 31, 542-58 (1979) and successfully challenged by the Environmental Defense Fund. These determinations formerly allowed electric utilities and other equipment owners/operators to use PCB-containing transformers, capacitors, and electromagnets intact and non-leaking. This single event led the Edison Electric Institute (EEI) and the Utility Solid Waste Activities Group (USWAG) to seek and file jointly, with other parties to the litigation, a motion for temporary stay of the Court order. A stay of 18 months was accomplished. Effectively, the Court's acceptance of the motion would allow the use of PCB-containing equipment under certain conditions. These conditions were that EEI/USWAG undertake a record-building information study and equipment owners/operators implement an Interim Measures Program to inspect and maintain certain transformers.

For the purpose of this seminar, I will address some PCB history to present day, the scope and schedule of the information study, some study findings so far, EEI/USWAG's policy posture, and some insights and concerns for the future.

PASSAGE INTRODUCING OUR NECESSITY OF BEING

"There is still very limited awareness of the nature of ... threat - (societal risk). This is an era of specialists, each of whom sees his own problem and is unaware of or intolerant of the larger frame into which it fits ... we urgently need an end to false assurances and the sugar coating of unpalatable facts. The public must decide whether it wishes to continue on the present road, and it can do so only when in full possession of the facts. In the words of Jean Rostand, "The obligation to endure gives us the right to know."

These words were written nearly a decade ago. They have meaning for any human situation. For now, they capture the essence of societal humility in the struggle to know and manage a material called Polychlorinated Biphenyls (PCBs). The words were written by Rachel Carson in 1962 in the opening chapter of Silent Spring.

What brings us all here is a common quest to know PCBs better than we did last year, last month, or just yesterday. We seek the facts, where sometimes there are no facts. Both truth about PCBs, if you will, and philosophy abound. As people intimately involved in PCB management, let us keep in mind that our perceptions should reflect the best knowledge so that we can strive to gain even better knowledge and make better decisions where they need be made.

For my part in the program, I propose a variation on a theme. EPA has presented its historical perspective; I will present the utility's point of view of key events which are pertinent to

PCB rulemaking. I will then depart you dangling on the brink of final, concluding regulation of PCBs in electrical equipment around August 12, 1982. And, then, let the conference move forward to enlighten us about all initiatives.

EARLY ON

In the late1960's and early 1970's, a Panel on Hazardous Trace Substances in the White House of Science and Technology undertakes a critical review of PCBs. Information generated by this group serves as background for an Interagency Task Force on PCBs. This task force, at the request of the Office of Science and Technology and the Council on Environmental Quality, is directed to manage government decisions about PCBs.

The Interagency Task Force studies analytical methods, effects of PCBs on the environment, biological properties and the implications for human health, including the benefits of PCB uses. In 1972 the task force reports that: PCB migration in the environment is not expected to be appreciable; acute toxicity is low; and electrical equipment represents essential uses of PCBs for reason of unsuitable replacement fluids and superb fire protection. It proposes that PCB use be restricted to closed or contained uses, meaning electrical systems.

Meanwhile, Monsanto, the primary producer of PCBs, ceases the production of PCBs for open uses in 1971. The Company responds to the recommendations of the federal Interdepartmental Task Force on PCBs by continuing to manufacture PCB-containing dielectric fluids for electrical or enclosed uses.

Beginning in late 1975, early 1976, PCBs are found widespread in the global environment. Russell Train, Administrator of EPA,

approaches the electric utility industry to discuss the enclosed uses of PCBs. Voluntarily, the industry organizes a small task force of six or seven people and responds to inquiries. EPA follows with disposal guidelines thanking EEI for guidance ... then comes TSCA ... voluntary efforts give way to governmental regulatory intents.

TSCA: TOXIC SUBSTANCES CONTROL ACT OF 1976

In 1976, Congress passes legislation enabling to control the manufacture, distribution in commerce, use, and disposal of toxic substances. The statute is without a doubt necessary. In addition to the inventory of existing toxic substances, however, the Congress specifically seeks the regulation of PCBs.

Section 6(e) is written in the Toxic Substances Control Act out of a concern for the widespread occurrence of PCBs, significant potential damage to human health and wildlife and, to some extent, on the slow movements of EPA. The section lays out a schedule to dispose of PCBs, to phase out the manufacture, processing, and distribution of PCBs, and to limit the use of PCBs. Tools or the means to limit use are further provided in the Act.

Congress declares that "no person may manufacture, process, or distribute in commerce or use any polychlorinated biphenyl in any manner other than in a totally enclosed manner." The Administrator is given the authority to allow similar non-totally enclosed activities if the activities do "not present an unreasonable risk to health or the environment." Totally-enclosed manner means "any manner which will ensure that any exposure of human beings or the environment to a polychlorinated biphenyl will be insignificant as determined by rule."

The Administrator is given the task of answering two fundamental questions:

(1) What exposure to "any" PCB is "insignificant?"

(2) What exposure is not an "unreasonable risk?"

EPA REGULATIONS IMPLEMENT 6(e)

EPA publishes final rules governing the use, marking, and disposal of PCBs on May 31, 1979 in the Federal Register.

EPA defines all electrical capacitors, electromagnets, and non-railroad transformers as totally-enclosed. Totally-enclosed refers to equipment in distribution and use, except servicing, that is intact and non-leaking. A leak is defined as "any PCBs on any portion of the external portion of a PCB article." The agency essentially classifies electrical equipment fitting the description as totally-enclosed and an allowable use of PCBs, whether containing a "made-to-order" high concentration of PCBs or incidentally low concentrations.

EPA sets a regulatory cut-off of 50 ppm to distinguish unregulated from regulated concentrations of PCBs. The purpose for a cut-off is more to determine the ultimate fate of PCBs in terms of disposal. PCB concentrations below 50 ppm, between 50-500 ppm, and over 500 ppm are subject to different disposal regulations as EPA determines in the Disposal Regulation, 43 Fed. Reg. 7, 151 (1978). With accord to the use of PCB levels in totally-enclosed electrical equipment, PCB concentrations between a detectable level and 500 ppm are allowed to be used indefinitely. Totally-enclosed equipment containing over 500 ppm must be retired for disposal upon the termination of its useful service life.

EDF CHALLENGES EPA BAN REGULATIONS

EDF challenges the EPA Ban Regulations promulgated on May 31, 1981. The basic thrust behind the challenge is the large quantity of PCBs left unregulated.

EDF challenges three EPA determinations which include: the authorization of non-totally enclosed uses, particularly the servicing of transformers; classification of transformers, capacitors, and electromagnets as totally enclosed uses, and establishment of a 50 ppm regulatory cutoff.

EEI and others potentially affected industries intervene in the case. EEI intervenes in support of the existing regulations.

COURT DECIDES THE CASE

On October 31, 1981 the U. S. Court of Appeals for the District of Columbia upholds EPA's authorization of non-totally enclosed uses, but the Court sets aside determinations to classify certain equipment as totally-enclosed and establish a regulatory cutoff of 50 ppm. The decision is based on evidence in the record supportive of EPA determinations.

The Court finds the EPA rulemaking record sufficient to justify authorization of non-totally enclosed uses. EPA analysis of the unreasonableness of risk shows that it is not unreasonable to authorize non-totally enclosed uses. Thus, the continued servicing of transformers containing PCB is allowed.

In its opinion, the Court finds the evidence lacking to support EPA findings of totally-enclosed and 50 ppm determinations. The Court remands these parts of the PCB Ban Regulations to EPA for new rulemaking. Both decisions are discussed separately in the text of the Court's ruling.

First, the Court concentrates on EPA's Support Document/ Voluntary Environmental Impact Statement - the documentation for the final Ban Regulations. It highlights EPA's policy that "any release of PCBs into the environment will eventually result in widespread exposure of wildlife, including man's major food sources, and humans and that such exposure may have adverse effects," and cites the government's scientific evidence backing up the policy.

Then, the Court goes on to question the 50 ppm cutoff. It is apparent that EPA has not performed an "unreasonable risk" determination to substantiate a cutoff level. EPA is apparently unaware of the PCBs produced by commercial processes. Statutory language does not support a 50 ppm cutoff, in fact, and refers to "any poly-chlorinated biphenyl." Although, the Court is reluctant to interpret "any" as 1 molecule in the absence of support in the legislative history. The selection of a cutoff appears to undermine a Congressional intent to regulate non-ambient sources of PCB contamination. EPA also appears to avoid the control of ambient sources greater than 50 ppm in defiance of Congressional intent. A proper analysis of the benefits and burdens of regulating below 50 ppm is clearly lacking.

On the question of a totally-enclosed classification of certain equipment, the Court makes several statements. First, no substantial evidence exists in the record to support totally-enclosed classifications. Second, EPA defines "insignificant exposure" as no exposure. Hence, "any release of PCBs into the environment will eventually result in widespread exposure of

wildlife, including some of man's major food sources, and humans, and that any such exposure may have adverse effects." In the face of these strict standards, EPA classifies all "intact, non-leaking" electrical equipment to be totally enclosed and yet EPA has no idea which items are "intact, non-leaking" versus the non-totally enclosed variety. No self-reporting or inspections are provided leading the Court to conclude that the totally-enclosed designation is a "blanket" for all transformers, capacitors, and electromagnets.

The Court acknowledges the provisions in the statute for totally enclosed uses, but expresses concern that the probability and magnitude of leaks is unknown, and that current criteria of "any release" are strict.

In conclusion, the Court sets aside two portions of the existing Ban Regulations, finds them unlawful, and requires EPA to commence a new rulemaking. Departing words of the opinion admonish EPA for falling short of the mark established by Congress in section 6(e) and ponders the life-threatening nature of toxic chemicals, such as PCBs, and continued survival of the planet.

COURT-ORDER IS TEMPORARILY STAYED

The first week in November of 1980, EEI and others commence discussions with EPA over the consequence of the Court's opinion and in issuance of the mandate in a short while. EPA assesses its options. Issuance of the Court order means to EPA that all formerly classified, totally enclosed electrical equipment that contains PCBs is subject to a ban under TSCA. EPA considers a plan to issue

a "no enforcement policy" until final rules are promulgated or seek a stay of the Court order provided it is sought jointly. EEI assesses the provision for citizen suits under TSCA and seeks negotiation with EDF and EPA to arrive at the terms for a motion to be filed jointly with the Court for a temporary stay of the Court order until final regulations are promulgated.

Negotiations between the three parties, and other intervenors in the case, generate two Court-apparent desires: Record-building data and inspection of electrical equipment. EEI, EDF, EPA and intervenors architect the data gathering study for totally-enclosed uses and an Interim Measures Program, both of which are described in the Federal Register on March 11, 1981.

EPA and EDF negotiate with other industries on the study of incidental manufacturers of PCBs in industrial processes to support a rulemaking on the 50 ppm cutoff.

Joint motions are filed on the two issues. The Court temporarily stays its mandate for 18 months until August 12, 1982 when new PCB Regulations must be published. The stay is granted on the conditions of satisfactory completion of data gathering and adherence by owners/operators to an Inspection Maintenance Program of certain transformers.

STUDY OF TOTALLY ENCLOSED EQUIPMENT

In concept, EEI/USWAG studies the Court's opinion, the EPA rulemaking record, and proposes to address the totally-enclosed issue anew. Project planning begins on February 12, 1981 and lasts until April 12, 1981.

The objective of the study is simply to collect data on the geographic settings and population of electrical equipment by type, its typical PCB concentration, losses of dielectric fluid from equipment, the health effects of PCB exposure, existing protection from exposure, and alternative risk-reduction options. EEI establishes a policy that we study PCBs in integrated fashion - each element of data - make an assessment and supply EPA a proposal for the future regulation of PCBs in utility-owned electric equipment.

Regulatory questions which demand answers are:

1. Does electric equipment leak?
2. What is the magnitude and frequency of leaks?
3. Do leaks constitute a significant exposure?
4. Is the risk unreasonable?
5. What measures are feasible to phase-out or inspect/ maintain/contain electrical equipment?
6. What reduction in relative risk of exposure can be expected for what cost of additional control measures?

Because of EPA initial interest in Study Tasks 1-4 as set out in Court-order, and EPA's and EDF's indifference to Study Tasks 5, 6 and 7, EEI/USWAG hires an independent consultant, Resource Planning Corporation (RPC), to prepare a plan to study these data elements. RPC does some investigative work, visiting 13 different utilities, to establish a foundation from which to develop a research design and data collection plan. A plan is prepared and discussed with the Agency and EDF in early July of 1981.

RPC decides that it is best to survey the 100 largest utilities (in kilowatt sales) to collect data on electrical equipment. The sample is estimated to represent over 70% of the electric equipment owned by the electric utility industry. A questionnaire is developed and circulated to the CEO's of the sample, seeking data on tasks 1-4.

Meanwhile, EEI, the National Electrical Manufacturer's Association (NEMA), and the Chemical Manufacturers Association (CMA) discuss, develop, and agree upon a scope of work to update and critically review the scientific literature on human health effects (Task 5 of EEI Study). EEI and NEMA eventually decide to co-sponsor Drill, Friess, Hayes, Loomis and Schaeffer, a consulting firm of toxicologists.

Approaches to the analysis of the pathways of PCB migration from electrical equipment resulting from fluid releases and exiting the "pool" of PCBs already in the environment is underway.

All study tasks, assessment of the data, and EEI/USWAG recommendations are scheduled to be submitted on January 12, 1982.[1] Final rules are expected by mid-August of 1982.

STATUS OF STUDY: RESULTS SO FAR

EEI completes Task 1 and Task 2 of the Court-ordered study and submits them to EPA and EDF on October 30, 1981. The tasks deal with the types and uses of, population of, typical PCB levels in electrical equipment. Data collected on small leaks, moderate leaks, and spills are reported. Data on geography and work protection are also reported. Data compiled for Tasks 1 and 2 show:

[1] A new submission date has been set for Friday, February 12, 1982.

1. The estimated bulk quantity of PCBs (in pounds) resides in two equipment types: Askarel Transformers (74,597,283 lbs.) and PCB Capacitors (87,552,960 lbs.), accounting for 99.8% of all the PCBs in the utility industry.
2. Mineral-Oil Filled Transformers are estimated and projected to contain 262, 230 pounds of PCBs. The remaining mineral oil items-Voltage Regulators, Oil-Filled Circuit Breakers, Oil-Filled Reclosers, and Oil-Filled Switches/Sectionalizers, summed together, are estimated to bear 20,134 pounds of PCBs.
3. Of particular significance, in an analysis of the distribution of PCB concentrations in Mineral-Oil Filled Transformers, 10% of the equipment is contaminated at levels of 50 ppm or greater, 90% contain less than 50 ppm levels. The estimates differ slightly for other mineral-oil filled equipment.
4. Fluid losses. The annual % of equipment developing small, moderate leaks, and PCB spills is generally well under 1%, except for PCB Capacitors which exhibit small leaks at 2.3% per annum. Leak information were not available for Oil Filled Reclosers and Oil-Filled Switches/Sectionalizers of the equipment inspected in substations. PCB spill rates were based on reported spills over the last year.
5. Data tabulations are attached.

6. Geographic distribution of equipment has been provided on the basis of reported PCB spills' locations.

As an example, PCB spills from Mineral Oil Transformers occur accordingly: 0.3% near waterways, 0.09 rural desert land, 0.1 rural wetlands/marsh lands, 9.2 rural grassland, 13.9 industrial areas, 70.6 in residential neighborhoods, and 5.9 in public areas (shopping center, schools, etc.)

7. Inspection, maintenance, and worker protection procedures.

   a. Smaller equipment located in distribution systems is infrequently inspected or tested.

   b. Larger equipment located in substations is inspected and tested according to routine cycles which vary from weekly to every two or three years.

   c. Sampled utilities report the availability of protective equipment: boots (99% of the utilities), gloves (100%), protection (100%) glasses/eye protection (99%), and respirators (91%). Eighty-nine percent report that they have employee training programs devoted to PCB issues, including health effects (93%), protective clothing (100%), and spill clean-up (99%).

Of the health effects study, we will be reviewing the results of that effort shortly. It is a Category I/Category II review that we will discuss: Body burdens, metabolism and kinetics; general toxicity; skin and other cutaneous tissues; liver effects;

gastric lesions; carcinogenesis; experimental and chemical; reproductive effects; mutagenesis; Yusho disease and Yusho carcinogenesis; other health effects; and epidemiology. The study should be a most comprehensive and up-to-date review of the human health effects literature.

OUTLOOK FOR NEW REGULATIONS

Beginning in the mid-1970's, the electric utility industry steadily began an active involvement in the management/control of PCBs. First through a voluntary effort and then in the form of the formal rulemaking process. It became clear following the decision in the EDF v. EPA case that a great deal was expected of industry. A substantial challenge was presented. The message has come through, TSCA is a risk-balancing statute that requires the assessment of the reasonable versus unreasonable risk. A complete and accurate data base need be assembled to secure decisions now that must stand firm. It has been and will continue to he the policy of Edison Electric Institute to help develop good data to make better decisions.

EPA and the industry encounter two possible routes to future control PCBs in electrical equipment. These are reclassification of electrical equipment as totally-enclosed or a use authorization. Both require an assessment of the risk.

In the first instance, EPA must rethink the policy that "any exposure" to PCB is "significant." The policy has not been a workable one; and only by recasting this policy can any piece of equipment or structure embodying PCBs be considered totally-

enclosed. The alternative is to provide a use authorization for a equipment containing PCBs on the basis that exposure to these PCBs does not pose an unreasonable risk. Several factors may be taken account of in the analysis of unreasonable risk, including replacement materials, environmental and human health, and social and economic factors.

The matter of establishing a regulatory cutoff at 50 ppm confronts EPA. This cutoff applies more to final disposal than equipment use. Therefore, it makes sense to distinguish the use of PCB from the disposal; they represent two different situations entirely. Perhaps a regulatory concept that analyzes the total quantities of PCBs would be a better basis on which to judge the protection of public health and the environment.

It is strongly hoped that the deliberately comprehensive nature of the EEI/USWAG study and the study findings will be used to devise realistic and reasonable regulation of PCBs for once and for all. EEI certainly intends to continue its cooperation with EPA to reach this end. Hopefully, the analysis of EEI/USWAG data in January will bring about formal and conclusive regulations.

DISCUSSION

Q. What is the source of EDF funding?

A. Primarily individuals.

Q. Have you any study data on health effects?

A. EEI - NEMA health effect study is now in progress with a completion date of mid-January 1982.

Comments: Several questions were asked regarding possible changes of the 50 ppm level to a level that would be "safe and reasonable". It was pointed out that Congress established PCB as hazardous and efforts to remove PCB from the hazardous category would probably involve Congress. The basic goal of EPA is to eliminate additional PCB from entering the environment.

Tables extracted from Resource Planning Corporation Report on Study Tasks 1 and 2.

TABLE 1: AMOUNT OF ASKAREL AND OIL-FILLED EQUIPMENT OWNED BY THE ELECTRIC UTILITY INDUSTRY BY PCB CONCENTRATION

Equipment Type	Number of Units in the Industry	Number of Units Containing 50 ppm or Greater PCBs	Number of Units Containing 500 ppm or Greater PCBs
Askarel Transformers	39,640	39,640	39,640
Mineral Oil Transformers	20,227,428	2,386,077	219,918
PCB Capacitors	2,800,619	2,800,619	2,800,619
Voltage Regulators	145,159	20,322	2,468
Oil-Filled Circuit Breakers	180,939	3,256	0
Oil-Filled Reclosers	170,158	0	0
Oil-Filled Switches	385,768	54,007	0
Oil-Filled/Askarel Electromagnets	77	-	-
TOTAL	23,949,788	5,303,921	3,062,645

In addition to the above equipment, there are 6,545 miles of oil-filled underground cable owned by the utility industry. There are limited data available on the PCBs contained in this cable that indicate PCB concentrations are below 10 ppm.

TABLE 2: VOLUME OF FLUID AND POUNDS OF PCBs CONTAINED IN UTILITY INDUSTRY EQUIPMENT

Equipment Type	Total Gallons of Fluid	Total Pounds of PCBs
Askarel Transformers	8,525,404	74,597,283
Mineral Oil Transformers	958,365,880	262,230
PCB Capacitors	7,547,669	87,552,960
Voltage Regulators	17,840,968	6,707
Oil-Filled Circuit Breakers	137,335,668	12,685
Oil-Filled Reclosers	3,403,670	410
Oil-Filled Switches/ Sectionalizers	1,415,769	329
TOTAL	1,134,435,028	162,432,604

TABLE 3: ANNUAL LEAKAGE AND SPILL RATES FOR EQUIPMENT IN THE UTILITY INDUSTRY

Equipment Type	Annual % of Equipment Developing Small Leaks of 50 ppm PCBs	Annual % of Equipment Developing Moderate Leaks of 50 ppm PCBs	Annual % of Equipment Developing PCB Spills
Mineral Oil Transformers	0.15%	0.09%	0.007%
PCB Capacitors	2.3	0.77	0.09
Voltage Regulators	0.10	0.10	0.024
Oil-Filled Circuit Breakers	0.27	0.19	0.008
Oil-Filled Reclosers	Not Avail.	Not Avail.	0.004
Oil-Filled Switches/ Sectionalizers	Not Avail.	Not Avail.	0.007

TABLE 10: DISTRIBUTION OF PCB CONCENTRATIONS FOR MINERAL OIL TRANSFORMERS IN THE UTILITY INDUSTRY

PCB Concentration (ppm)	Percent of Transformers
1	43.1%
1-9.9	30.8
10-19.9	7.3
20-29.9	4.7
30-39.9	2.5
40-49.9	1.6
50-99.9	3.7

TABLE 10: DISTRIBUTION OF PCB CONCENTRATIONS
FOR MINERAL OIL TRANSFORMERS
IN THE UTILITY INDUSTRY (CONTINUED)

PCB Concentration (ppm)	Percent of Transformers
100-499	5.1
500	1.2
TOTAL	100.0%

ENVIRONMENT CANADA

K. Childs

Waste Management Branch
Environmental Protection Service
Canada

ABSTRACT OF A PRESENTATION TO THE
ELECTRIC POWER RESEARCH INSTITUTE
PCB SEMINAR
DALLAS, DEC. 1st, 1981

by K. CHILDS, WASTE MANAGEMENT BRANCH, ENVIRONMENTAL PROTECTION SERVICE

In Canada there are PCBs awaiting destruction. In Canada there are technologies capable of destroying PCBs. Why then are these two factors not brought together?

This brief paper examines the legislation that exists to control PCBs, the responsibilities of the various levels of government as it relates to their management and what activities are presently underway to develop solutions to a problem of debatable quantitive extent but apparently unlimited social concern.

Control of PCBs in Canada is exercised through the provisions of the Environment Contaminants Act passed in 1975. Restricted use regulations under that Act originally passed in 1978, and subsequently amended, together with the presently pending Release and Product regulations will effectively eliminate all opportunities to release PCBs to the environment.

Responsibility for waste management in Canada is vested in the provinces. Each province can establish its own legislation, priorities, and systems. Each province is doing just that with some being somewhat more aggressive than others depending upon its perception of need and its capability to pay. At this time there is essentially no facility in Canada which has the capability to manage PCBs beyond the level of storing.

Research activities in Canada are limited due to funding constraints and priority setting. Currently there is work underway in Ontario (Plasma Arc and Ontario Hydro) and in B.C. (B.C. Hydro). There will probably be some further work done on the diesel engine system - if an acceptable site can be found.

PCBs represent a small percentage of the total hazardous waste management challenge. We seem to have spent an inordinate amount of time on the problem and have really not too much to show for it except a seemingly well defined problem and some unused technologies.

DISCUSSION

Q. What limit is used in Canada?

A. Canada agrees with the USA, i.e., using a 50 ppm lower limit for "management" of PCB waste.

Q. You discussed difficulty in communication with the public. What methods do you recommend?

A. Small group meetings are best. Large groups are not satisfactory. Comments: The need to provide facts to the politicians, as well as the public, was stressed. A "short course" seems to be desirable for those who are willing to listen.

U.S. CAPACITY TO REPLACE OILS AND CAPACITORS AND TO DESTROY PCBs

E. Norton
Electric Power Research Institute

U.S. Capacity to Replace Oils and Capacitors and to Destroy PCBs

Edward Norton - EPRI

The information I am presenting this morning wasn't as easy to put together as I originally thought. Some of the markets here are very elastic and some are not. I have approached the problem with little bias. I have not tried to prove any particular premise but simply have drawn conclusions based on the best numbers I could obtain. the numbers presented here are based on my judgment of the information presented by the latest Resource Planning Inc., survey of equipment population and estimated contamination level, The Conference Board Survey, NEMA, Electrical World, and private conversations with utilities, manufacturers, and oil companies.

I don't want to pretend that these numbers are precise but I feel their accuracy is about ± 20%. I started with differences of surveys of one order of magnitude. The industrial segment is not represented here, however, it is substantial both in the askarel transformers and the small mineral oil filled power transformer.

Summary

- 163 million pounds of PCBs
- Mostly in capacitors and askarel transformers
- 262,000 pounds in mineral oil transformers
- 7 1/2 years to replace 2.8 million capacitors

Discussion

Q. Your data is only 13% of the original estimate of 1.2 billion pounds in utility equipment. Where is the other 87%?

A. The question is the validity of the old vs the new data. The new data is believed to be more accurate, since it was a controlled survey, while the original was strictly an estimate.

Q. What are the economic implications, i.e., cost of replacement?

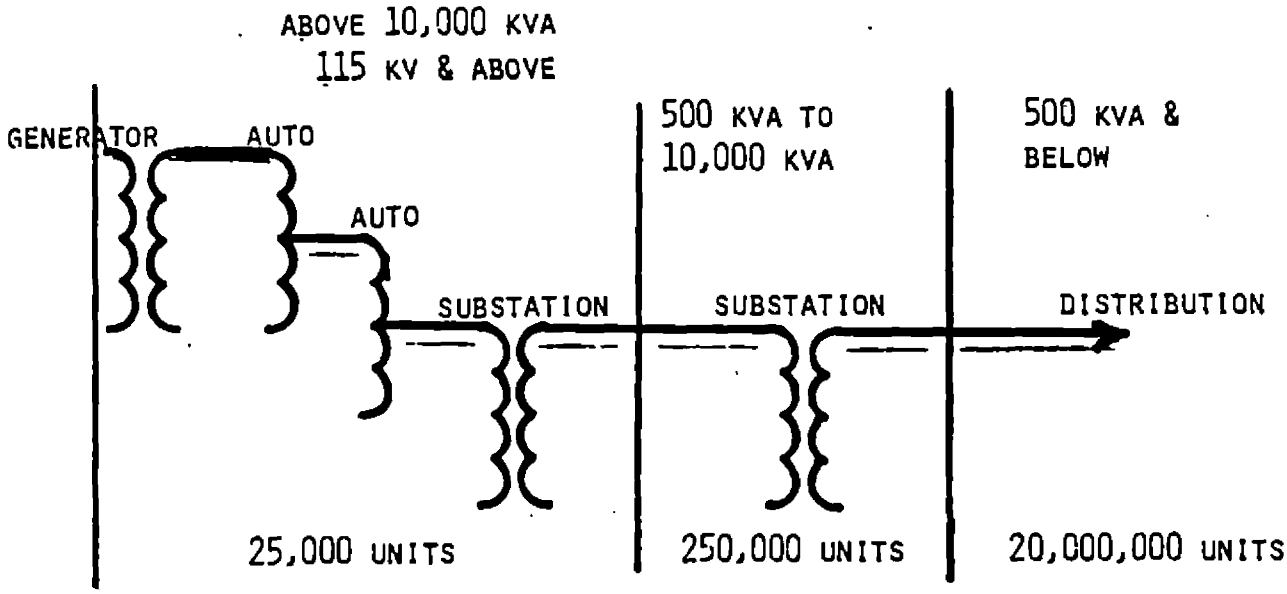
A. Capacitor replacement should be in larger size units, say 200 KVAR at $3. to $5./KVAR.

Comment: If we assume $800/unit and 1.5 million units - the cost of replacing utility capacitors would be $1.2 billion without the disposal cost.

Comment: A representative of industry reported that 50% of the transformers they had tested were over 50 ppm, which does not follow the "survey" data.

Comment: In reply to questions, concerning the distribution of contaminated transformers by size of utility, Mr. Onishi stated that the survey did not indicate any relationship to size of company.

MINERAL OIL TRANSFORMERS



- TOTAL QUANTITY OF MINERAL OIL 1 BILLION GALS.
- 10% CONTAMINATED (50 PPM OR MORE) 100 MILLION GALS.
- 2 MILLION TRANSFORMERS CONTAMINATED, DISTRIBUTED OVER ALL THREE CATEGORIES
- IF THIS OIL WERE REPLACED WITH NEW OIL, IT WOULD EQUATE TO A ONE-YEAR SUPPLY BY THE OIL COMPANIES

ASKAREL DISTRIBUTION

TRANSFORMERS		CAPACITORS
DISTRIBUTION	25 MILLION #	
501-5000 KVA	50 MILLION #	
TOTAL	75 MILLION #	88 MILLION #

163 MILLION #

CONTAMINATED MINERAL OIL TRANSFORMERS

262,000 #

CAPACITORS

UNITS IN SERVICE 2,800,000 AVERAGE SIZE 100 KVAR
MVAR IN SERVICE 280,000 MVAR 1980 PRODUCTION 21,000 MVAR
1980 PLANT CAPACITY OPERATED AT 60%

CAPACITY INCREASE BEING ACCOMPLISHED BY:

1. IMPROVING PRODUCTIVITY AND OPERATING AT FULL CAPACITY (100% IMPROVEMENT)
2. INCREASED DEMAND FOR MORE KVAR PER CAN (50% IMPROVEMENT)

NEW CAPACITY

60,000 MVAR/YEAR

CONCLUSION

TO REPLACE 2,800,000 CAPACITORS (280,000 MVAR) AND SUPPLY NORMAL CAPACITOR NEEDS WITH ABOVE ASSUMPTIONS WOULD TAKE 7.5 YEARS.

ESTIMATES BY THE INDUSTRY OF 5 TO 10 YEARS FOR REPLACEMENT SEEMS REASONABLE.

EPRI PCB PROGRAM

G. Addis
Project Manager
Electric Power Research Institute

EPRI PCB PROGRAM

by

Gil Addis, Project Manager
Electric Power Research Institute

Introduction

The background of the PCB problem has been repeated often enough for most of our readers to have committed it to memory; it does not bear further repetition. However, this background has fostered the emergence of new and different research and development programs. EPRI, as the R&D arm of the electric utility industry, has set as its goal, the initiation of a program that will aid the industry by developing improved PCB analytical techniques and means of destruction. It is anticipated that such developments could substantially reduce the cost to utilities in meeting regulations concerning PCBs in the electrical equipment. EPRI plans to do this by developing front-end feasibility with multiple approach funding. There is no intent or need to create competition for other developing processes.

Problems

The current set of problems, continuously updated, and already obsolete by the time this report is printed may be summarized as follows.

1. Detection and Analysis - Millions of transformers (how many million is still subject to some discussion) may be contaminated with PCB at some level. Knowing the level of contamination becomes particularly important in the case of spills, repairs, or eventual retirement and disposal. A rapid, field-useable, low cost means of analysis is needed. "On the spot analysis of spills" is particularly important. The removal of many drums of soil etc., followed by a repeat performance several days later, after laboratory analysis, is bound to have a poor psychological effect on nervous onlookers--not to mention the added cost to the utility.

2. Disposal of PCB liquids, until recently, was one of the prime areas of concern. Now, several commercial processes have come on stream, and others appear to be on the way. However a suitable approach for cleanup of PCB spills is still being sought.

Many utilities are looking for means to either replace PCBs with new non-flamable fluids in existing transformers or to replace the transformers entirely with non-PCB equipment. An optimized retrofilling technique to minimize material usage, disposal needs, and elapsed time is required.

3. PCB capacitors, because they constitute the greatest public exposure, are a problem of highest priority. A means of preventing their rupture and possible splattering of PCBs is needed. Today's commercial disposal operation requires shredding of the capacitors and does not seem at present to completely meet needed destruction capacity.

4. Contaminated Oil is perhaps the most widespread problem because of its presence in a significant proportion of utility equipment. The problem is of varying intensity depending on whether the contamination is below 50 ppm, between 50 and 500 ppm (considered contaminated by regulation), or above 500 ppm (considered equivalent to PCB liquids). Several commercial and semi-commercial processes now exist for destroying PCBs in contaminated oil and to some extent in the range above 500 ppm. There is a question about the reuseability of treated oil in transformers. As discussed in E. Norton's paper, the apparent need for pursuing reuseability has now diminished. In addition, a short time after this seminar, laboratory data has indicated no apparent loss of functionality of oils treated by several processes for PCB removal.

5. Health Effects - Many PCB animal studies have been made, and several epidemiological studies of PCB workers have been completed. No significant studies have been made on health effects on utility workers. Such studies might make positive answers available in response to health effects questions.

EPRI's Current Program

1. Detection and Analysis - A field usable instrument for total chlorine analysis has been modified and is presently being field tested by several utilities. (See papers by J. McQuade and A. Marquez in this volume).

   Several contracts for field usable PCB analysis instruments are in the evaluation or negotiation stage (E. Walsh and R. Nordstrom, Ibid). These may also be adopted for use in aiding spill cleanup.

2. PCB Liquids - Two projects are underway in which new designs will utilize substitute fluids [Westinghouse -

tetrachloroethylene (C_2Cl_4) and General Electric - trichlorotrifuoroethane (Freon R113)] and two phase cooling. Successful completion may provide transformers using new fluids that have lower evaluated cost than the PCB transformers they are meant to replace.

3. Capacitors - A package of instruments is being assembled by Westinghouse under EPRI contract to detect incipient failure of capacitors in service. This will permit removal of defective capacitors before they rupture, thus reducing public exposure in the area most prone to adverse publicity. (R. Tackaberry, Ibid)

   An experimental program for chemically destroying the PCB in shredded capacitors is underway with Acurex as the contractor. Other proposals to destroy capacitors without the need for shredding are being evaluated.

4. Contaminated Oil - EPRI has several contracts underway in this field. RTE has made a theoretical study of the adsorption of the PCB on solid insulation materials, and rate of diffusion into mineral oil (M. Thompson, Ibid). Both Franklin Research Center and General Electric are under contract to EPRI for the investigation of decontamination of mineral oil (A. Saggiomo and T. Rouse, Ibid). General Electric also is testing several decontaminated oils for reuseability in utility equipment.

5. Health Effects - SRI is engaged in a feasibility study to determine if enough data is available to make an epidemiological study of health effects in utility PCB workers. A workshop is planned for the near future.

Information Dissemination

Communication of PCB information from EPRI takes several forms. Formal reports are written at the conclusion of each project. One such report is FP1207. This four volume report on disposal of PCBs includes:

Vol I Disposal of PCBs and PCB-Contaminated Materials - (Oct 1979)

II Suggested Procedure for Development of PCB Spill Prevention and Control Countermeasure Plans (Oct 1979)

III Example Preparation of a Utility PCB Spill Prevention Control and Countermeasure Plan (Oct 1979)

IV Test Incineration of Electrical Capacitors Containing PCBs (Sept 1980)

A second form is the PCB Technical Report from EPRI. This is a short newsletter mailed at irregular intervals to those inter-

ested in PCB problems. It is issued whenever we feel there is something worthwhile to talk about.

EPRI sponsored an analytical workshop for PCBs in transformer oil during October 1980. This was followed by the PCB seminar in Dallas in December 1981. From the seminar have come, of course the procedings you are reading. In addition, a videotape of interviews of a number of the seminar speakers was made and is being edited for distribution.

Last but not least, we have tried to act as a clearing house for information. We have been receiving calls daily. Many of these callers are asking for advice, while others have information to pass on or suggestions for new avenues for future PCB related research.

Conclusion

EPRI will continue to actively seek solutions for current problems. We will modify our goals as EPRI perceives new needs or they become evident to our utility advisors. Several such impending needs surfaced following the involvement of a PCB transformer in a fire at a state office building in Binghamton, N.Y. One problem is the cleanup of contaminated particulate material (soot). A second and broader problem area is the development of more rapid and lower cost analytical means, coupled with toxicity data for polychlorinated dibenzodioxin (PCDD) and polychlorinated dibenzofuran (PCDF). A companion problem is the determination of what conditions, if any, cause the formation of PCDD and PCDF in utility PCB or PCB contaminated equipment. In the case of the PCDD/PCDF problems, EPRI is contemplating a coordinated attack with other interested groups.

Section 2

DETECTION AND ANALYSIS

PCB ROUND ROBIN ANALYSIS

T.O. Rouse
General Electric Company

PCB ROUND ROBIN ANALYSIS

T. O. Rouse
General Electric Company

A proposed method for the analysis of polychlorinated biphenyls (PCBs) in mineral insulating oils by gas chromotography is being developed by ASTM Committee D27-Electrical Insulating Liquids and Gases. The method has been given the designation D4059 and is being balloted at the Society level. It should be issued as a standard method in the 1982 Annual Book of Standards - Part 40 Electrical Insulation. (A preliminary version is in the 1981 version of part 40, p. 1063. The method has been modified to include the addition of oil to the chromatographic standards.)

A round robin analysis was conducted in 1981 to provide the basis for a statement of the precision of the method. The results are summarized in Table 1. Six transformer oil samples containing Aroclor 1242, 1254, and 1260 or mixtures were analyzed. Standards obtained from the Environmental Protection Agency were supplied along with the samples to be analyzed. EPA supplied standards were used to prepare five of the unknown samples. An Arcolor sample from another source was used for the sixth. Ten laboratories participated using the method as written. (Four additional labs used variations in the procedure and their results are not included in the summary). Transformer oil was added to the standards to compensate for the reduction of response of electron capture EC detectors caused by the oil in the unknown samples. Samples were treated with Florisil and/or

concentrated sulfuric acid to remove impurities containing electronegative elements to which EC detectors would respond.

The results have been analyzed in a preliminary way.

The average recovery - the amount found divided by the amount added was 98%. There is a hint in that data, that recovery of Aroclor 1260 is systematically low. More data is needed on this point. The average deviation is 15% (7.5 ppm at the 50 ppm level.) The data will be carefully evaluated statistically and an interim precision statement developed and added to the method. Concurrently another round robin will be gotten underway, this time involving a wide range of PCB concentrations.

Discussion:

Comments: There was discussion of the relative sensitivity and accuracy of the electron capture vs conductivity method. It was stated that there could be 20% difference in the methods. Versar is awaiting sample returns and it will be two to three months (Spring 1982) before data is available, and six months (July 1982) before the draft report is available.

Summary of Results
Round Robin

Method - ASTM D4059
Analysis of PCB in Mineral Insulating Oil

Committee D27 - 1980

	1 1242/1254	2 1242	3 1242/1260
$\bar{X}$ (ppm)	49.0	4.8	58.4
$\hat{\Sigma}$ (ppm)	6.3	---	7.5
V (%)	13	-0-	13
Added	46.8	5.0	68.1
Recovery (%)	105	---	86

	4 1260	5 1254/1260	6 1254
$\bar{X}$ (ppm)	49.0	39.2	30.9
$\hat{\Sigma}$ (ppm)	8.7	6.3	4.4
V (%)	18	16	14
Added	50.3	36.7	31.6
Recovery (%)	92	107	98

Average Recovery = 98%

Average V - Coefficient of Variation = 15%

PCB ANALYSIS BY X-RAY FLUORESCENCE

J. M. McQuade
General Electric Company

PCB ANALYSIS BY X-RAY FLUORESCENCE

J. M. McQuade
General Electric Company

In light of present federal regulations, it would be desirable to have a PCB field monitor that could signal that a given oil sample contained greater than or less than 50 PPM of PCB. I would like to review some aspects of an EPRI funded program aimed at the development of such a monitor.

This program was initiated in late 1979 and was funded in the amount of $73,000. During the course of the program, a number of methods were explored for potential field use. These included among others methods based on Combustion, Electrochemistry, Gas Chromatography, X-ray fluorescence and Spectrophotometry. Equal emphasis was not placed on each method. Heavy development emphasis was given to those methods which offered potentially the best combination of rapidity, simplicity, accuracy and reliability when used by non-technical people in the field. One of the methods that appeared to have a good chance to meet these criteria was x-ray fluorescence and so an intensive effort was launched. Before getting into the details of this method, I would like to point out that x-ray fluorescence is an indirect method for PCB analysis and actually measures the total chlorine content of the oil. Any field device that measures the total chlorine content must accommodate two facts.

First - Oil contaminated with PCB's may contain other chlorinated materials.

and

Second - A given chlorine level in PPM will correspond to a different PPM of PCB for different askarel compositions.

How then does one set a chlorine level to correspond to 50 PPM of PCB? Calculations relating the PPM of chlorine equivalent to 50 PPM of PCB for various askarel compositions were made. Askarels 1 thru 6 are mixtures of various aroclors and chlorobenzenes that were commonly used by transformer manufacturers. If one were to assume PCB contamination of oil occurs thru contamination by these askarels, the PPM of chlorine that need be detected by a field instrument is between 30 and 78 PPM. Since a field analyzer based on total chlorine is unable to discriminate between various askarels, it becomes obvious that one must assume no prior knowledge as to the source of contamination and it becomes prudent to assume all contamination comes from compositions like Askarel 2. This then in effect sets the sensitivity requirements of the analytical technique at 30 PPM of chlorine and also sets this level as a signal that the oil is contaminated with at least 50 PPM of PCB. The setting of the chlorine limit at 30 PPM would, of course, result in overestimating the PCB content of the transformer oil in many cases but this is desirable from a safety factor viewpoint.

Chlorine Equivalent to 50 PPM

Of PCB For Various Askarels

Askarel 1	66
Askarel 2	30
Askarel 3	46
Askarel 4	71
Askarel 5	78
Askarel 6	62

Chlorine Equivalent to 50 PPM

PCB For Various Aroclors

Aroclor 1242	21
Aroclor 1254	27
Aroclor 1260	30

Using the same rationale relative to contamination by transformer aroclors one would set the PPM level at 21.

In any event it became obvious at the outset of this program that the minimum sensitivity of the analytical field analyzer must be in the neighborhood of 20 to 30 PPM of chlorine.

The exact level above which one would assume greater than 50 PPM of PCB was still somewhat questionable early into the program. It was decided, however, that perhaps the signal level might be established by a comparative analysis for PCB and chlorine contents on oil samples taken from transformers at random. Field samples normally submitted to our laboratory by Utilities for PCB analyses were used for this comparative analysis and I will have more to say about this later.

Our activities and strategies, relative to x-ray fluorescence, were straight forward. First, we set out to establish that non-portable, wave length monitoring laboratory equipment, could be used as a go/no go screen to detect less then or greater than 50 PPM of PCB in transformer oil. In other words, we felt, that if the concept didn't work in the laboratory under carefully controlled conditions, using sophisticated equipment it certainly would not work in the field. At about the same time, we initiated cooperative efforts with manufacturers of portable x-ray equipment. I would like to say at this point that no portable equipment with the desired sensitivity was commercially available. It was our job to convince the manufacturers, that there was a need for such equipment and that they undertake the required research and development necessary for redesign. Obviously, we also evaluated the various offerings and suggested needed changes.

By way of review, it will be recalled that when an atom like chlorine is bombarded by x-rays, electrons are dislodged from the orbitals or shells and holes are created. These holes are immediately filled by electrons from other shells within the atom. This results in the emission of the secondary x-rays whose energy is equal to the difference in the electron energy before and after transition.

When transitions occur from the L shell to the K shell for instance, a secondary x-ray is emitted. This radiation can be characterized by its wave length and energy, both of which are related mathematically. The detection, counting, resolution and integration of these emissions is referred to as x-ray fluorescence analysis and the total of these emissions is proportional to the concentration of the element being studied.

Most permanently installed laboratory equipment monitor the wave length of the secondary x-rays. This tends to be more sensitive, in general, than those portable instruments which are termed non-dispersive and monitor the energy of the emitted radiation. In some cases, the energies associated with electronic transitions in the chlorine atoms, are very close to electronic transitions taking place in other atoms in the transformer oil.

This sets up a mutual interference and requires corrective action. By way of example, sulfur is a known interferrant when measuring chlorine by non-dispersion techniques.

Since a GEXRD-6 wave length dispersion instrument was available in our laboratory, we used it to determine whether or not chlorine in low concentrations in oil could be measured accurately and related to the PCB content. It was first determined that because of the resolution of the instrument, there were no elemental interferences. In other words, sulfur was no problem. Chlorine standards were then prepared by dissolving trichlorobenzene in transformer oil, the emitted radiation measured and a working curve of radiation intensity VS. chlorine concentration drawn. It will be noticed that the curve is linear over the entire concentration range of 0 to 500 PPM of chlorine. Five more samples were prepared as before. These were treated as unknowns and the chlorine concentration determined using the working curve. The comparison of the measured concentration VS. the actual composition looks like this. Obviously, the agreement was quite good and encouraging.

Several more samples were prepared, this time using aroclor rather than trichlorobenzene. A comparison of chlorine found and that actually present or calculated is quite good. It will be noted that the results are accurate over the complete concentration range for each of the aroclor tested.

With this then as background, we proceeded with our go/no go evaluation, using transformer oil samples which had been submitted by Utilities for conventional PCB analysis by gas chromatography. In this evaluation, a total of 177 samples were measured for total chlorine by the laboratory x-ray method just described. Those samples which contained less than 25 PPM of chlorine were predicted to contain less than 50 PPM of PCB and those that contained greater than 25 PPM of chlorine were predicted to contain greater than 50 PPM of PCB.

The results of these predictions were as follows:

. The number of samples predicted to be less than 50 PPM of PCB and were, was 118.

. The number of samples predicted to be greater than 50 PPM of PCB and were, was 37.

. The number of samples predicted to be greater than 50 PPM of PCB and were less, was 22.

. The number of samples predicted to be less 50 PPM of PCB and were more, was 0.

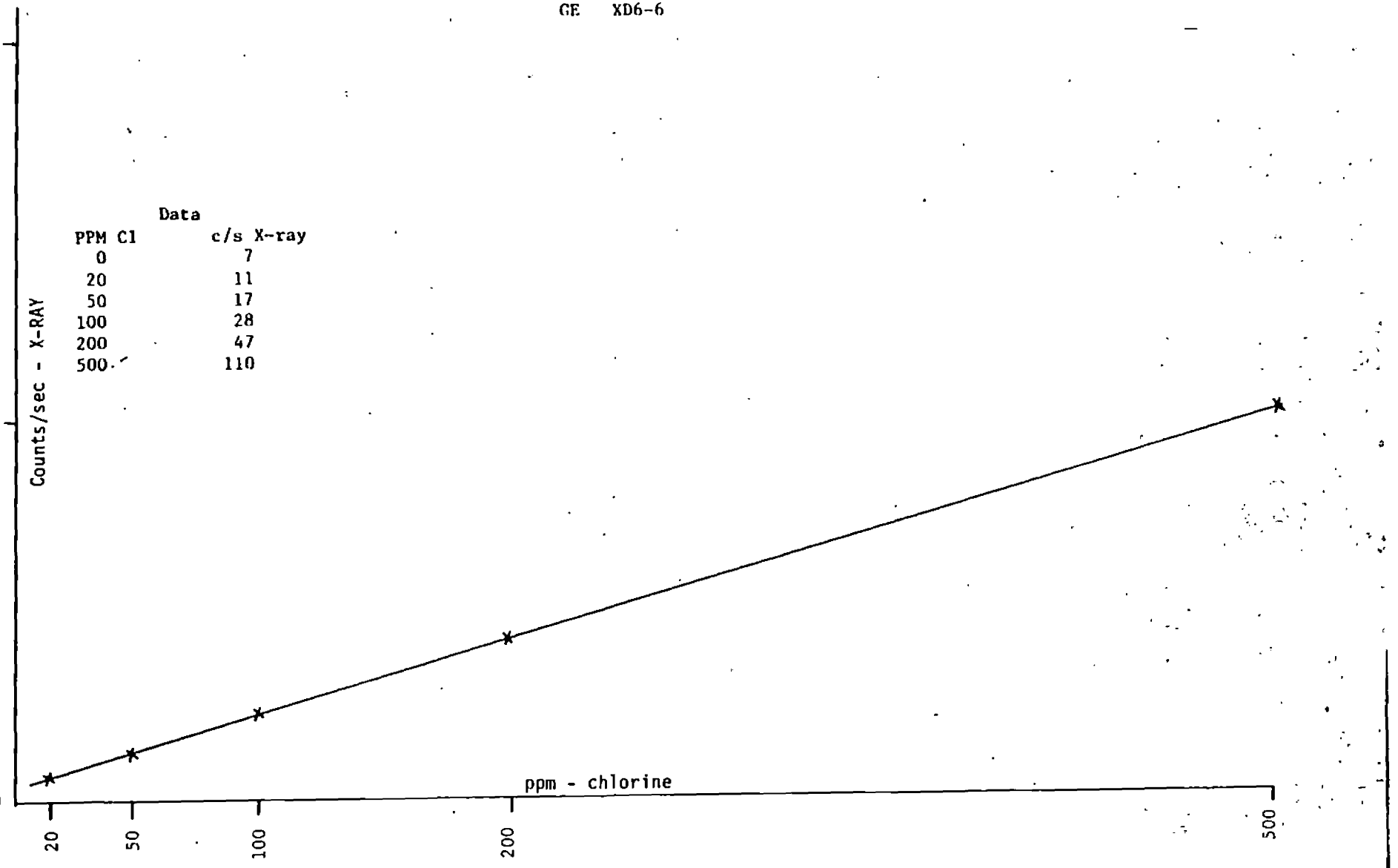
The most important predictions are the first and last. The last one says that in no case did the x-ray method predict less than 50 PPM when it

Working Curve

GE XD6-6

Data

PPM Cl	c/s X-ray
0	7
20	11
50	17
100	28
200	47
500	110



Unknown Comparison

GE XRD-6

Sample	Counts Sec.	PPM Cl (x-ray)	PPM Cl (actual)
1	12	24	25
2	18	54	50
3	8	4	10
4	13	28	28
5	29	104	101

Chlorine Determination By X-rays

GE XRD-6

Sample	Type	Calc. PPM (Cl)	Found PPM (Cl)
1	1254	200	208
2	1260	288	290
3	1016	191	192
4	1254	40	40
5	1260	58	50
6	1016	38	34
7	1221	15	10
8	1254	20	24
9	1260	29	34
10	1016	19	20
11	1221	8	< 10

was actually more. This would, of course, be an intolerable situation. The first prediction is important because it says that if the above samples had been field tested as unknowns, it can be seen that 118 or 67% of the samples would not have required further testing by gas chromatography. This, in turn, would result in substantial cost savings.

This now brings us to portable x-ray equipment. None of the commercially available instruments were specifically designed to measure low level chlorine concentrations. Two companies, however, Horiba Instruments and Princeton Gamma Tech. agreed to modify their equipment and have it evaluated by us at General Electric. Our evaluation of these prototypes indicated that the sensitivity and repeatability needed improvement but for a first try the results were not too bad. Horiba has redesigned their instrument and this second generation instrument, the MESA-200, is what I would like to discuss now.

The MESA-200 is a desk top, non-dispersive x-ray fluorescence analyzer. It's primary design objective was to provide an easy to operate, non-destructive, time-saving analytical method for chlorine in transformer oils. The instrument requires the use of helium gas and consists of two sections, the analyzer section on top and the data processing section on bottom. The analyzer section accepts the sample in a disposable sample cell as seen in this slide. The data processing section contains a micro computer unit, an electronic digital display and a printer. The latter supplying a permanent record of the test results.

Each section of the MESA-200 is 16 inches wide, 10 inches high, and 20 inches deep. The unit weighs under 100 lbs, 87.5 lbs to be exact, and while movable and, therefore, portable, you wouldn't carry it in your back pocket. The unit utilizes a low energy x-ray tube and no special licensing is required.

The specific instrument which we evaluated was precalibrated by Horiba and was kept in calibration by an occasional referencing operation which required measurements on two standard samples. The operation of the instrument is simple and only requires the pushing of a couple of buttons. There is no special sample preparation required nor is the operator required to interpret the results. While the count time and the number of repeat count times can be adjusted, we found that 100 second count times repeated three times, for a total of five minutes, was totally satisfactory. The printer, outputs a paper tape, which records for each sample, the average PPM of chlorine and sulfur and also the standard deviations.

Single specimen repeatability tests, using 100 second count times, were performed with samples at five different chlorine levels. The solutions used, actually contained 12, 22, 25, 55 and 61 PPM of chlorine. Ten consecutive repeat measurements were made with the results as shown. Also shown are the average values and the standard deviations. The single specimen repeatability is obviously very good.

SINGLE SPECIMEN REPEATABILITY

MEASUREMENT #	12	22	25	55	61
1	5	24	27	57	57
2	4	28	24	61	67
3	5	21	27	55	56
4	3	22	25	56	55
5	2	17	23	54	56
6	12	30	22	61	69
7	11	28	23	60	54
8	6	20	21	53	61
9	6	21	26	52	63
10	8	18	23	59	69
AVE.	6	23	24	57	61
STD. DEV.	±3	±2	±2	±3	±5

MULTI-SPECIMEN/MULTI-DAY REPEATABILITY

	PPM Cl				
TEST #	11	23	55	61	110
1	8	19	56	65	119
2	9	19	55	60	124
3	11	20	61	64	129
4	10	22	66		131
5	8	17	55		131
6	14	21	53		127
7	10	27	58		127
8	10	14			
9	5	25			
10	9	21			
AVE.	9	21	58	63	127
STD. DEV.	±2	±3	±4	±2	±4

- Each value is an average of 3-100 sec. counting timer

As previously noted, sulfur is a known interferrant to chlorine, in non-dispersive systems, but in the MESA-200 there is a built-in sulfur correction routine. To check this feature, oil containing .04 and .16% sulfur was spiked with trichlorobenzene to yield solutions containing 6, 11, 30, 49 and 99 PPM of chlorine. These results show that the sulfur correction is quite adequate at these levels of sulfur.

With this then as background, we proceeded with our go/no go evaluation, using transformer oil samples which had been submitted by Utilities, for conventional PCB analysis by gas chromatography. In this evaluation, a total of 142 samples were measured for total chlorine, using the MESA-200 just described. Those samples which contained less than 25 PPM of chlorine were predicted to contain less than 50 PPM of PCB and those that contained greater than 25 PPM of chlorine were predicted to contain greater than 50 PPM of PCB.

The results of these predictions were as follows:

- The number of samples predicted to be less than 50 PPM of PCB and were, was 90.
- The number of samples predicted to be greater than 50 PPM of PCB and were, was 29.
- The number of samples predicted to be greater than 50 PPM of PCB and were less, was 23.
- The number of samples predicted to be less than 50 PPM of PCB and were more, was 0.

The selection of 25 PPM of chlorine as the cut-off level would have resulted in accurately screening out 63% of all samples from further analysis. It will be recalled that this is approximately the same percentage as determined on different field samples using our laboratory equipment.

The effect of varying the cut-off level between 20 PPM and 30 PPM on the same set of 142 field samples while using the MESA-200 can be seen on the slide.

Here Land L means, the percent of samples predicted to be lower than 50 PPM of PCB and were lower.

Hand H means the percent of samples predicted to be higher than 50 PPM of PCB and were higher.

Land H means the percent of samples predicted to be lower than 50 PPM of PCB and were higher.

EFFECT OF SULFUR

CHLORINE (PPM)

PRESENT	MEASURED	
	.04%S	.16%S
6	4	2
11	10	8
30	26	29
49	50	45
99	102	98

EFFECT OF "CUT-OFF" LEVEL ON PREDICTIONS

"CUT-OFF"	L & L	H & H	L & H	H & L
20 PPM Cl	59%	21%	0	20%
25 PPM Cl	63%	21%	0	16%
30 PPM Cl	65%	21%	0	14%

The point here is, that the cut-off level you use, will depend on how safe you want to play it. If you believe that the PCB contaminating the transformer oil is accompanied by tri or tetrachlorobenzene use 30 PPM as the cut-off. If you have reason to believe aroclor 1242 alone, is the contaminant, use 20 PPM as the cut-off. In any event, out of every 100 samples, only 6 more need be analyzed by G.C. by selecting the cut-off at 20 as compared to 30 PPM. In either case, approximately 60% of the samples screened by x-ray would require no further analysis.

Discussion

Q. Is the method acceptable to EPA?

A. It has not been discussed with EPA since this method is considered screening and there are no screening standards.

Q. Will the method be accurate, down to 7 ppm?

A. We do not know, but estimate it will be satisfactory at 25 ppm but not at 7 ppm.

Q. Does a change in the contamination level of the samples from 0 - 100 ppm have any effect on detection?

A. No. Each sample is in its own cup. There is no contamination transfer.

Q. What is the possibility of using the method on spill clean-up residue?

A. High concentration of salts in the soil or residue could result in bad reading.

SALT RIVER PROJECT'S EXPERIENCE WITH THE HORIBA SULFUR/CHLORINE-IN-OIL ANALYZER

A. L. Schwalb
A. Marquez
Salt River Project

SALT RIVER PROJECT'S EXPERIENCE WITH THE HORIBA SULFUR/CHLORINE-IN-OIL ANALYZER

A. L. Schwalb and Al Marquez.

Because of the present EPA guidelines and the uncertainty felt by many utility people on the requirements for compliance, it is generally held that the only way to know that a transformer oil is non-PCB is to do an analysis on the gas chromatograph. The accuracy of results obtained by different laboratories is a subject of much discussion by many utilities. It will not be discussed in much detail in this paper, but it is of concern in our evaluation.

What is of equal importance is the expense of doing many analyses and the time involved in getting the results. There are many times when it would be helpful to have a quick, simple, accurate analysis on the level of contamination of an oil sample.

With the above considerations in mind, EPRI entered into a project with General Electric to investigate commercially available instruments to develop a simple, reliable test to measure PCB content in transformer oil. During the course of this work, the Horiba Instrument Company modified their sulfur-in-oil detector to include chlorine. The new instrument developed was the Horiba Mesa-200 Sulfur/Chlorine Analyzer.

The Salt River Project entered into an agreement with EPRI as a volunteer utility to test and evaluate the Horiba analyzer under various conditions. This presentation describes our experience with the use of the instrument in a laboratory setting and a limited portable field use.

The Horiba analyzer quantitatively measures total chlorine (and sulfur) in transformer oil based on non-dispersive fluorescent x-ray method. The method is non-destructive, and the analyzer can repeat each analysis up to 99 times, and will calculate average chlorine values and standard deviations. The analysis time can be selected from 10 to 1,000 seconds. All data is printed on paper tape.

The objective of the analysis for total chlorine content is to establish a level of chlorine below which it could be assured the level of PCB's would be under 50 parts per million (ppm). Based on the work performed at General Electric, it was concluded that measurement of 30 ppm of chlorine with the analyzer resulted in less than 50 ppm PCB's.

Our task at Salt River Project, as prime host utility, is summarized as follows:

I.a. Test the accuracy and repeatability of the instrument in a laboratory environment with oil samples of known levels of PCB's.

b. Test samples of oil with unknown levels of PCB's from transformers in the field.

c. Retest the same samples on gas chromatographs to measure PCB's.

c. Compare test results with the conclusions drawn by General Electric.

EXPERIENCE WITH HORIBA SULFUR/CHLORINE-
IN-OIL ANALYZER
ALSchwalb/Al Marquez

II.a. Install the instrument in a station wagon provided by EPRI.

b. Drive to various substations, draw samples, and test at the locations.

c. Record and catalog the information.

III.a. When the SRP work is completed, ship the instrument to the EPRI-selected utilities, providing the procedures developed, materials needed, and technical assistance as required.

b. Integrate information on experience gained at other utilities to refine the test procedures.

c. Check calibration on the instrument as it comes back from any utility and before it goes out to the next one.

Our work with the Horiba Analyzer, so far, has been a combination of all three tasks. Prior to taking part in this project, we had begun a program to analyze all our substation transformer oils. We simply combined that program with this project.

We have recently installed the instrument in a station wagon, and started going to several substations. About one month ago, I took the instrument to two utilities -- one in the Midwest and one on the West Coast.

Our report summarizes our work at all locations up to this time. We still have some more testing to do, especially in the portable mode, but the results we've had are of interest.

Initial tests performed on the unit were satisfactory in terms of repeatability and stability and, as far as we could determine, accuracy. That is, oil samples were tested and retested at different times and with varying lengths of analysis time and also varying number of repeats. The averages for the same, or duplicate, samples were within one to three ppm of each other. Measurement of the chlorine content of the materials used for calibration were consistently within one or two percent of the analyzed amount. After the initial tests, we tested around 80 oil samples taken from transformers on our system.

Since part of our task is to arrive at an optimum combination of number of repetitions and length of analysis on each repetition, we experimented with different combinations. At the time, we settled on testing each sample three times at an analysis time of 100 seconds each.

The results of our tests at SRP to this point are similar to those of General Electric.

Approximately 57% of the samples measured 30 ppm or less chlorine. Of this numbe all of those for which we have gas chromatograph (GC) analyses were under 50 ppm PCB's. We are in the process of analyzing the remainder of the samples.

EXPERIENCE WITH HORIBA SULFUR/CHLORINE-
IN-OIL ANALYZER
ALSchwalb/Al Marquez

Of the oil samples analyzed by GC, 75% were actually under 50 ppm PBC's. Only one was over 500 ppm PCB's.

More comments on review of the results later.

Midwest Utility Tests

We took the Horiba Analyzer to a Midwest utility to test approximately 430 oil samples from their system transformers. Twenty-one samples had been analyzed on the GC before the tests and an additional thirteen were done afterwards. The results are as follows:

Chlorine Content PPM			
0-30	31-50	51-300	Over 300
306	34	81	9

Before beginning the testing, we checked the accuracy of the analyzer by running some previously tested samples and also some calibration materials with known amounts of chlorine. The results were within two or three ppm of previous tests and very acceptable.

After a number of samples were run, a downward drift was noted and corrected by "re-referencing" and calibrating the instrument.

The results, in general, were similar to the pattern found before, Throughout the range of 0 to over 100 ppm PCB's, some samples were close in chlorine to PCB count, some were higher, some lower. Chlorine count less than 30 ppm resulted in levels of less than 50 ppm PCB's, except in one single case.

One sample tested 28 ppm chlorine on the Horiba analyzer and 90 ppm PCB according to the utility's GC analysis. Subsequent testing by SRP's consultant laboratory resulted in 79 ppm PCB's. A discussion on possible causes follows later.

West Coast Utility

The Horiba instrument was next shipped to the West Coast for use at a West Coast utility. Again, prior to testing, it was checked for accuracy.

Around fifty samples were tested on the analyzer. The interest was to check on the accuracy and repeatability of the instrument.

Most of the oil samples were analyzed for PCB levels or "spiked" with known amounts and types of aroclors. After testing began, it was again noted that the instrument had drifted. This time, upward. After "re-referencing," testing continued.

A review of the results indicate the readings may have remained somewhat high. The chlorine count on each sample was consistently higher than the PCB level or estimated chlorine level.

EXPERIENCE WITH HORIBA SULFUR/CHLORINE-
IN-OIL ANALYZER
ALSchwalb/Al Marquez

It was noted that, in general, levels of chlorine of 30 ppm or less, as measured by the instrument, resulted in levels of PCB much less than 50 ppm. However, one oil sample "spiked" at 50 ppm PCB with aroclor 1242 measured 29 ppm chlorine.

Analysis of Results

Our experience shows that the contamination of oil by PCB's, when it is found, usually consists of one or two of the aroclors 1242, 1254, or 1260. As it is generally known, the chlorination of the biphenyl was to a weight content percent of 42, 54, and 60, respectively. In addition, depending on certain specifications, the aroclors were mixed with chlorinated solvents in varying amounts, except for one askarel. According to ASTM Standard D2283-80, seven types of askarels (A through G) have been produced. All except Type E (containing aroclor 1242) were mixed with varying amounts of trichlorobenzene or tetrachlorobenzene, or a blend of both.

Since the Horiba analyzer measures total chlorine, it may be reasonable to assume a one-to-one ratio of chlorine to PCB on all types except Type E. For Type E containing aroclor 1242 and no solvents, the PCB amount would be multiplied by 0.42 to approximate the chlorine content, or conversely, divide the chlorine content by .42 to arrive at an approximate level of PCB's.

Since we have no way of knowing which aroclors are present in the oils, perhaps a count of 21 ppm chlorine would be the level we could be assured that less than 50 ppm PCB's are present.

It may be that, on a practical basis, there will be few cases of Type E askarel involved at the critical levels. Experience may show that the 30 ppm chlorine level will remain a conservative estimate for a threshold of 50 ppm PCB's.

Operating Experience with the Horiba Mesa-200

The instrument is simple to operate and easy to learn to use. The operator skill level would be on the order of an engineering technician or test technician.

Our experience showed that, at a stationary location, the instrument remained accurate and stable. Frequent checks of previously tested samples showed close results.

We have limited experience in using the analyzer in a portable mode. We noted a slight drift, easily corrected.

Of a little more concern may be in frequent shipping of the instrument by air freight. Some calibration and amplifier adjustment has been necessary. We are advised that the production model of this instrument automatically corrects for small amplifier drift.

We started out using three repeats and 100 seconds on each oil sample. However, on a large volume, we found that three repeats at 30 seconds gave us reasonable

results. Marginal averages or results with a large standard deviation can be reversed, usually with small changes. Routine testing will average around four minutes per sample, including sample preparation.

In testing large numbers of samples, it is wise to occasionally retest a known sample. It is also good to note the tread of results. For samples with no detectable levels of PCB's, the instrument often records low negative numbers. The absence of low or low negative numbers or too many may indicate a drift in the accuracy.

One precaution that needs to be taken is to avoid contamination of the oil samples with solvents on any substance that contains chlorine, since it will be measured by the instrument.

Using the instrument outdoors in the station wagon becomes a little more difficult. Sample preparation involves using a small piece of very thin mylar over a small plastic cup with oil. If any wind is present, it makes it difficult to handle. The digital readout window on the instrument is impossible to read in bright sunshine without shading.

The analyzer uses purified helium to purge the area around the sample window to remove dust or moisture, which can affect accuracy. In the instrument, we are using the helium runs constantly during and between tests, and has to be shut off at the end of testing. We understand that the production model turns the helium on only during an actual test. The use of helium should be much lower.

We will continue our evaluation of the instrument under different conditions. We are especially interested in the effect of large variations in temperature and moving the instrument in a station wagon.

Progress reports will be made to EPRI, and a final one will be made at the end of the testing period.

DISCUSSION

Q. The equipment is provided with a reuseable test cell. Did you use that cell?

A. No. The test cells were purchased separately and not reused.

Q. What is the cause of "drift"?

A. We believe it was due to transportation.

Comment: There will be some change in gain that will require rechecking for very low values of chlorine. It was suggested that some field readings of over 50 ppm from 5 ppm PCB contaminated oil may be due to other chlorine compounds in the oil. This method is a screening test which will eliminate a large number of samples from further testing. It is not absolute.

CHEMICAL TESTING FOR PCBs IN INSULATING OILS

E. J. Walsh
Westinghouse Electric Corporation

Chemical Testing for PCB's in Insulating Oils

by E. J. Walsh, Westinghouse Electric Corp

What is being described is a project to utilize chemical test methods to qualitatively and quantitatively analyze for PCB's in insulating oils. This EPRI sponsored project is scheduled to start in early 1982.

When using chemical reactions, the reaction matrix should be relatively well defined. This project addresses PCB's in insulating oils only. The reactions developed would not be directly applicable to soil or waste samples. However, once a reaction sequence is established, subsequent work could be performed to develop isolation techniques useable for these other mediums which could then utilize this chemical test method.

What we are proposing is a two tier test system which involves first applying a rapid semi-quantitative technique. If the data obtained from the screening test indicates the possibility for significant quantities of PCB's, a second more quantitative test would be applied. Our goal is to develop both types of tests using highly portable chemical test kits.

The advantages of chemical testing compared to currently utilized instrumental testing are: a) speed of test, b) portability of test equipment, c) very low investment in capital equipment, d) no special operator requirements, and e) elimination of sample disposal problems.

The screening test will be based on a rapid chemical destruction of the PCB's, and all other chlorine containing molecules, to give sodium chloride, then aqueous extraction. Following, we will apply a low cost and rapid method for detecting chloride or chlorine in water.

This latter detection can be carried out in a variety of well established methods. We propose, for reasons of accuracy and simplicity, to use a chloride specific electrode.

This method utilizes reuseable equipment, thus the only recurring costs are for the chemicals. A preliminary cost analysis indicates that sampling time will be the predominant cost factor. Therefore, the cost of chemicals can vary significantly without greatly affecting the overall cost of the test.

We will utilize known chemical processes for both the destruction and analysis. Field handling and safety will be primary considerations in selecting the final test scheme.

The main reason that this screening method cannot be used to quantitatively determine PCB content is that many arochlors or askarels contain tri and/or tetrachlorobenzenes. The chlorines in these species thus introduce an error in the PCB content proportional to their concentration in the mixture.

The tier two quantitative chemical tests will be designed to identify just the chlorinated biphenyl species thus reducing the analytical error to ±10%, or very close to the error in gas chromatography. This effort will be primarily conducted by a subcontractor and we have already identified several potential reaction schemes which could be utilized for this analysis. Selective nitration, coupling reactions, and ozonolysis are some of the proposed analytical routes.

In this portion of the project, the chemical reactions to be followed are not as well defined as destruction reactions. For this reason, the development time will be slightly longer to bring this test to the field test stage. We still anticipate that by the end of 1982, such a tier two test kit will be available.

INFRARED SPECTROSCOPY FOR FIELD MEASUREMENTS OF PCBs

R. J. Nordstrom
Battelle-Columbus Laboratories

B. McIntosh
Analect Instruments

INFRARED SPECTROSCOPY FOR FIELD MEASUREMENTS OF PCB'S

by

Robert J. Nordstrom
Battelle-Columbus Laboratories

and

Bruce McIntosh
Analect Instruments

We are at the beginning of an EPRI sponsored program to investigate and develop the use of infrared spectroscopy for quantitative measurements of polychlorinated biphenyls (PCB's) at the 50 to 500 ppm levels in transformer oils. In general, the spectroscopic method is a sensitive technique for studying the structure of molecules and the composition of samples. We have performed background work on the spectroscopy of certain Aroclors in order to establish the feasibility of the infrared method to make accurate field measurements of PCB levels in transformer oils. This background work was done using Aroclor 1242 and Aroclor 1016. We will soon begin studies using Aroclor 1260 and Aroclor 1254 along with pure PCB material in a variety of types and ages of transformer oil.

Fourier transform spectroscopy was used to collect transmittance spectra of thin film samples of the Aroclors and of uncontaminated oil. Samples were held between infrared transparent crystals. Figure 1 shows that if the radiation incident on the sample has a intensity I_o at frequency ν, then the intensity which exits the sample can be written

$$I_{out}(\nu) = I_o(\nu)\exp(-k(\nu)L) \quad , \qquad [1]$$

where L is the total path length through the sample, and $k(\nu)$ is the absorption coefficient.

Figure 2 shows the absorption coefficients of Aroclor 1242 and Aroclor 1016 which were run on our instrument. The strong, narrow absorption features are ideal for identification and measurement of the Aroclor. When the Aroclor 1242 is diluted in clean transformer oil at a level of approximately 500 ppm, the absorption features are still clearly visible as shown in Figure 3.

The goal of the research effort before us will be to optimize the infrared instrumentation for detection of PCB in transformer oil while discriminating against other compounds. The infrared region was selected for this task because the instrumentation is reliable and easy to use. Furthermore, it is sensitive, discriminating, cost effective, and very versatile. We are confident that in a year we will be able to report the operation of a breadboard model of our field portable detector for PCB measurement which will operate on the infrared absorption principle.

DISCUSSION

Q. What test rate will be available?

A. The rate will be less than 5 minutes per sample with the laboratory instrument. The goal for the field instrument is 3 to 5 minutes per sample.

Q. How about Aroclor 1260? You have shown results using 1016 and 1242.

A. The higher the chlorine content, the easier it is to interpret the record and the results.

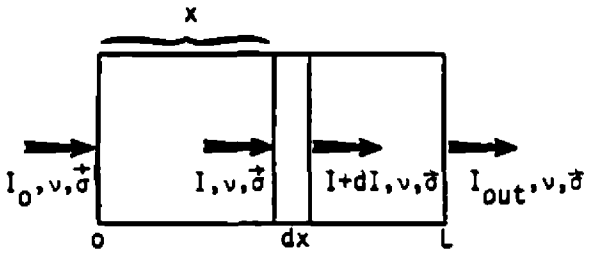
Q. Why not use the method for screening? Could the time be reduced?

A. The method can provide quantitative results in 3 to 5 minutes. If screening could be done in 5 to 10 seconds, it might have advantages and should be explored.

Q. What is the lower detection limit?

A. The signal to noise ratio is 300 to 1. Therefore, it can easily detect 50 ppm. How far below is still uncertain.

AN ABSORPTION EXPERIMENT



AT A DISTANCE X INTO THE ABSORBING MEDIUM,

$$dI = -kIdx$$

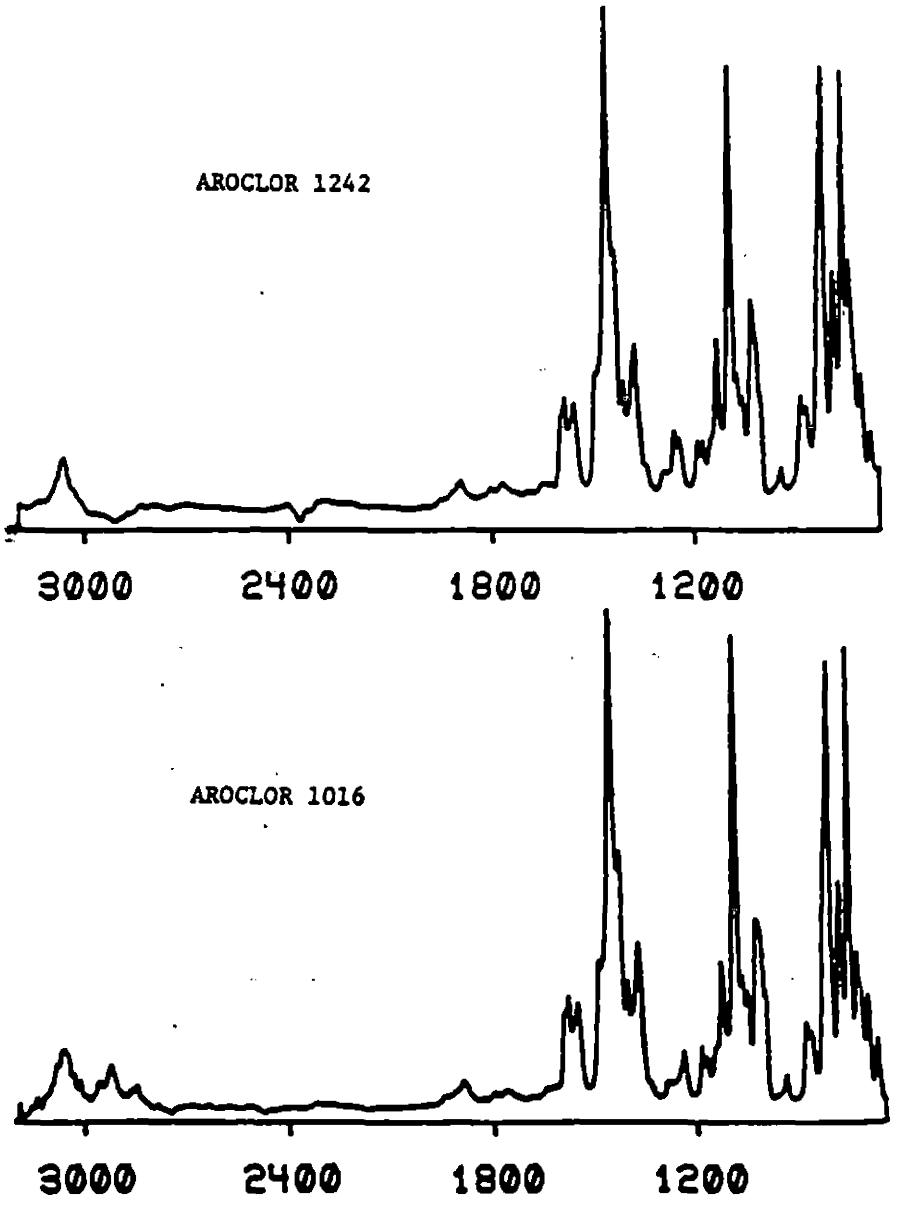
$$\int_{I_o}^{I_{out}} \frac{dI}{I} = -\int_{o}^{L} kdx$$

$$\ln\left(\frac{I_{out}}{I_o}\right) = -kL$$

$$I_{out} = I_o \exp(-kL)$$

k is the absorption coefficient at frequency ν

FIGURE 1.



INFRARED ABSORPTION COEFFICIENTS OF TWO COMMON AROCLOR MIXTURES

FIGURE 2.

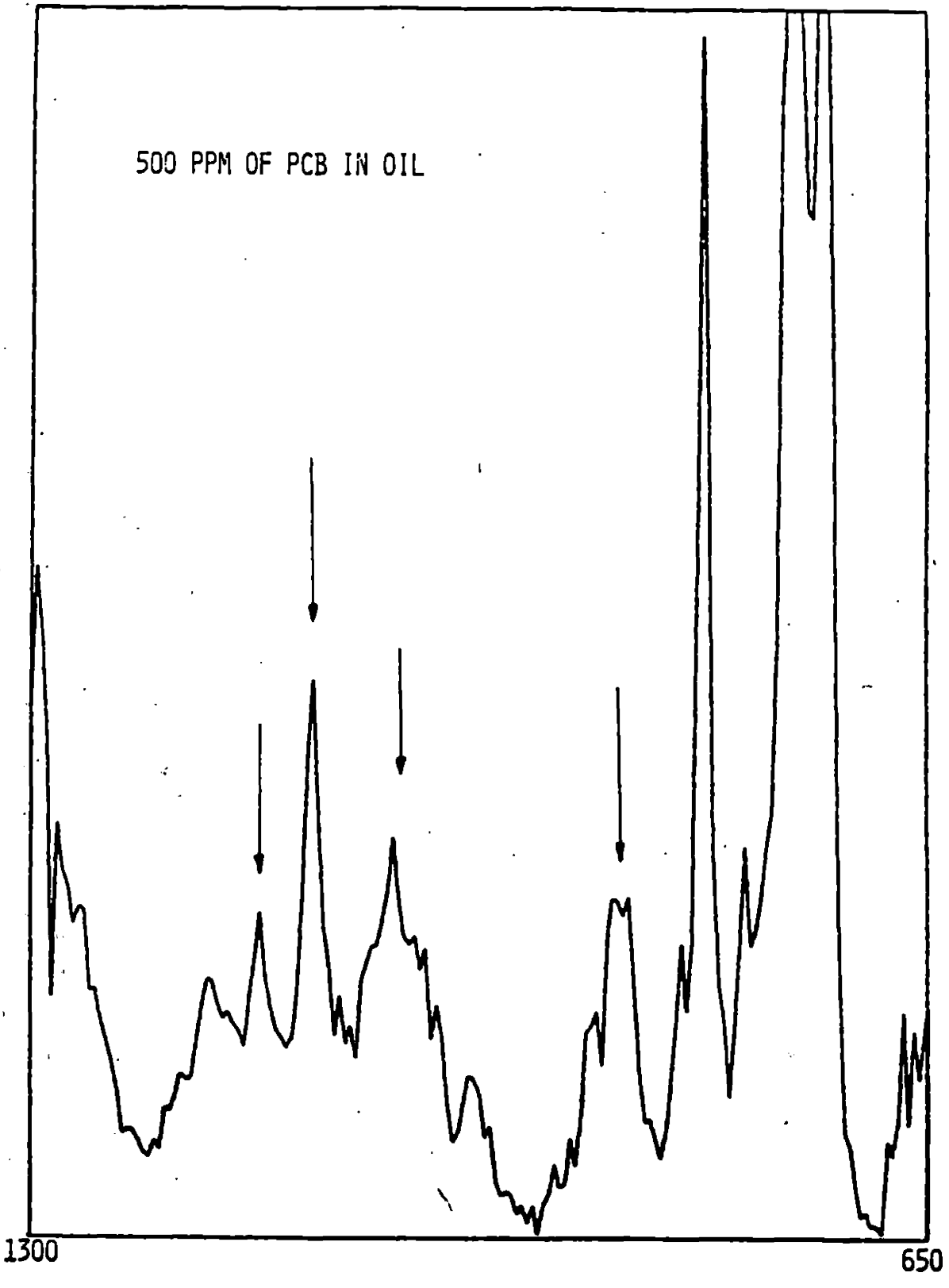


FIGURE 3.

Section 3

SPILL CLEANUP - ANALYSIS AND TREATMENT

PORTABLE FIELD MONITOR FOR PCBs

M. S. Denton
Chemical Separations Corp.

S. R. Dinsmore
W. D. Bostick
Oak Ridge National Laboratory

PORTABLE FIELD MONITOR FOR PCBs*

M. S. Denton, Ph.D.
R and D Department, Chemical Separations Corp., One Technology Drive, Knoxville, Tennessee 37922

S. R. Dinsmore and W. D. Bostick, Ph.D.
Advanced Technology Section, Chemical Technology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830

ABSTRACT

With the advent of recent regulations and those yet pending concerning allowable concentrations of polychlorinated byphenyls (PCBs), personnel in all aspects of the electric power industry, analytical support personnel, and those in the regulatory functions themselves have realized that the PCB problem, as well as these associated regulations, has far surpassed available monitoring capability. In short, detailed, stringent regulations are being set for contamination levels where no accepted ASTM procedure or instrumentation exists. The largest PCB problems exist in the form of PCB-contaminated oil in field transformers and storage containers, and pure askarel in transformers and capacitors. The most immediate need for a portable field instrument would be for use under PCB spill conditions. For use in such events, portable monitors based on the principles of photoionization detection (PID) and infrared spectroscopy (IR) have been adapted and evaluated. The latter includes both flow cell and horizontal multiple internal reflectance (HMIR) sampling configurations. For use in such spill conditions, extensive work has also been performed on solvent-solvent and solvent-soil extractions as well as PCB adsorption on packings.

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INTRODUCTION

Photoionization Detector (PID) Evaluation

Our initial intent in evaluating monitors for polychlorinated biphenyls (PCBs) was to adopt an analyzer based on photoionization detection (PID). The principle of the PID was simply that an organic molecule (RH) is bombarded by a photon of light (hv) of an energy equal to or greater than the ionization potential of the organic molecule. The charged species is then captured and quantified. The simplified mechanism is given below:

$$RH + hv \longrightarrow RH^{+} + \bar{e}$$

A six-month effort using this fascinating detection device found some difficulties inherent in PIDs, but these did not seem insurmountable. The real problem stemmed from the myriad of interferences found in various sources of PCB contaminated oil (PCB/OIL) and askarel. Askarel is a liquid insulation which had its origin in 1932 and was made by thinning Aroclor 1260 (60 weight % of chlorine on a biphenyl matrix) with trichlorobenzene or a tri-, tetrachlorobenzene mixture. This chlorinated, non-PCB solvent is, of course, the inherent difficulty of total chlorine detectors. In monitoring PCB/OIL or askarel spills, it became clear with interferences such as some polyaromatic hydrocarbons, nitrogen heterocyclics, and especially primary amines that we were dealing with an excellent sensitivity without the necessary selectivity.

A great deal of useful spin-off information was obtained, however, in this initial phase of the evaluation. One such area was the development of a bioassay for PCBs to determine toxicological effects. Tubing bomb

experiments where PCBs were heated in an oxygen environment were carried out to look at the possibility of furan and dioxin formation and their effects on biological systems. A more pertinent spin-off was the data compiled in attempting to overcome the interferences in PCB/OIL, etc. to PID. These attempts were in three discrete areas; (1) varying PID lamp energies, (2) evaluating solid adsorbents for PCBs or their interferences, and (3) utilizing radiolabeled PCBs in extraction experiments. In the first area, a great deal of effort was put into developing and fabricating an experimental 8.3 eV lamp. Such a lamp was to have enough energy to ionize PCBs without ionizing interferences. An 8.3 eV (146 nm) lamp was successfully developed but lacked the sensitivity capability of the commercially available 10.2 eV lamp. Some dozen solid adsorbents were also evaluated for their ability to isolate PCBs or their interferences. The most useful scouting work done (which was also applicable to our second phase infrared (IR) studies) was accomplished with radiolabeled PCBs. These tracer studies provided us with critical distribution coefficients in solvent-solvent and solvent-soil extractions. Such a counting technique also provided this data very rapidly (overnight) relative to conventional electron capture gas chromatography (one week).

It became increasingly clear in this initial phase of PCB-spill monitoring studies that what was really needed rather than cleaning up interferents in mineral oil (e.g., 10-C oil) was to make use of a technique that was not inherently plagued by oil. The obvious choice was that of infrared (IR) spectroscopy where oil is the solvent of choice over all other organic or aqueous solvents. That is to say that the

spectroscopic window afforded by 10-C oil (or any oil for that matter) is the best available to the technique. The mineral oil is also the solvent of choice for PCBs (thus the whole problem of oil contamination). We thus turned to IR feasibility studies which are the heart of this presentation.

Infrared Spectrometer Evaluation

Preliminary feasibility studies were carried out on a Digilabs Fast Fourier Transform Infrared (FTIR) Spectrometer. This unit afforded us the state-of-the-art in IR of sensitivity and flexibility. It should be pointed out here that FTIR was being considered for a fast turnaround feasibility study and not for portable or mobile operation. FTIR, by definition, requires a fairly sophisticated (and thus bulky) computer package and is a very delicate instrument due to internal moving mirrors.

Our first FTIR spectrum taken was that of 10-C oil. the region from 4000 to 700 wavenumbers (or cm^{-1}) is shown in Figure 1. The area of interest for PCBs (i.e., chlorine stretches) is from 1300-800 cm^{-1} (or 7-12 μ, which is the terminology we will use). The clear window that we hoped for is certainly evident here. Figure 2 is the spectrum of askarel (45% Aroclor 1260, 55% trichlorobenzene, TCB). The chlorine absorptions here are from PCB and TCB. The primary area of interest (7-13 μ has been pinpointed (with selected wavelengths) in Figure 3 for 10-C oil and further blown up in Figure 4. Looking at this same narrow region of 7-13 μ for an askarel/10-C oil (1:10) dilution in Figure 5, shows very sensitive chlorine peaks (e.g., 8.5, 9.2, 9.7, 11.3, 11.5 and

12.3 μ). These significant askarel/oil peaks are compared three-dimensionally with a 10-C oil spectrum in Figure 6.

INSTRUMENTATION

With this encouragement from our preliminary FTIR work, we turned our attention to possible portable IR instruments with conventional, simple and rugged single beam optics.

Miran 1-A

The instrument of choice for our initial evaluations is shown in Figure 7. The Miran-1A (Foxboro Analytical, South Norwalk, CT) is one of the simplest IR instruments available and, even with its capabilities, can be hand carried. Note the flow cell (0.2 mm pathlength, ZnSe windows, 9 μl cell volume) with its inlet and outlet tubing. An optical schematic is given in Figure 8 to more clearly illustrate the major components. Wavelength selection here is made with a circular interference-wedge filter, which does not give as much spectral resolution as a grating instrument but does provide higher sensitivity (due to less light loss). Figures 9 and 10 more clearly illustrate the operational characteristics and flexibility of the instrument. The first choice we were faced with after selecting the instrument was that of a cell window material. Table 1-A and 1-B list the choices available and their respective characteristics. Based on its wide spectroscopic range, durability, and inertness to aqueous samples (some water would, no doubt, be found in transformer oils), we chose zinc selenide (ZnSe) windows. As it turned out, this was the material of choice for horizontal multiple internal

reflectance spectroscopy (HMIR) to be discussed later. However, for high-sensitivity flow-cell work in the 7 to 12 μ region, barium fluoride (BaF_2) provided more light throughput (approximately 70% vs 40% transmission for ZnSe) and comparable water insolubility.

Miran-980

The majority of our work on monitoring PCB spills was actually carried out on a Miran-980 programmable IR, yet another Foxboro instrument (see Figure 11). This spectrometer was equally rugged, had similar optics (and thus similar resolution and sensitivity), and could be fitted with either a flow cell or HMIR like the Miran 1-A. What sets this instrument apart, however, is the fact that it is microcomputer controlled and is capable of on-the-fly background-corrected spectral scanning. Thus the black body curve, 10-C oil matrix, or TCB matrix can be subtracted. The Miran-980 also provides automatic analysis of mixtures with complete data reduction. As can be seen from Figure 11, the 980 provides (1) a keyboard for operating and data reduction functions, (2) a printer for "peak picking" and absorbance, transmittance or concentration readout, and (3) a cassette for methods storage.

Multiple Internal Reflection Spectroscopy

In addition to conventional, short-pathlength flow cell operation, we adapted a multiple internal reflection (MIR) cell to a Miran-980. The two common configurations of MIR cells are illustrated in Figures 12-A and 12-B. The former shows a vertical multiple internal reflection (VMIR) cell while the latter illustrates a horizontal multiple internal reflection (HMIR) window. Obviously, the sample sees twice as many

reflections in a VMIR cell as in a HMIR cell. The HMIR configuration, however, was used for all of our MIR studies due to its convenience and simplicity in handling spill-condition samples (e.g., askarel, PCB/OIL, or contaminated soil). A sample can be simply applied, scanned and wiped off (with an organic solvent) with no carry-over contamination or flow-cell clogging. For reasons of inertness, durability and wide spectral range, our Miran-980 work was done with a ZnSe-window HMIR. (For field work, ZnSe would be a must.) Table 2 lists the properties of available MIR crystals while Figure 12-C illustrates the light path, typical angle of incidence, and typical dimensions of such a crystal.

The principle of operation of MIR, also referred to as attenuated total reflection (ATR), is based on the fact that infrared energy being totally, internally reflected within a high refractive index optical material (e.g., ZnSe) will actually penetrate a short distance into the applied sample. If the sample absorbs energy from specific wavelengths, this attenuation of the beam, usually expressed as an absorbance, is related to concentration. Such MIR spectra closely resemble absorption spectra using a transmission cell. Figure 13 schematically represents a MIR optical diagram from source to detector which would apply to VMIR or HMIR. Finally, the advantages of MIR for field analysis are outlined in Table 3.

RESULTS AND DISCUSSION

As was mentioned previously, infrared spectroscopy is a natural choice for work in oil of any kind. We obtained the IR scans of several commonly used oils such as Nujol, which is, in fact, commonly used in the

sample preparation of IR mulls. Its characteristic absorbances, see Figure 14, were quite similar to those obtained by HMIR of light medicinal mineral oil (Figure 15), and 10-C oil (Figure 16), commonly used in filling transformers. The problem with this possible background matrix is, therefore, not one that would vary a great deal from sample to sample or utility to utility.

Our primary interest in developing an infrared detector for PCBs was in quantitative analysis, however, IR does lend itself also to qualitative identification. While it does not exhibit the characterization capabilities of gas chromatography (GC), the particular region we were dealing with is commonly referred to as the fingerprint region. As we had done previously by PID/GC, we examined several different PCB mixtures commonly found in cutting, cooling and transformer oils by HMIR. Figure 17 represents the scan of Aroclor 1242 (Thermino Fr-Lo, Monsanto). Subtle differences can be seen between the scan of this PCB (42 weight percent chlorine on biphenyl) and that of Aroclor 1248 (48 weight percent), shown in Figure 18. The spectral differences become more apparent when compared further with a scan of Aroclor 1260 (Figure 19). It is this latter PCB that is of primary concern in transformer contamination and spills. Unlike the lower molecular weight PCBs which have a liquid to syrup consistency, 1260 is a wax-like material. To scan this type of material by HMIR, required dissolution in a volatile organic solvent such as hexane, carbon tetrachloride, acetonitrile, etc. As this solvent vaporized from the horizontal MIR stage, a thin film was deposited. This has become the basis for extracting, depositing and preconcentrating PCBs from soil. Preconcentration is accomplished by

repeating these film deposition steps. A comparison of such a neat, standard 1260 film with several PCB/Oil dilutions is given in Figure 20. The 10-C oil (mineral oil) contribution was subtracted out from these, and all PCB/Oil scans, as was the black-body curve of the instrument.

A second interferent in PCB measurement in askarel is the typical thinning agent trichlorobenzene (TCB). The scan of TCB is shown in Figure 21. Although both PCB and TCB scans exhibit chlorine absorbances, significant differences in spectra are apparent. This solvent can represent from 40 to 60%, by volume, of an askarel (Pyranol is 45% 1260; 55% TCB). To determine which wavelengths were most selective for PCB 1260 over TCB, we ran HMIR scans of 1260 diluted (volume:volume) with varying amounts of TCB versus a neat TCB blank (see Figure 22). The observed peaks represent wavelengths selective for Aroclor 1260 over TCB. Conversely, the regions at the top of the figure, where transmission apparently exceeds 100%, represent wavelengths of selectivity for TCB over 1260 (due to the subtraction of the very large peaks in the TCB blank). From this scan, a plot of Aroclor 1260 weight/weight (W/W) versus Absorbance at various wavelengths (λ) was made. The linear least-squares regression analysis of this plot is given in Table 4. The correlation coefficients and relative standard errors are quite good for such a method. Looking at these factors and the fact that the 8.5 μ absorbance is the most distinct 1260 peak, this wavelength was concluded to be the most selective for PCB over TCB.

The final step in authenticating a transformer spill required the analysis of an actual askarel. For this purpose, a Pyranol (45 weight per-

cent 1260) sample actually extracted from an askarel transformer was scanned (see Figure 23). As was done with the Aroclor 1260 standard (Figure 20), this Pyranol sample was serially diluted with 10-C oil and scanned as shown in Figure 24. Each scan was blanked versus 10-C oil, with the top scan representing neat 10-C oil. Again, from these scans, plots were made for a number of wavelengths of Aroclor 1260 W/W versus Absorbance. These very linear plots are shown in Figures 25 and 26. Linear least-squares regression analyses of these plots were again made, and are presented in Table 5, to determine the best selection of wavelengths for sensitivity and selectivity. Combining the factors of sensitivity (slope), linearity (correlation coefficient), and precision (standard error), 9.2 μ was determined to be the best window for 1260 in 10-C oil. Similarly, 8.5 μ was selected as the best window for 1260 in TCB. Again, the relative errors (2-4%) are quite acceptable. Table 6 summarizes this rationale for wavelength selection.

Our final studies involved the development of two methods for measuring PCB in soil. In the first method, PCB was "extracted" from the soil using 10-C oil as the extractant/diluent. Here, varying amounts of used Pyranol were added to soil (14 to 70 mg 1260 per gram of soil). This contaminated soil was then contacted with 2 ml of 10-C oil. A theoretical removal efficiency of 100% was assumed for calculations, with an actual of 95%. The resulting supernate was subsequently injected into a flow cell (0.2 mm pathlength, ZnSe windows) on the Miran 1-A and scanned (100% transmittance was set with new 10-C oil). The calibration curves for these scans at several selected wavelengths are illustrated in Figure 27. It is clear that the IR absorbance is linearly related to

the amount of PCB or askarel applied to the soil.

The second quantitative method involved measuring the PCB in soil directly. This is, of course, the simplest possible technique for use in spill conditions. Here a sample of standard soil (60E Claiborne) was scanned by HMIR (dashed spectrum of Figure 28). Natural moisture was responsible for the spectrum present here. In other soil samples, no peak was seen at 10 μ providing an even better window. To this same soil was added a known quantity of used Pyranol (0.041 W/W 1260). This contaminated soil was then applied directly to the ZnSe, horizontal stage window and scanned (solid spectrum of Figure 28). It is evident from the overlay of these two spectra that a good window exists for PCB in soil.

With this qualitative success in direct PCB/soil measurement, a more quantitative experiment was designed. Here, a standard soil (68E Collegedale) was scanned (see the top spectra of Figure 29) and stored, along with the black-body curve, for background correction. Varying amounts of used Pyranol were then added to known weights of this soil, which were then scanned. These scans, as well as calibration curves for several wavelengths, are shown in Figure 29. IR absorbance was again quite linear with respect to the amount of Aroclor 1260 in the soil.

CONCLUSION

A method has been developed for the use in measurement of PCB or askarel under spill conditions. Appropriate instrumentation has been evaluated for use in portable, or at least mobile, field monitoring. Table 3 best

summarizes the advantages of HMIR spectroscopy in this application. Also, appropriate wavelengths for IR analysis have been chosen for sensitivity and selectivity under varying matrix interferences (i.e., mineral oil and trichlorobenzene). A film deposition technique has been described which will allow quantitative measurements of small quantities of askarel in soil (and other land-based substances). This is accomplished by multiple deposition of PCB films by evaporation of the extracting solvent. Finally, methods have been described for the analysis of PCBs in soil by extraction, as well as by direct measurement.

A good deal of work is yet ahead in confirming these preliminary results, checking various soil effects (e.g., moisture, etc.), screening possible interferences (e.g., pesticides), simplifying and specializing instrumentation, and finalizing the sampling protocol. Even with this as future work, it is felt that a feasible technique with associated, rugged and simple instrumentation has been demonstrated for askarel measurement in soil under spill conditions.

ACKNOWLEDGMENT

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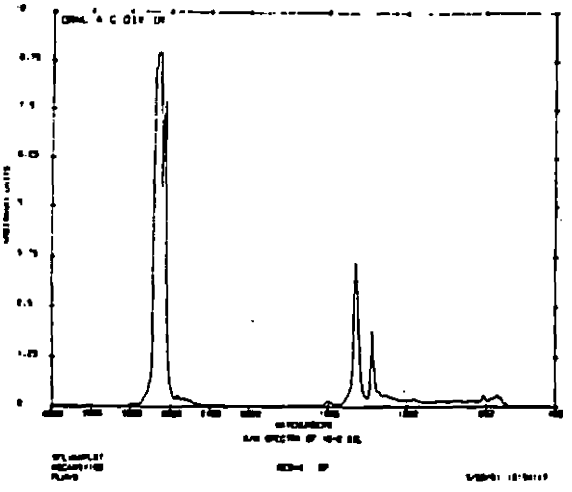


FIG. 1

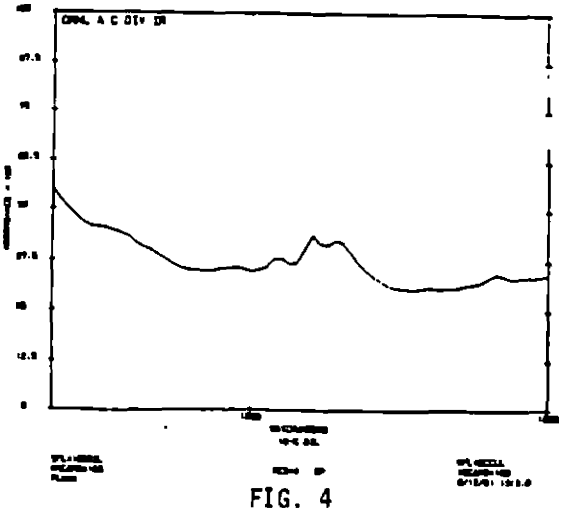


FIG. 4

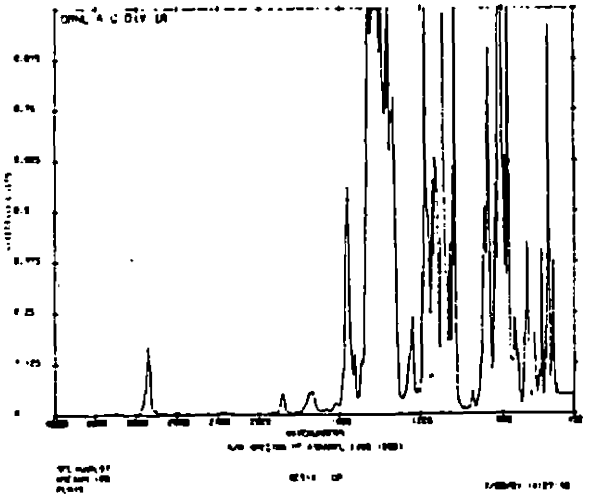


FIG. 2

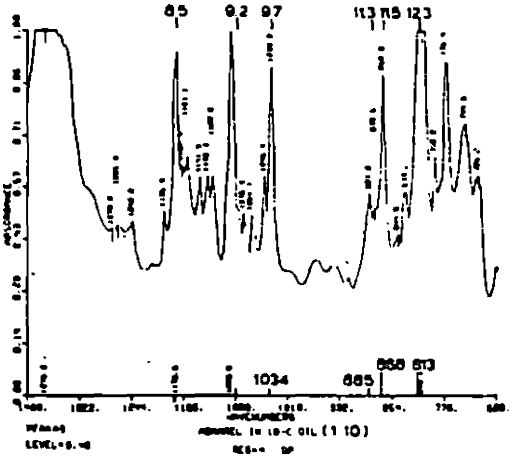


FIG. 5

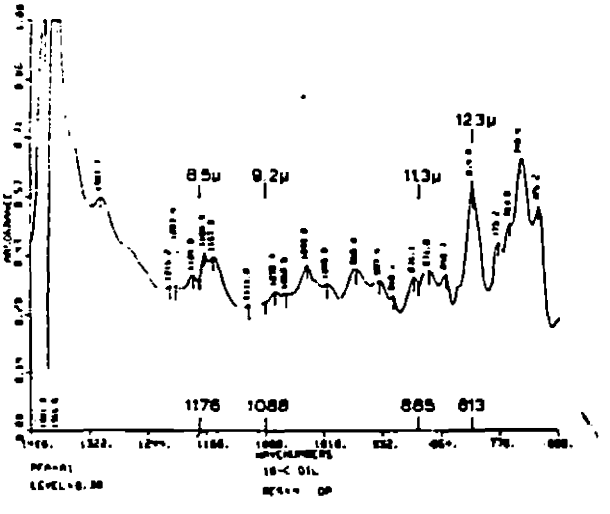


FIG. 3

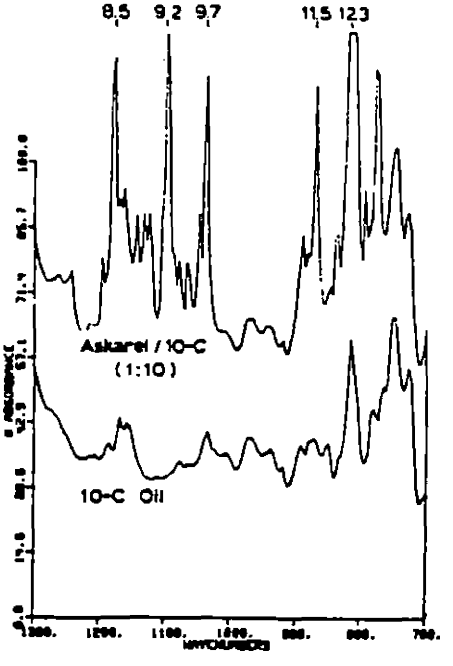


FIG. 6

MIRAN-1A IR Spectrometer

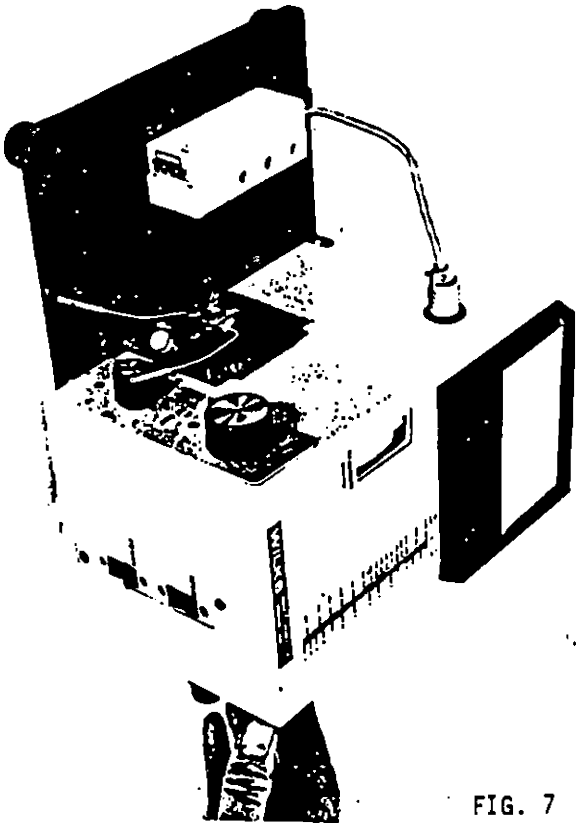
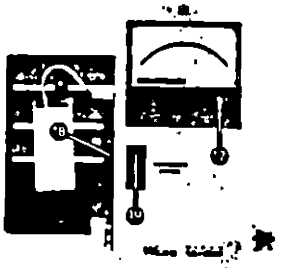


FIG. 7



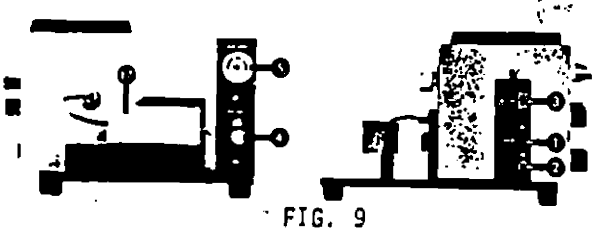


FIG. 9

Controls & Indicators

MIRAN-I

Optical Schematic and Major Components

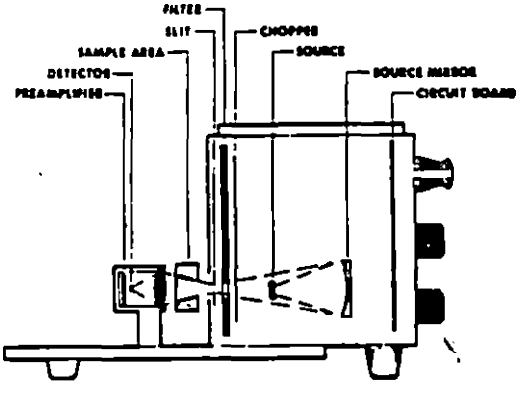
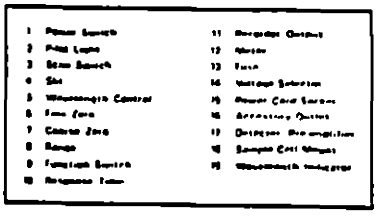


FIG. 8



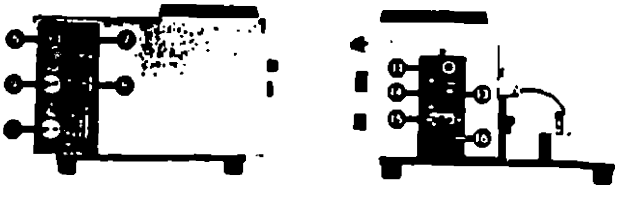
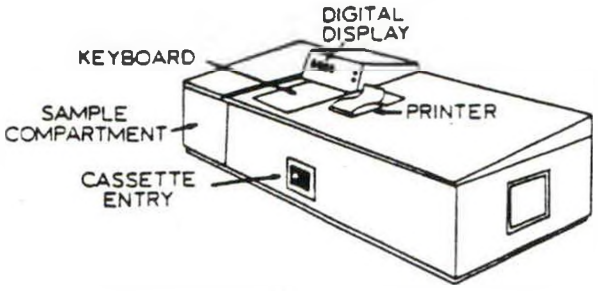


FIG. 10



MIRAN-980

FIG. 11

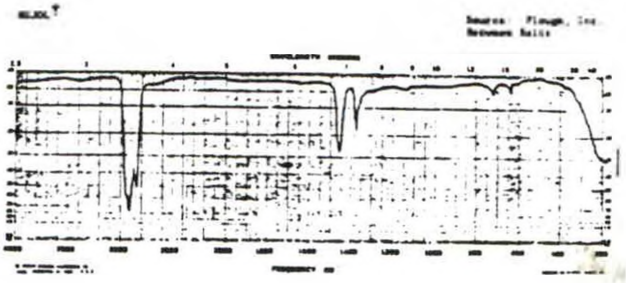


FIG. 14

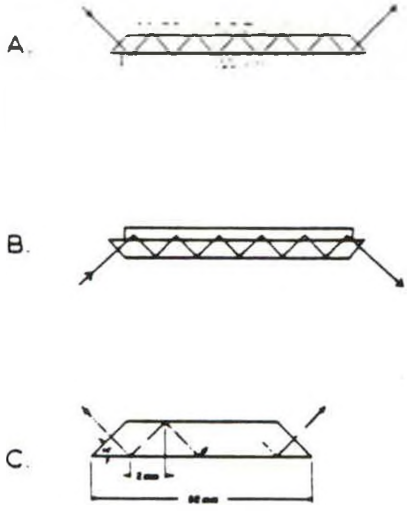


FIG. 12

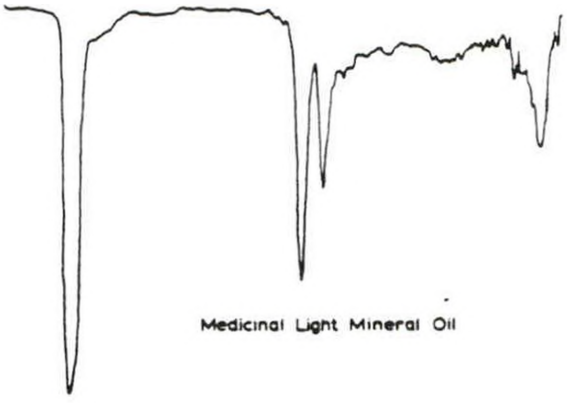
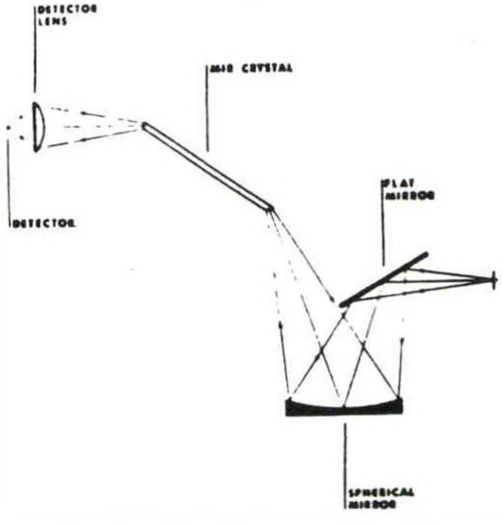


FIG. 15



TYPICAL MIR OPTICAL DIAGRAM

FIG. 13

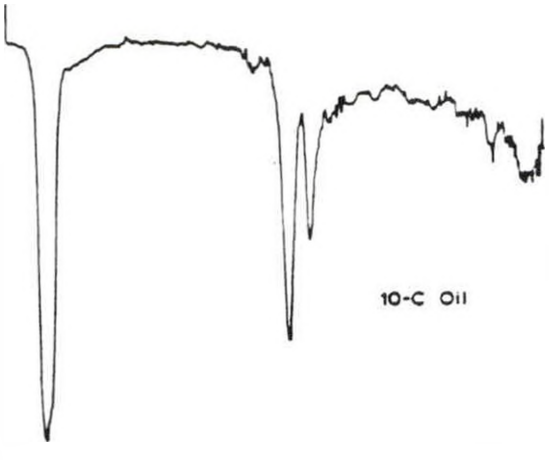


FIG. **

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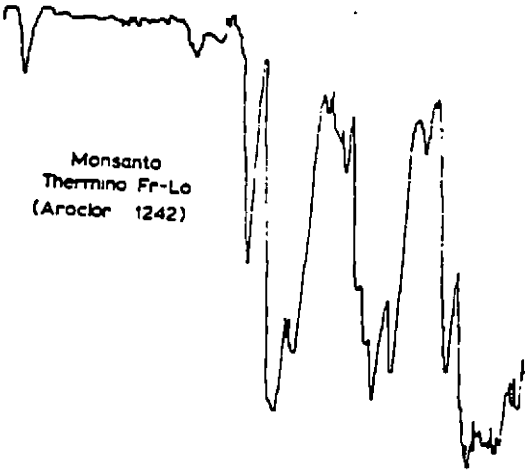

FIG. 17

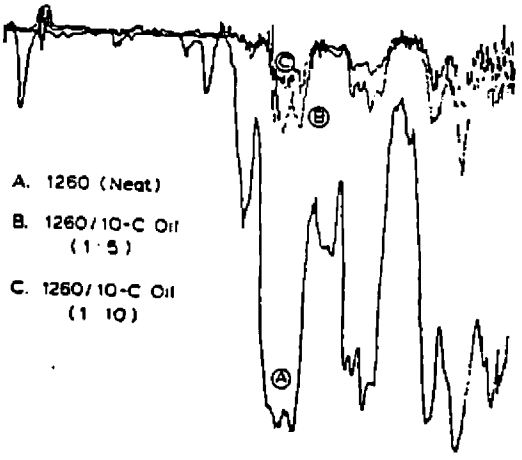

FIG. 20

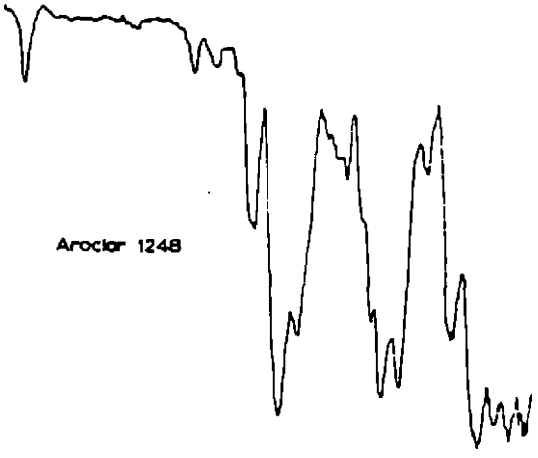

FIG. 18

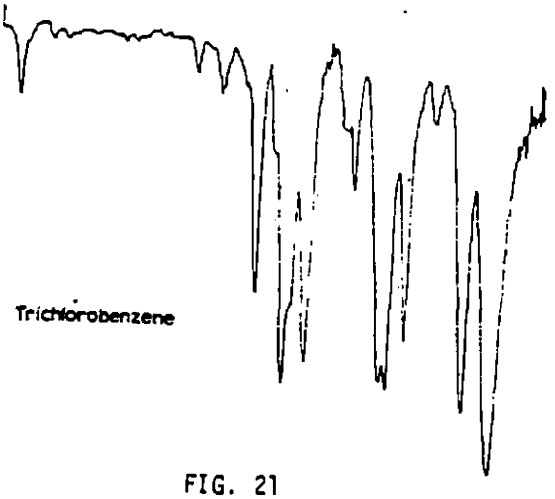

FIG. 21

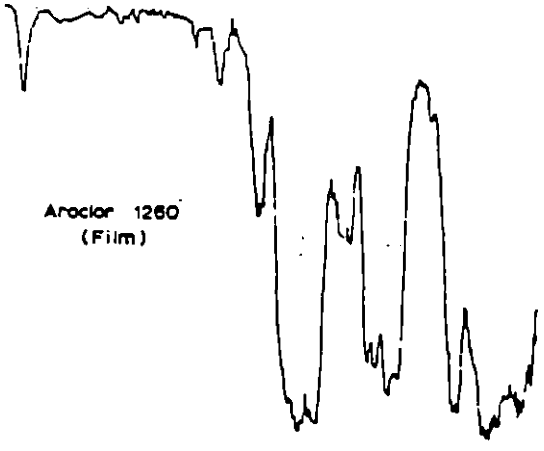

FIG. 19

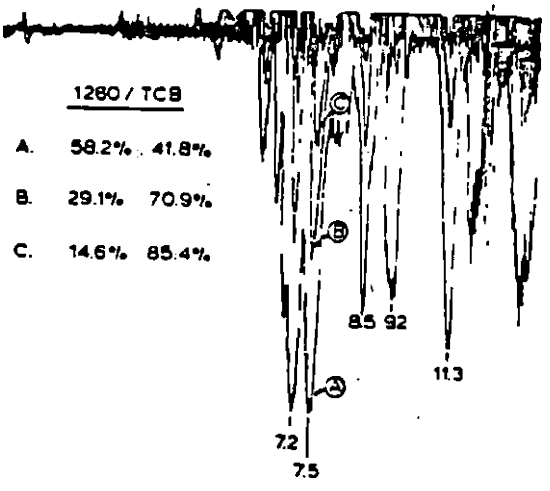

FIG. 22

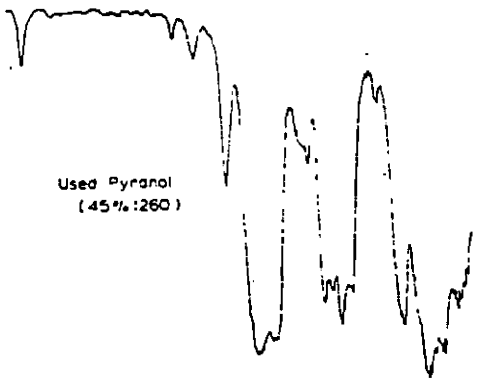

FIG. 23

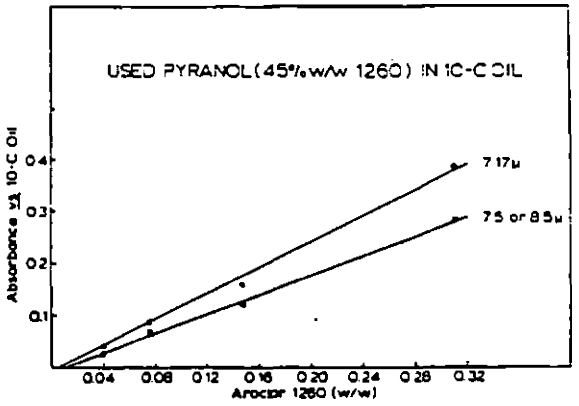

FIG. 26

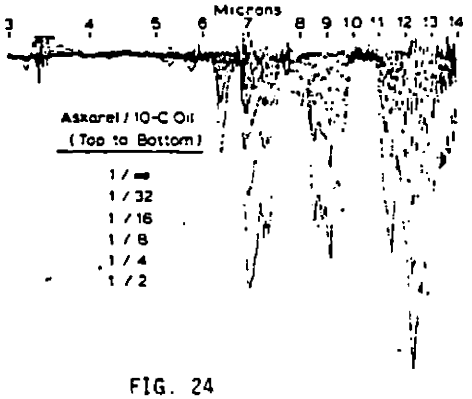

FIG. 24

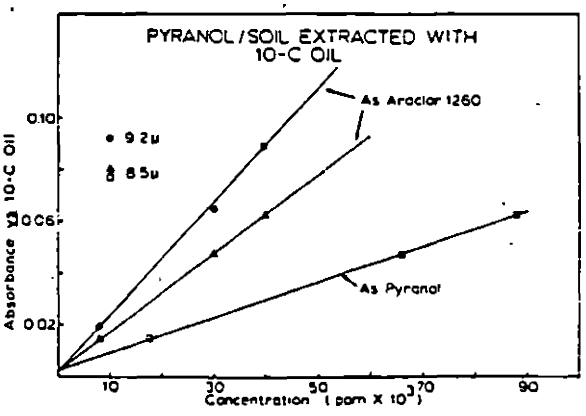

FIG. 27

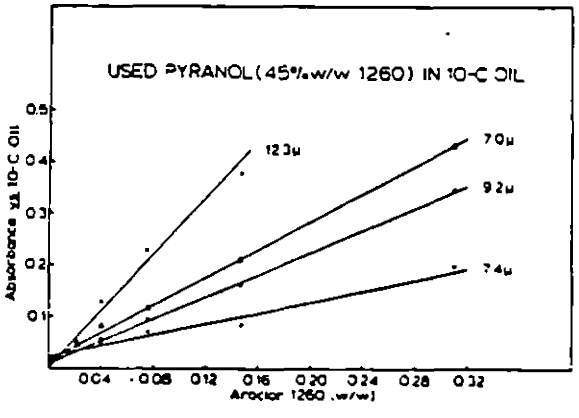

FIG. 25

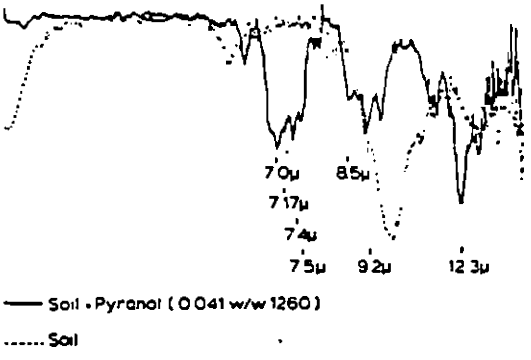

FIG. 28

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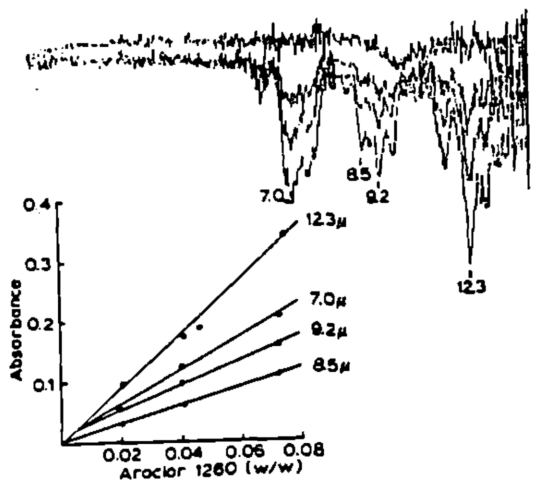


FIG. 29

PROPERTIES OF MIR CRYSTALS

MATERIAL	TRANSMISSION RANGE	INDEX OF REFRACTION	REMARKS
KRS-5 Thallium Bromoiodide (KRS-5)	0.5 - 35 um	[illegible]	Do not use with aqueous solutions. Good for solid samples but will cold flow with sustained pressure
Ge Germanium	2 - 11.5 um	4.0	Best for liquid sampling at room temperature. Do not use where high pressure contact with solid sample is required
Si Silicon	[illegible] - 6.2 um	[illegible]	Excellent for the near IR region
ZnSe Zinc Selenide	1 - 18 um	2.4	Best for aqueous samples. ZnSe is brittle and must be used with care for solid sampling
Sapphire	1 - 5.5 um	1.8	High chemical resistance. Best in the near IR
Diamond	[illegible] - 50 um	2.4	High chemical resistance

TABLE 2

PROPERTIES OF TRANSMISSION WINDOWS

MATERIAL	TRANSMISSION RANGE	INDEX OF REFRACTION	REMARKS
KBr	0.25 - 25 um	1.53	An excellent, low cost material with extended transmission range. More hygroscopic than NaCl
NaCl Sodium Chloride	0.25 - 15 um	1.52	The most generally useful low cost cell material. Water soluble. Withstands thermal and mechanical shock
BaF_2 Barium Fluoride	0.2 - 11.5 um	1.46	Has wider transmission range than CaF_2. Insoluble in water and resistant to fluorides. Sensitive to thermal and mechanical shock. Do not use with solutions of ammonium salts

TABLE 1A

ZnSe Zinc Selenide	1.0 - 18 um	2.4	Best for aqueous samples. ZnSe is brittle and must be used with care for solid sampling.
AgBr Silver Bromide	0.5 - 35 um	2.2	Broader useful range than AgCl. Soft material and flows under pressure. Loses transmission after exposure to UV light.
CaF_2 Calcium Fluoride	0.15 - 8 um	1.42	Particularly useful in high pressure cells. Insoluble in water and resistant to acids and bases. Do not use with solutions of ammonium salts.
[illegible] Infrasil	0.21 - [illegible] um	1.46	Limited IR transmission range. Water insoluble. Strong and resistant to acids and oxidizing agents.

TABLE 1B

ADVANTAGES OF MIR

- USEFUL FOR STRONG IR ABSORBERS
- AQUEOUS SAMPLES OR THOSE CONTAINING SOME WATER (ZnSe WINDOW)
- HORIZONTAL MIR IS BEST SUITED FOR NON-VOLATILE, VISCOUS, GUMMY, OR SEMISOLID SAMPLES
- VERTICAL MIR CELLS ARE AVAILABLE FOR VOLATILE OR LOW VISCOSITY SAMPLES
- CAN BE USED FOR LIQUIDS CONTAINING SUSPENDED SOLIDS (ELIMINATES SCATTERING PROBLEMS COMMON IN TRANSMISSION CELLS DUE TO PARTICULATE MATTER)
- ELIMINATES DILUTION ERRORS
- ELIMINATES CELL ALIGNMENT
- RAPID SAMPLING WITH NO CARRY-OVER CONTAMINATION
- ELIMINATES INTERFERENCE PATTERNS FOUND IN SHORT PATHLENGTH TRANSMISSION IR CELLS

TABLE 3

Aroclor 1260 in TCB vs TCB

(Plot Aroclor 1260 w/w vs Absorbance $a\lambda$)

Selectivity — Linear Least-Squares Regression Analysis

	λ_1 7.17μ	λ_2 7.5μ	λ_3 8.5μ*
Slope	1.687 ± 0.110	1.697 ± 0.187	0.922 ± 0.085
y-Intercept	-0.198 ± 0.042	-0.153 ± 0.072	-0.109 ± 0.033
Corr. Coeff.	0.9979	0.9940	0.9958
Rel. Std. Error	5.35%	8.05%	7.56%

*Best selectivity (distinct peak)

TABLE 4

Aroclor in 10-c Oil vs 10-c Oil

(Plot Aroclor 1260 w/w vs Absorbance $a\lambda$)

I. Sensitivity — Linear Least-Squares Regression Analysis

	λ_1 7.0μ	λ_2 7.4μ	λ_3 9.2μ	λ_4 12.3μ
Slope	1.275 ± 0.049	0.553 ± 0.078	1.088 ± 0.029	2.552 ± 0.076
y-Intercept	0.032 ± 0.008	0.021 ± 0.013	0.009 ± 0.005	0.017 ± 0.012
Corr. Coeff.	0.9978	0.9828	0.9995	0.9987
Rel. Std. Error	4.85%	10.7%	2.19%	4.52%

*9.2μ Best window in 10-c oil

II. Selectivity

	λ_1 7.17μ	λ_2 7.5 or 8.5μ**
Slope	1.274 ± 0.054	0.948 ± 0.033
y-Intercept	-0.0125 ± 0.0095	-0.009 ± 0.006
Corr. Coeff.	0.9982	0.9986
Rel. Std. Error	4.66%	4.0%

**8.5μ Best selectivity for 1260 over TCB

TABLE 5

IR Absorptivity

$\lambda(\mu)$	Aroclor 1260	Pyranol	TCB	10-c Oil
7.0	↔(P)	↔(P)	↔(S)	↔↔(P)
7.14	↔(S)	↔(S)	±(V)	- (V)
7.4	↔(P)	↔(P)	±	±
7.5	↔(P)	↔(P)	-(V)	-
8.5	↔(P)	↔(P)	±(S)	-
9.2	↔↔(P)	↔(P)	±(V)	-
12.3	↔↔(P)	↔↔(P)	↔↔(P)	±

↔↔ Strong Absorbance

↔ Moderate Absorbance

± Weak Absorbance

- Very Weak Absorbance or Window

(P) Peak

(S) Shoulder

(V) Valley

TABLE 6

TREATMENT OF PCB-CONTAMINATED SOILS WITH THE THAGARD HIGH-TEMPERATURE FLUID-WALL REACTOR

E. Matovich
Senior Vice President

Thagard Research Corporation
2712 Kelvin Avenue
Irvine, California 92714
714/556-4470

ABSTRACT

A High-Temperature Fluid-Wall Chemical Reactor in which the process stream is kept out of physical contact with any part of the Reactor, and a process in which energy is totally provided by coupling of blackbody radiation to provide continuous process temperatures greater than 4000°F, has been developed by Thagard Research Corporation, and has been used to completely pyrolyze a wide variety of halogenated organic compounds and to fix their inorganic residues into non-leachable glasses. The infinite turn-down ratio of the machine and the heterogeneous nature of the radiative heat transfer mechanism in which only radiatively absorbing species are heated rather than the entire process stream, leads to the prospect of efficient and low-cost treatment of PCB-contaminated soils.

Simple pyrolysis tests with hexachlorobenzene as a chemical surrogate have indicated consistent destruction levels better than 99.9999% with indications of destruction levels better than nine nines.

An EPA-sanctioned series of tests with 500 ppm PCB in Southern California soils, representing an accidental capacitor or transformer spill is currently underway in a 3-inch bench scale Reactor.

Process scaling parameters are described up to a throughput level of 100 tpd and the cost factors are described for an operational plant at this level.

I. INTRODUCTION

Many chemical and physical methods for destroying PCBs, whether pure or as high-level contamination in oils, have been developed and proposed as environmentally safe practices to be applied to removal of PCBs from those particular forms.

However, most wastes in which PCBs occur are generally very complex mixtures of many chemicals, along with inert materials and frequently at very dilute levels, such as the 200 to 500 ppm levels encountered in contaminated soils from spills from power line capacitors and other pole-mounted apparatus. Another form of dilute PCBs is in contaminated silts and deposits found in river, lake, and lagoon beds. While these finely-divided forms of contaminated materials represent only a portion of the PCBs problem, they are uniquely suited to thermal treatment in the Thagard High-Temperature Fluid-Wall (HTFW) Reactor, where rapid excursions on the surfaces of the individual solid particles to temperatures as high as 4000°F promote complete reactions of a wide variety of chemicals to benign substances such as flareable gases and non-leachable slags.

This non-specific characteristic of reactions performed in the reactor allows a wide variety of contaminated substances to be treated without undue concern for the starting composition of any.

II. THERMAL TREATMENT OF TOXIC SUBSTANCES, IN GENERAL

It is possible, at least in theory, for all substances to be converted into physical and chemical forms which can be introduced into the environment without adverse long-term effect. The cost effectiveness of such processes, however, is somewhat more problematical.

From a purely technical point of view, we can categorically state the following:

1. All organic chemical compounds are made up of a relatively few characteristic chemical bonds, all of which can be broken by application of sufficient energy to overcome the bond strength.

   Corollary a. The energy can be supplied by any number of methods including energetic particle impact, chemical reactions or vibrational energy from thermal excitation.

   Corollary b. Once the chemical bond has been broken, it can be replaced with another bond which is more acceptable to the environment.

2. All inorganic toxic compounds, particularly heavy metals, can be converted into other compounds which by themselves or in combinations with yet other compounds can, for all practical purposes, be rendered insoluble in water of any naturally-occuring composition.

From a technological point of view, the most practical methods of achieving the mechanisms described in 1. are those which heat the substance for a sufficient period of time in:

a) the absence of secondary chemicals to produce elemental forms of the starting material such as C, H_2 and (e.g) Cl_2 in the case of chlorinated hydrocarbons (pyrolysis);

b) the presence of oxygen (air) to produce CO_2, H_2O, N_2 and HCl (incineration);

c) the presence of oxygen (air) and H_2O to produce CO, H_2 and HCl (gasification); or

d) the presence of oxygen, H_2O and $Ca(OH)_2$ to produce CO, H_2 and $CaCl_2$ (gasification with gettering). If necessary, further treatment is yet possible which will lock up the $CaCl_2$ in an insoluble vitreous mass.

Once having decided that thermal treatment is the preferred direction to take the waste treatment, it follows that the higher the temperature the faster the process or, conversely, given a fixed amount of time the more complete the process. Reactions proceed more or less according to the relative population of energetic vibrations, such as are given by the Arrhenius equation:

$$N_{(E)}/N_0 = EXP - \Delta E/kT, \text{ where}$$

$N_{(E)}/N_0$ is the fraction of all molecules at energies above ΔE,

ΔE = activation energy or bond strength, whichever is the limiting factor,

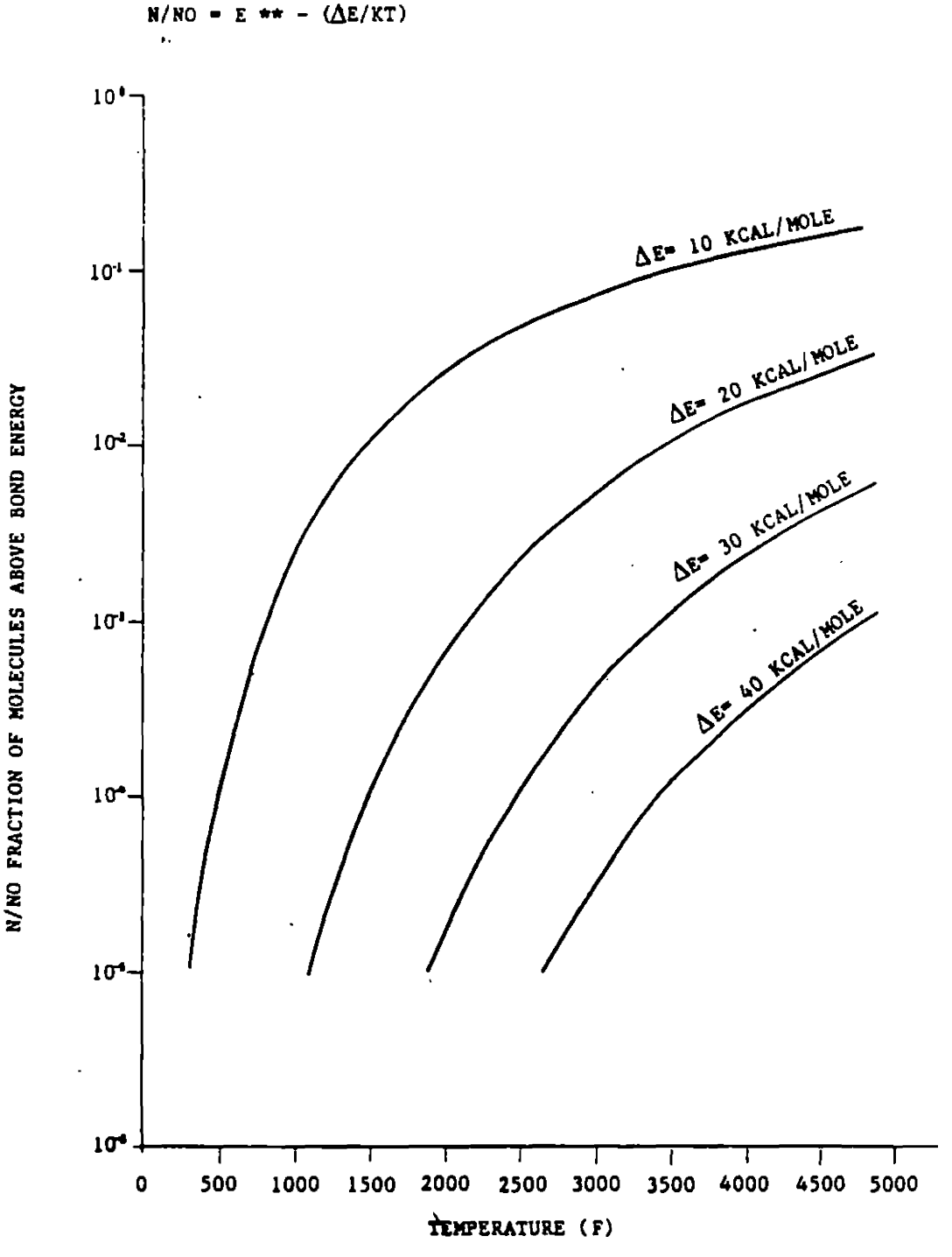
k = Boltzmann constant

T = absolute temperature

The above equation is plotted in Figure 1, showing N/N_0 vs T for hard energies of 10, 20, 30 and 40 Kcal/mole. Inspection of Figure 1 shows that for a 30 Kcal bond N/N_0 is about 100 times higher at 4000°F than it is at 2000°F.

The Thagard Reactor finds its greatest application in each of these cases when the very rapid rate of temperature change and the high terminal temperature produce the products in a fraction of a second with little or no possibility of secondary reactions.

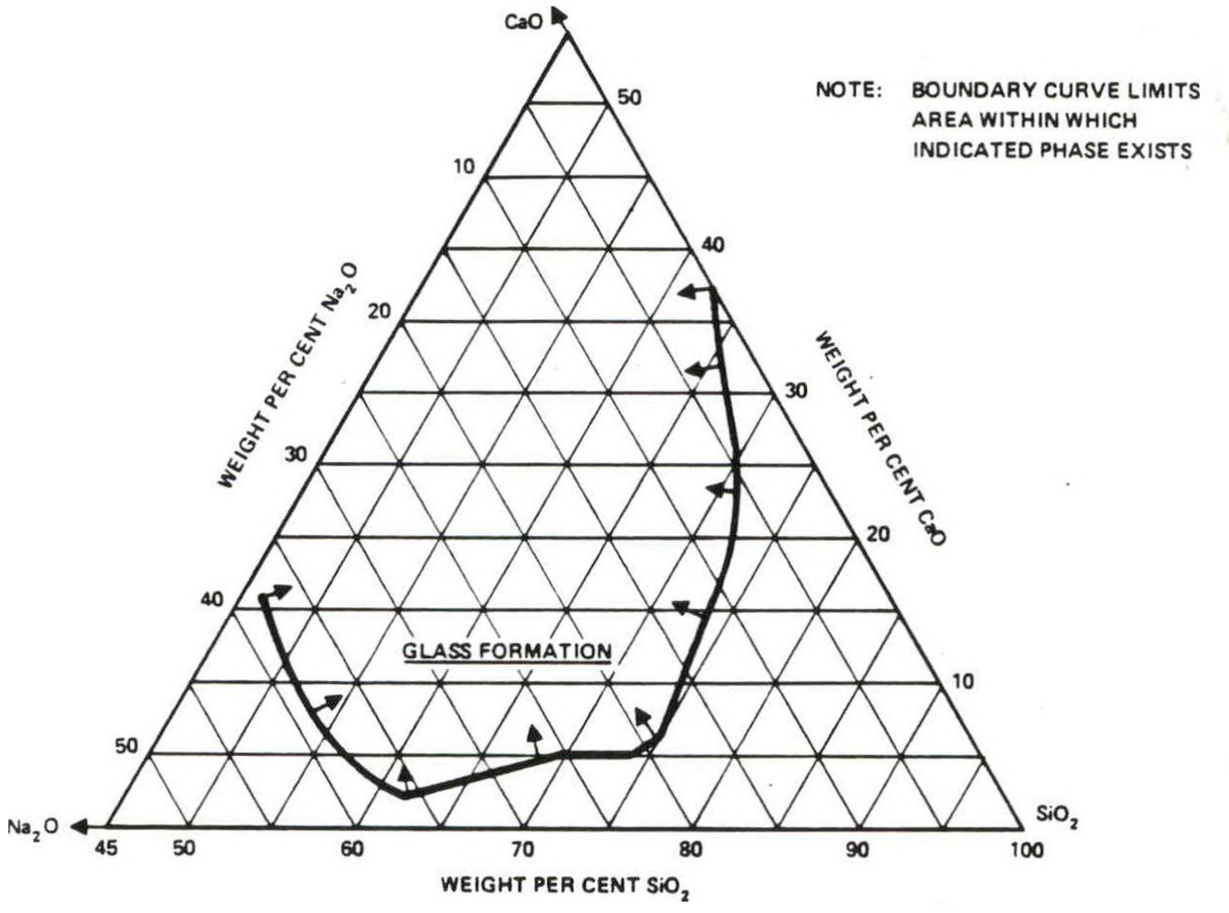
FIGURE 1: RELATIVE RATE OF REACTION VERSUS TEMPERATURE



To achieve the formation of insoluble precipitates of heavy metals, the second category, it is possible to formulate insoluble hydrated oxides by simply adding quicklime or hydrated lime to water solutions or suspensions of any of the heavy metals. This is the usual method of treating spent acid solutions which arise from the plating or electronic industries. The resultant lime sludges and cakes have, traditionally, then been buried in certified landfills with impervious clay liners. As the use of landfill falls into disrepute (again because of the impossibility of attaining a zero leach rate into the surrounding groundwater) it may be necessary to fix the offending chemical yet further, so that even in the failure of the impervious barrier, no soluble chemical will find its way into the groundwater.

It is here that a demonstrated process using the Thagard Reactor - vitrification - can be applied. In vitrification, a mixture of CaO, SiO_2 and Na_2O is formulated in combinations that will produce a glassy state upon fusing. In particular, a CaO-fluxed clay (kaolinite base for high temperature or bentonite base for lower temperatures) produces a glassy melt in which almost every known inorganic chemical is highly soluble. This is represented schematically in Figure 2. With proper formulation, these solutions can be quenched into glass shot in which all of the heavy metals, and other compounds, are chemically bound as part of the insoluble glass. If further security is required, the "glass" can be formulated into a "hydraulic" calcium silicate phase (otherwise known as Portland cement) which, rather than being dissolved by groundwater, actually increases its strength (and chemical stability) upon exposure to water. In each case, the probability of leakage into the groundwater table has been reduced to almost zero.

FIGURE 2: TERNARY DIAGRAM FOR THE SYSTEM CaO SiO_2, Na_2O



III. THERMAL TREATMENT WITH THE THAGARD HIGH-TEMPERATURE FLUID-WALL (HTFW) REACTOR

The use of high temperatures to destroy organic chemical substances and to produce glasses (in separate process) has been standard practice for many years. Practical process equipment operating much above 2000°F, however, has generally encountered limitations in materials of construction (most refractory liners either mechanically degrade or dissolve in the slags found in many waste streams) or in costs of operation (achieving high temperature processes with direct firing, for example, become relatively inefficient as the process temperature approaches the effective flame temperature).

Maintenance of pyrolysis or incineration equipment with moving parts in the high temperature region presents a major consideration in all instances, and a particularly severe one when uncharacterized feed materials with fusible species are introduced or precipitable products are formed.

The Thagard Reactor was developed originally for the continuous dissociation of methane into carbon fines and hydrogen. This particular process required the generation of stable temperatures above 3000°F and the prevention of precipitate formation on the Reactor walls.

To achieve both goals simultaneously, the reacting stream was kept out of physical contact with the Reactor wall by means of a gaseous blanket formed by flowing an inert gas radially inward through the porous Reactor tube (or core) and achieving both high temperatures and high rates of heat transfer by heating the porous carbon core to incandescence so that the predominant mode of heat transfer was by radiative coupling from the core to the stream. By avoiding physical contact of the stream with the

core, the problem of chemical compatibility of the two becomes a non-problem. Additionally, the heating of particles was accomplished without the necessity of bringing the entire system to the same temperature.

The resulting device, while successfully pyrolyzing methane to carbon and hydrogen at rates of commercial interest, also demonstrated its usefulness in numerous other processes including the pyrolysis of almost any organic material to carbon and hydrogen or to carbon, carbon monoxide and hydrogen (depending on the composition of the starting material), and the production of high-melting-point refractories and Portland cement.

A partial vertical cross section of a typical Thagard Reactor is shown in Figure 3, and a horizontal cross section is shown in Figure 4. The Reactor is heated electrically with the six carbon resistance heaters. Because of the extreme temperatures encountered in operation of the device, the insulation package consists not of refractory brick but of a radiation shield made of multiple layers of graphite paper backed up with carbon felt.

The blackbody power radiated by any substance at a temperature above absolute zero is given by

$$P_{(A)} = \sigma \varepsilon T^4, \text{ where}$$

$P_{(A)}$ = power radiated per unit area, watts cm^{-2}
σ = Stefan-Boltzman constant, 5.3×10^{-13} W $cm^{-2} {}^{o}R^{-4}$
ε = emissivity of the substance, $0<\varepsilon<1$
T = absolute temperature of the substance ^{o}R

FIGURE 3: VERTICAL CROSS SECTION OF A TYPICAL FLUID-WALL REACTOR

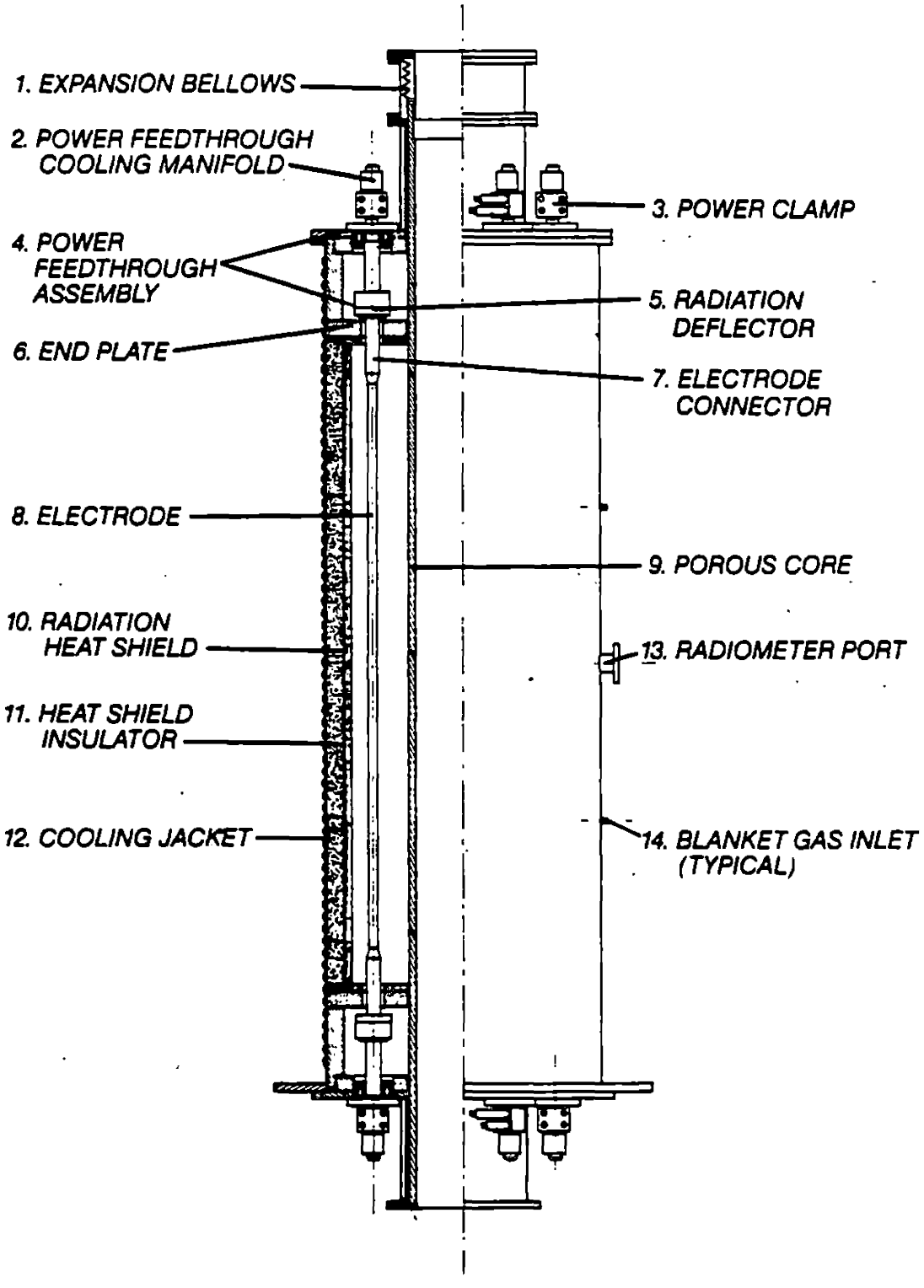
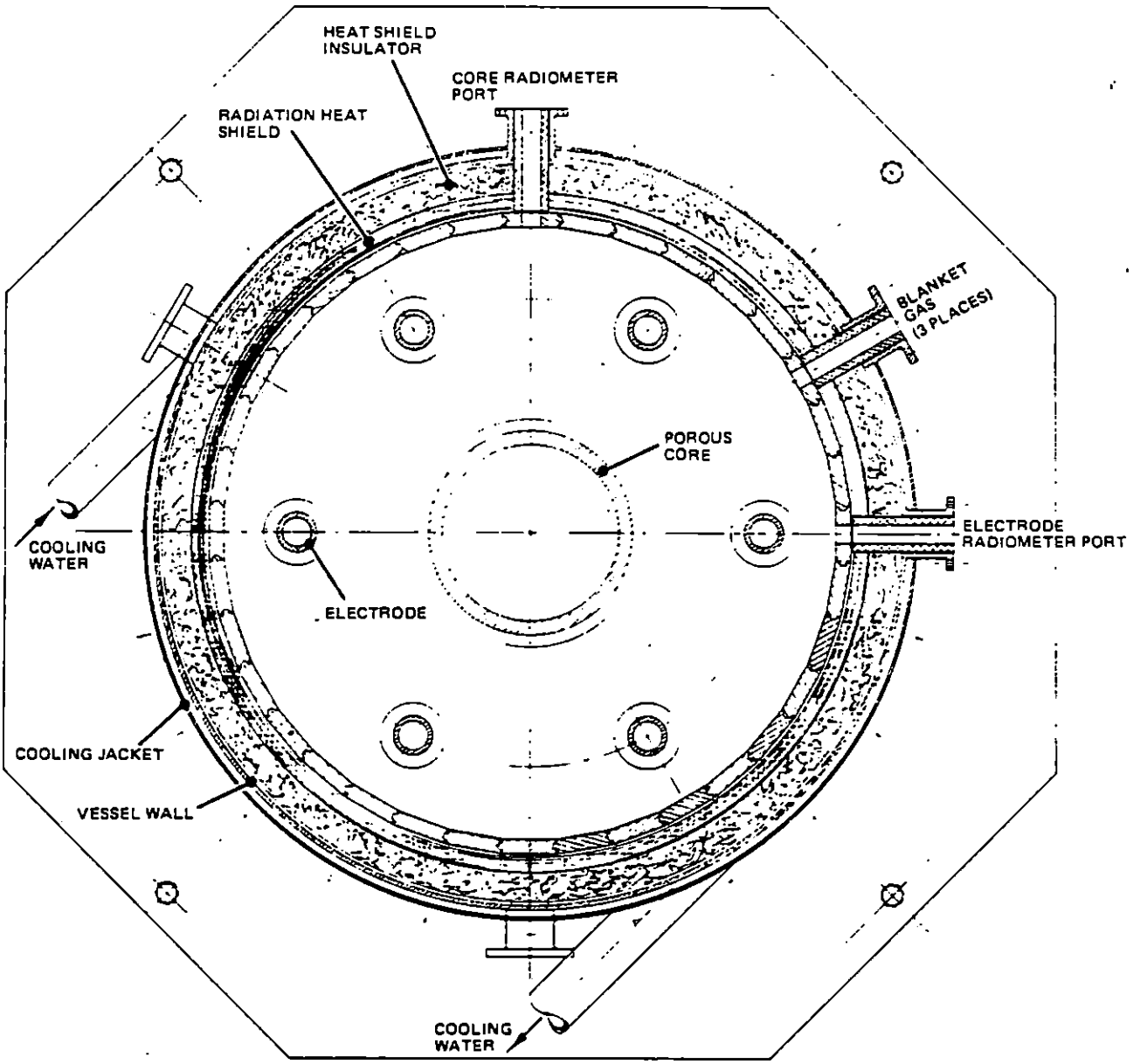


FIGURE 4: HORIZONTAL CROSS SECTION OF A TYPICAL FLUID-WALL REACTOR



This function is plotted in Figure 5. Inspection of Figure 5 will show that radiation as a heat transfer method does not become significant until temperatures on the order of 2500°F are reached.

The emitted spectrum of the blackbody radiator changes, of course, with temperature. Figure 6 shows the relative spectral distribution of blackbody radiators for several different temperatures. Inspection of the curves will show that in the vicinity of 4000°F most of the radiation is in the near infrared.

The interaction of this radiation with strongly absorbing materials (most solids) behaves according to the familiar Beer-Lambert law:

$$P_{(A)E} = P_{(A)o} \exp -\alpha x \text{ , where}$$

$P_{(A)E}$ = radiant power density, W cm^{-2}, emerging from an absorption cell of thickness x cm and absorption coefficient α cm^{-1}

$P_{(A)o}$ = incident power density, W cm^{-2}

α = absorption coefficient, cm^{-1}

x = thickness of absorption cell, cm

The power which is absorbed $P_{(A)}A$ is, of course,

$$P_{(A)}A = P_{(A)o} - P_{(A)E} \quad \text{or,}$$

$$P_{(A)}A = P_{(A)o} (1 - \exp - \alpha x).$$

FIGURE 5: BLACKBODY RADIANT EMISSION vs. TEMPERATURE

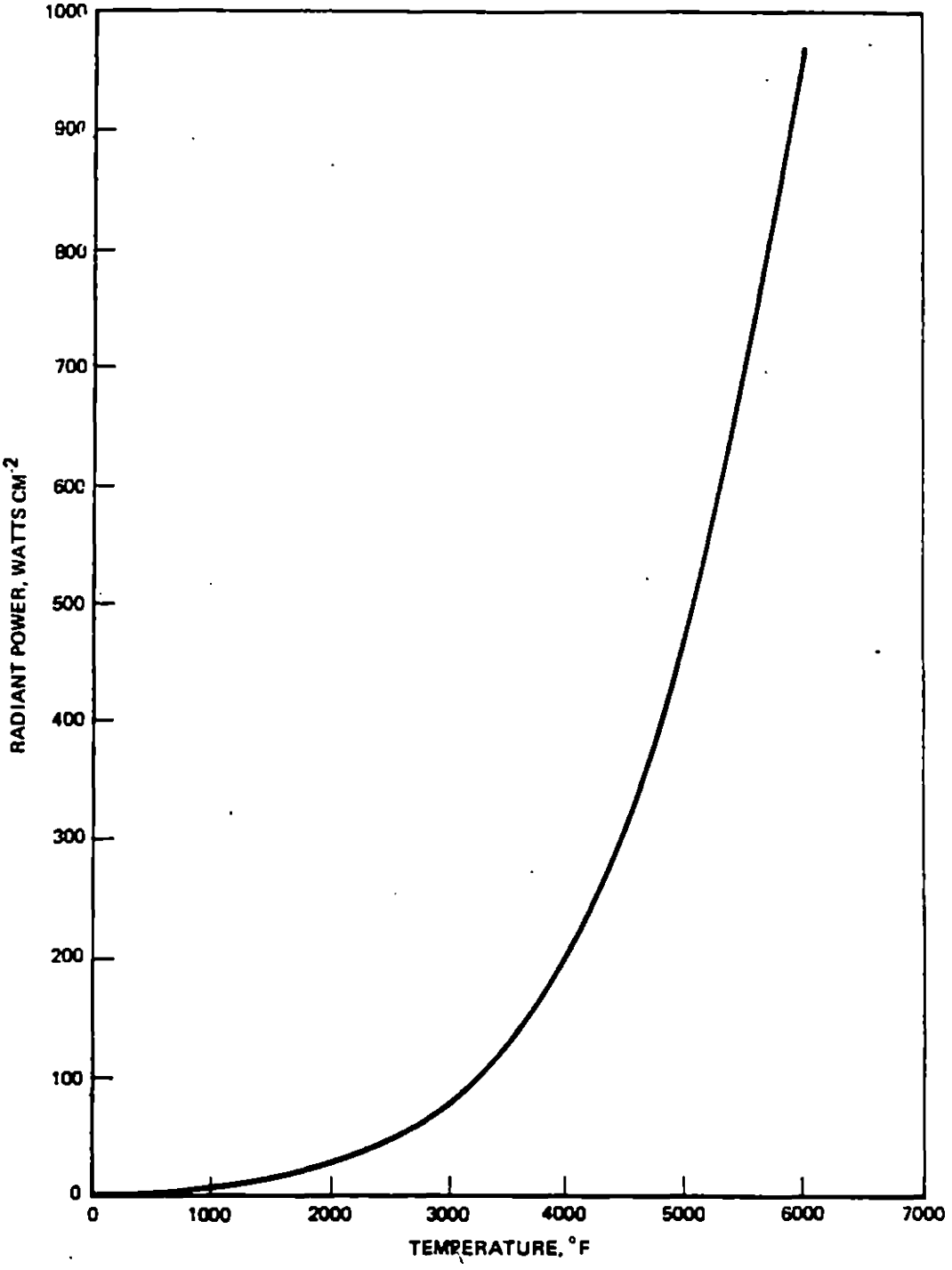
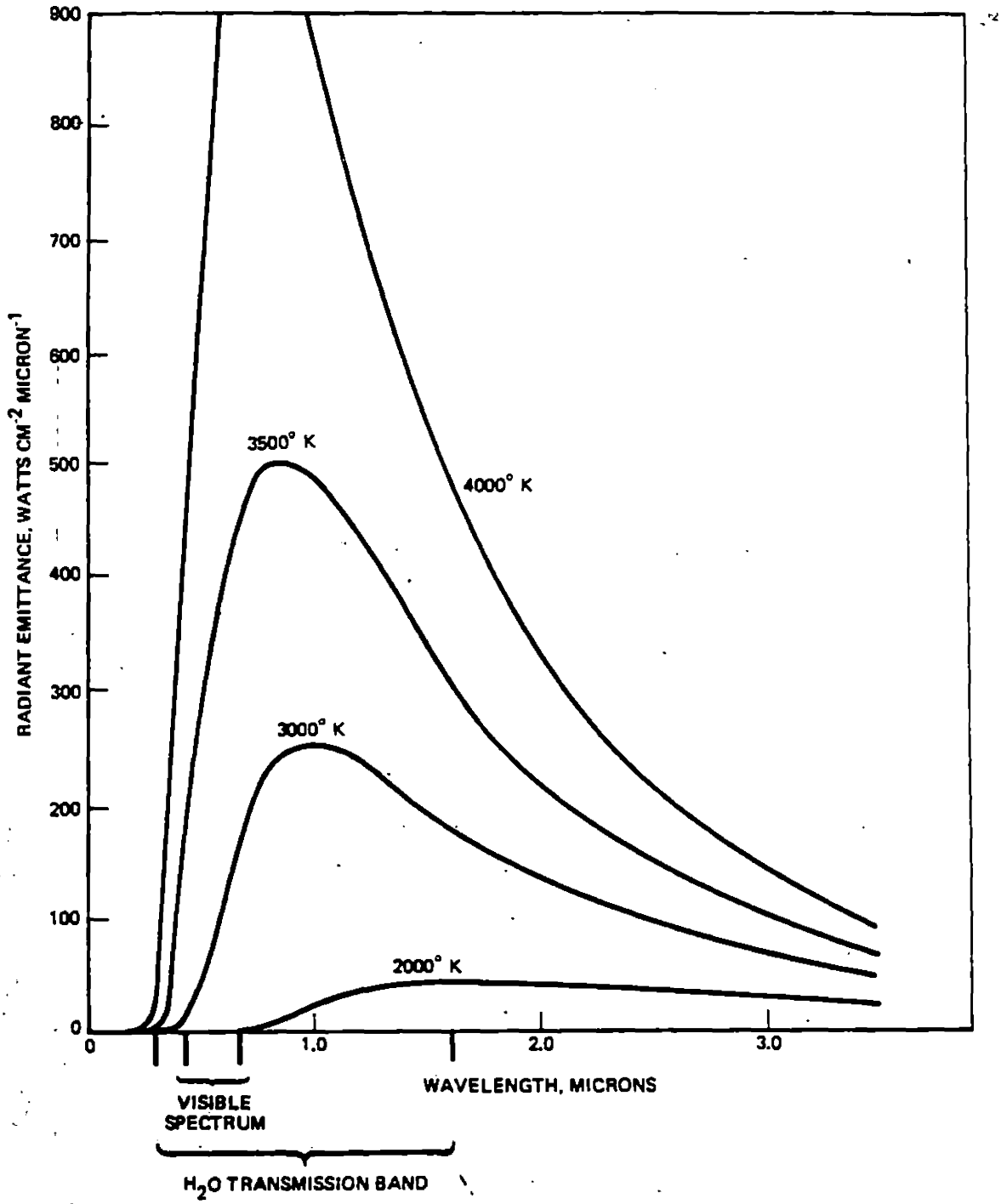


FIGURE 6: SPECTRAL OUTPUT OF BLACKBODY RADIATORS AT VARIOUS TEMPERATURES



In the near infrared, many materials exhibit very strong absorption coefficients: Coal, for example, has an absorption coefficient on the order of 10^5 cm^{-1} which means (to a first approximation) that most of the incident energy is absorbed in a surface layer on the order of 10^{-5} cm thick.

At 4000°F, the blackbody radiative power density is on the order of 200 Wcm^{-2}. The specific heat of coal is ~.5jg $^{-1}{}^{o}F^{-1}$ and its density ~1.4 gcm^{-3}, so that the rate of temperature rise on the surface of a coal particle $\Delta T_s/\Delta T$, ^{o}F sec^{-1} is given by

$$\Delta T_s/\Delta T \simeq \frac{P_{(A)o}}{MC}$$

$$M \simeq \frac{\rho}{a}$$

$$\Delta T_s/\Delta T \simeq 200/(10^{-5})(1.4)(.5)$$

$$\Delta T_s/\Delta T \simeq 3x10^{7}{}^{o}F/sec.$$

Thus, the temperature on the surface of an absorbing coal particle reaches 4000°F in a time interval on the order of 100 microseconds.

Conversely, most gases exhibit absorption coefficients on the order of $10^{-5}cm^{-1}$, and thereby undergo almost no heating whatsoever. Thus, it is possible to heat the particles heterogeneously, with the reactor or process gases remaining in a relatively cool state.

With such temperature excursions on the solids, it is virtually impossible to form intermediate chemical compounds, and the products are therefore generally terminal states of whatever chemical materials were started with.

In the system of reactions with H_2, C, H_2O, O_2, CO_2, the terminal products are CO and H_2. In the system of reactions with H_2S, R-SH, MeS, CaO, the terminal product is generally CaS.

In the system of reactions with HF, HCl, HBr, etc., the terminal products will be the corresponding calcium salt.

If the system SiO_2, CaO, Na_2O, is added to the above, then an inorganic solvent is formed (see ternary phase diagram, Figure 2) which dissolves the CaS, holding it in solid solution upon quenching (since the particle droplet surface is at a high temperature, it will radiate energy rapidly. If the molten droplet has a high fusion temperature, then it will solidify rapidly upon emerging from the Reactor, allowing for simple subsequent handling of the now free-flowing granular shot.

All of this leads to the following: Almost any substance, regardless of composition which, when reduced to large surface area fines blended with appropriate fluxing agents, and dropped in the Thagard Reactor, will produce a fuel gas (which can be used beneficially or disposed of) and a free-flowing granular slag which, with proper pre-chemistry, can be rendered virtually insoluble in water.

We are now only beginning to explore the use of the Reactor specifically as a toxic substance management tool. However, the following tests have been run which indicate a broad applicability to the subject:

1. Preliminary work on gasification of high-sulfur (4.9% S by weight) coal indicates production of synthesis gas almost free of H_2S and COS upon exiting the Reactor. Similar results have been found with pyrolysis of high-sulfur residual oils.

2. Glass beads made from a simulated spent nuclear reactor core indicate almost no water leaching of heavy metals.

3. Hexavalent chromium tailings have been treated to where the direct leachate of Cr6+ was lower than EPA standards for drinking water.

4. Char formed from pyrolysis of heavy metal loaded organic refuse from automobile bodies indicates, again, almost no water leaching of Pb, Cd, Cu, or Zn.

5. Hexachlorobenzene has been pyrolyzed on carbon to a level where the remaining HCB was less than 10^{-6} of the starting material (10^{-6} being the limit of detectability of the test). Hexachlorobenzene was used as a surrogate for PCB, which requires special permits for testing.

6. Portland cement clinker beads have been successfully produced by direct quenching from a liquid melt, indicating that slags which are even more stable in water than the glass beads can be manufactured with the device.

IV. REACTOR TESTS WITH HEXACHLOROBENZENE

Prior to applying for permits to do tests with PCBs on soil, a series of tests to determine the effectiveness of the reactor in destroying aromatic carbon-chlorine bonds was run using hexachlorobenzene as a surrogate material.

Hexachlorobenzene was chosen because it was, at the time, an uncontrolled material and also a more thermally stable compound than PCBs. Thus, a successful demonstration with HCB would establish safety criteria for effluents from PCBs, and would also establish minimum destruction levels to be expected with PCBs.

The HCB study was done for the USEPA-Edison IERL, by Baird Corporation (Bedford, Massachusetts) using the Thagard six-inch reactor located at South Gate, California. The contract was monitored by Mason and Hanger - Silas Mason Company, Inc. (Edison, New Jersey).

Measurements were carried out on 23 and 30 October, and 3 November, 1980. An ambitious test matrix was scheduled and run but all matrix elements consisted principally of loading HCB onto -100 mesh graphite spheres at a 1% and 10% (by weight) level and passing the loaded spheres through the reactor at a feed rate of 2 g HCB per minute. The reactor was held at 4000°F for all tests. Residence time for all tests was approximately 0.1 seconds.

Samples of both solid and gaseous effluent were collected. Effluent gas was continuously drawn from the process stream immediately below the reactor thrugh a pre-extracted urethane plug in a glass cartridge. The urethane/glass cartridge was constructed per design of Jackson and MacLeod of EPA/RTP.

By metering the nitrogen flow through the reactor and knowing the sample gas rate it was then possible to calculate the HCB effluent rate in the gases.

Solids were collected from a cleaned stainless steel pan located approximately eight feet below the reactor outlet. All solids fell through the reactor by gravity.

Analysis was provided by the Environmental Monitoring and Service Center, Environmental & Energy Systems Division of Rockwell International (Newbury Park, California).

The plugs and solids were solvent extracted and subjected to gas chromatography per EPA Method 612.

Overall results are given below:

Test #	Total HCB Feed Rate, Micrograms/ Minute	Total HCB Effluent Rate on Solids µg/min	Total HCB Effluent Rate in Gas µg/min	Total HCB Effluent Rate µg/min	Destruction Efficiency, Per Cent
1	1,600,000	.20	.07	.27	99.99998
2	1,600,000	.20	.27	.47	99.88887
3	2,000,000	1.20	.16	1.36	99.99993
4	2,000,000	1.20	.32	1.52	99.99992

The above results were not corrected for blank samples which indicated an HCB level above zero, so these data represent the minimum destruction level which was seen.

V. PCB-CONTAMINATED SOILS TESTS

Fortified with confidence from the HCB tests, Thagard Research Corporation applied to USEPA Region 9 for a one-time permit to test destruction of PCB on soil to a level of 500 ppm. This permit was subsequently granted, and work on this phase began under a contract from Southern California Edison Company. As was discussed in the introduction, 200 to 500 ppm represents a typical spill from a pole-mounted capacitor or transformer.

As luck would have it, the only naturally occurring accidents available during early December 1981 produced soil contaminated to a level of approximately 100 ppm. The measurement method used had a statistical sensitivity of approximately 1 ppm on the residual slag, so "zero" could be verified only to two nines destruction level.

The tests were run in TRC's three-inch experimental reactor at Irvine, California. Feed rates were approximately 0.25 pounds per minute. Solids were collected and gases sampled as before. With the soil samples, the solids emerged as fused glass beads with a sieve range -60+200 mesh. Fines smaller than -200 mesh represented less than 0.5% of the total solids emissions. The "two-nines" zero was replicated on at least 4 tests.

Current status of this testing program: A request has been made to USEPA Region 9 to allow an increase in the amount of PCB used in the tests to approximately 1%, a level comparable to that used in the hexachlorobenzene runs. Simultaneously a request has been made to the Southern California Edison Company to located PCB-contaminated soils with levels approaching 10,000 ppm for this next set of tests.

Results will be published after this second set of tests and after EPA has had an opportunity to review the data.

VI. PRESENT DEVELOPMENT STATUS OF THE THAGARD REACTOR

The Thagard Reactor has been built with cylindrical core diameters of 3", 6" and 12" with heated core lengths of up to 72".

Principal design activity on the device over the past five years has been in characterization of gas flows and temperatures and non-recoverable losses, leading to scaling guidelines which allow a comfortable growth to 48" diameter. Principal manufacturing activity has been on the fabrication of critical high temperature components for these larger Reactors.

Principal process activity of the past five years has been in the establishing of proof of process chemistry and in prediction of process scaling to estimate Reactor size requirements for requested throughput levels.

An additional process which has commanded a fair amount of attention has been the use of combustion processes to produce blackbody radiation within the Reactor to offset electrical process power, to an extent that it now appears possible to use electricity only to maintain background temperature.

Figure 7 shows a 6" process development unit which has been used as a research facility since 1976. Figure 8 shows the outer metal shell for a larger (12") unit which is being fabricated for a client.

FIGURE 7: FLUID-WALL REACTOR FACILITY, 6" PDU

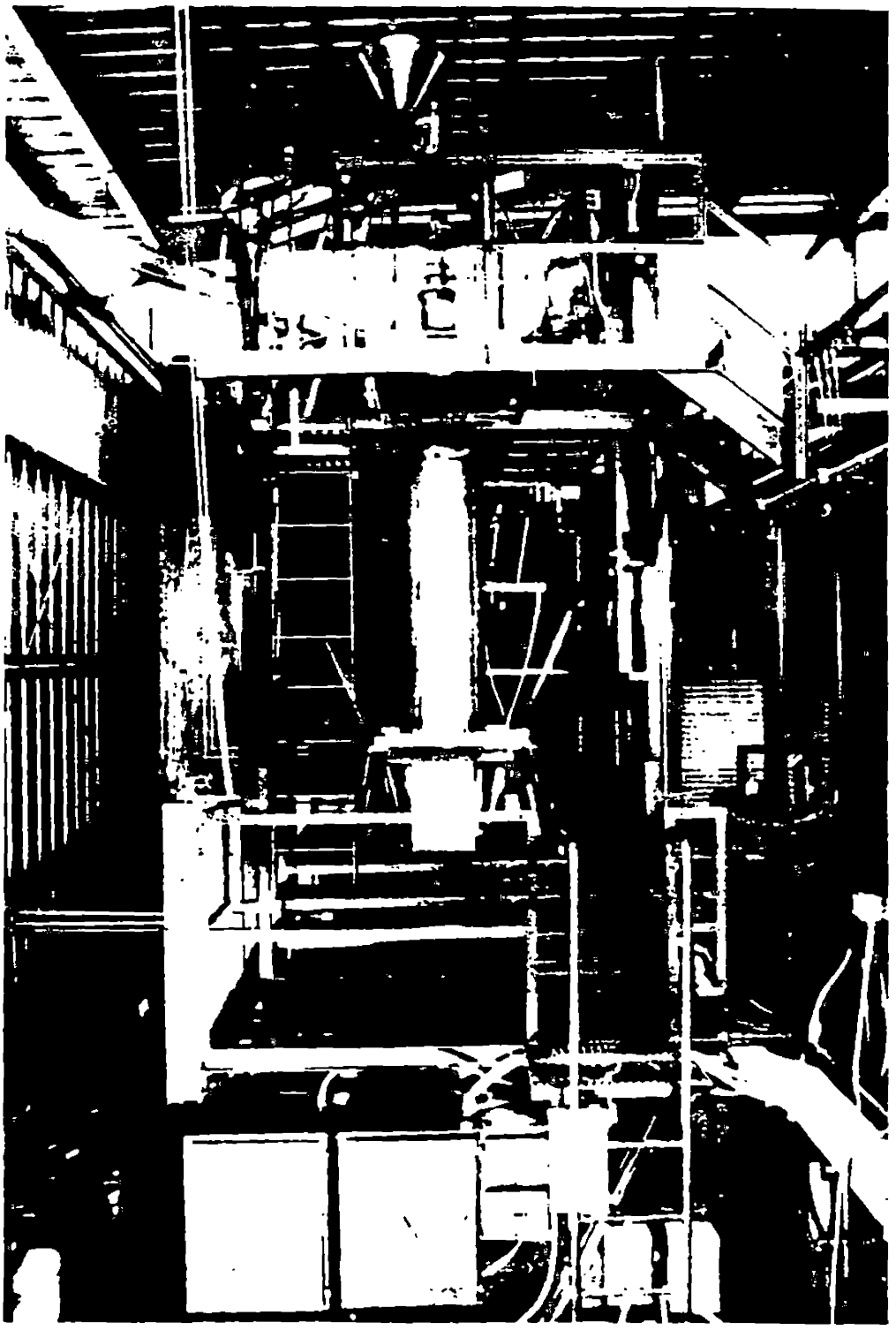
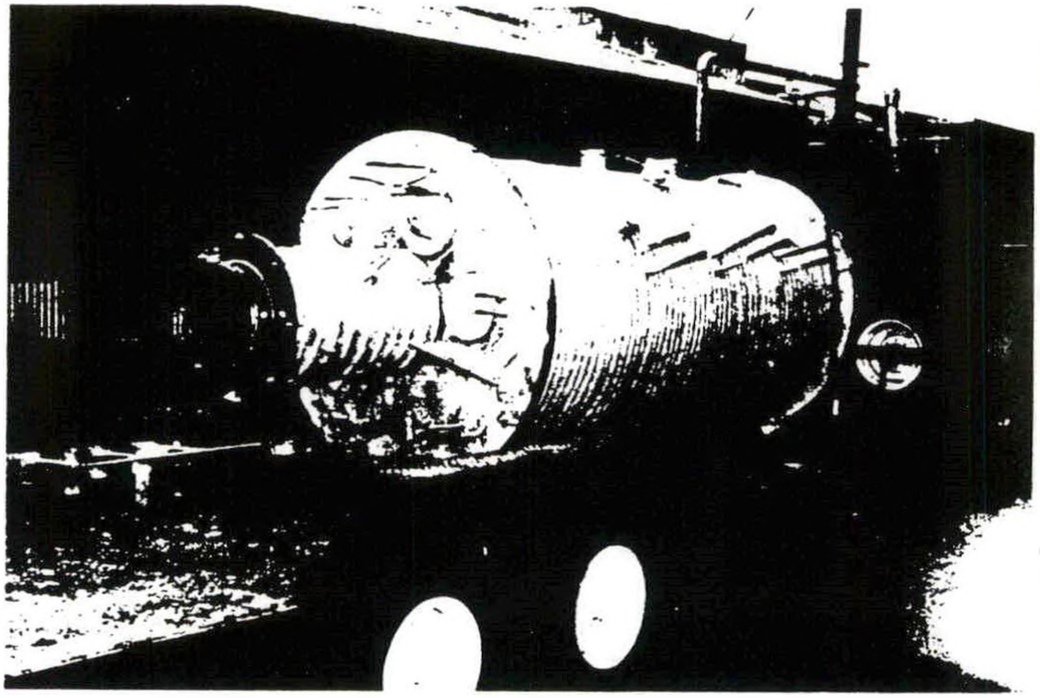


FIGURE 8: THACARD HTFW 12 INCH PILOT REACTOR SHELL



Current estimates of treating toxic wastes in the 150-250 ton per day throughput range appear feasible with available Reactor technology. At this level, most peripheral equipment can be purchased off the shelf.

Preliminary estimates for power consumption in an all-electrically driven contaminated soil treatment device at the 150 to 250 TPD level are on the order of 200 to 250 kwh per ton of contaminated soil (about $12 to $15 per ton at $0.06/kwh rate).

VII. CONCLUSIONS

In summary, the Thagard High-Temperature Fluid-Wall Reactor offers several unique advantages for the thermal destruction of toxic wastes: First, the high operating temperatures provide high radiant energy densities which assure rupture of the chemical bonds, thus breaking the wastes into their simplest constituents. Second, the rapid reaction rates promoted within the Reactor allow the complete reaction of any hazardous constituents into benign and stable forms. Third, proper formulation of feedstock additives results in a vitreous, non-leachable slag for ease of disposal. Fourth, the configuration of the Reactor and the nature of the process make scaling from pilot units a relatively simple procedure. And finally, the simplicity of design reduces capital outlay and maintenance costs.

The preliminary work with hexachlorobenzene and PCB-contaminated soil appears to hold promise for very high levels of destruction of a very wide range of forms of contaminated materials. Additional work under SCE and EPA auspices will establish a statistical base at higher PCB concentrations from which a rational basis for larger-scale operation can be derived.

UTILITY PCB SPILL CLEANUP PRACTICES
PANEL DISCUSSION

E. L. Morrison
Los Angeles Department of Water and Power

C. Manger
Baltimore Gas and Electric

H. Onishi
Commonwealth Edison

W. Renfro
Northeast Utilities

PANEL DISCUSSION - UTILITY PCB SPILL CLEAN UP PRACTICES

Earl L. Morrison, Chairman, Los Angeles Department of Water and Power
Carl Manger, Baltimore Gas and Electric
Harry Onishi, Commonwealth Edison
Bill Renfro, Northeast Utilities

Each member of the panel described the general practices of his organization for handling PCB spills and related some of the special problems encountered. It was their objective to provide a forum to share experiences and to help develop a sound general approach for cleaning up spills. It was noted that the disposal of PCBs and PCB contaminated materials is usually regulated by state and local agencies as well as the Federal government and that there is considerable variation in the requirements from region to region.

Cleaning up spills from ruptured capacitors appears to be the most difficult problem encountered by utilities. Procedures for sampling and analyzing materials contaminated by spills are not covered in detail. Each spill is different and may require unique handling. Guidelines for removing contaminated materials resulting from spills included the following:

1. Personnel involved in spill clean up should have basic information concerning PCBs. Sensitivity to public concern is essential.

2. Training in clean up practices is essential for personnel and crews involved handling major spills.

3. Materials for handling spills must be readily available as speed in initiating clean up procedures is desirable.

4. Areas exhibiting visible contamination should be roped off to avoid further spreading and inadvertent contact by the general public. All visibly contaminated materials should be covered by absorbent material or be removed and placed in appropriate containers to prevent contamination of additional material.

5. Samples of soil and other materials should be taken outside the visibly contaminated areas and analyzed in the laboratory to determine the extent of the legally contaminated area. This requires good judgement and common sense.

6. Nationally recognized procedures for extracting and analyzing PCBs contained in solid materials have not been established. Some laboratories are using Soxhlet extraction apparatus for removing PCBs from soil and other solid materials for analysis. ASTM method D4059 "ANALYSIS OF POLYCHLORINATED BIPHENYLS IN MINERAL INSULATING OIL BY GAS CHROMATOGRAPHY" is being used with minor modifications as the analytical procedure.

The panel presentation was followed by an extensive question and answer period. Some questions and answers were as follows:

Q. Is there any data available on health effects of PCB exposure?
A. The EEI - NEMA health effect literature review is to be completed by January 1982. This summary should be available by mid February 1982.

Q. What method is used for checking solid surfaces after a spill?
A. Filter paper moistened with solvent has been used to swab the areas. All the PCB in the filter paper is then extracted to determine the PCB per unit area.

Q. How is the priority established between restoration of service and clean up?
A. Public safety is always considered, but restoration of service has a high priority in all actions. No specific "rule" is possible.

Q. How does PCB behave in sea water?
A. It is much heavier than water but it does have some solubility. If concentration is high, there will be some in the water.

Comment: When determining when to report spills of less than 50 ppm, other regulations must be considered, such as the Clean Water Act under Superfund. Capacitor ruptures are reportable, since they may exceed 10 pounds of PCB.

Q. How fast can you get results of tests from samples?
A. Los Angeles DW&P's Laboratory has a gas chromatograph with automatic sample injection operating 24 hours per day, including weekends, and spill-sample testing has priority. The analysis of a sample including extraction can usually be obtained in two hours, routinely in three or four hours.

Boiler burning of PCB contaminated mineral oil - A show of hands was requested of those considering burning in their utility boilers. A large number indicated they were considering burning. However, only seven utilities are actually burning at this time.

PARTICULATE CONTAMINATION IN THE BINGHAMTON STATE OFFICE BUILDING

G. A. Eadon

Center for Laboratories and Research
New York State Department of Health

Binghamton is a small city (population about 55,000) located in south-central New York state, about 10 miles from the Pennsylvania border. The Binghamton State Office Building (BSOB), occupied in 1973, is the city's tallest structure. It is 18 stories tall and rises 260 feet above street level. About 700 state workers are ordinarily employed within its 186,000 square feet of net usable area.

At about 5:30 a.m. on February 5, 1981, an intensely hot local electrical fire occurred in or about the switch gear located within a basement mechanical room. It appears that the intense heat caused the bushings on a nearby transformer to crack. The transformer, which originally contained 1,060 gallons of Pyranol (65% Aroclor 1254, 35% chlorinated benzenes with additional trace additives), lost about 180 gallons of fluid. Apparently, significant pyrolysis of the transformer fluid occurred; a fine, black, oily soot covered most internal surfaces of the building. The mechanisms by which the soot was spread throughout the building remain unknown. However, a ventilation shaft running the entire height of the building and open to the mechanical room may have been involved.

The Center for Laboratories and Research, a part of the New York State Department of Health, has initiated a number of scientific investigations relevant to this problem. This paper will briefly summarize the status of certain of these projects as of January, 1982. It is expected that each of these investigations will eventually be described in full detail in the scientific literature.

Chemical Analysis

The Center for Laboratories and Research has analyzed over 800 samples from the BSOB for their PCB content. Air samples (1,2) taken throughout the building prior to clean-up averaged 1.48 µg Aroclor

1254/M^3. Levels of surface contamination were estimated by rubbing a dry 11 cm diameter filter paper over a measured surface area (1). Concentrations on exposed horizontal surfaces averaged 162 µg/M^2. Vacuuming of twelve horizontal surfaces reduced their average Aroclor 1254 levels to 11.3 µg/M^2. The efficiencies of a number of alternative cleaning procedures have also been probed.

Evidence in the scientific literature demonstrates that, under certain conditions, pyrolysis of PCBs can generate complex mixtures of polychlorinated dibenzodioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) (3,4). In February, 1981, the Center for Laboratories and Research had a major analytical program directed toward the isomer specific determination of 2,3,7,8-tetrachloro-dibenzodioxin (5); with minor modifications, this methodology was used to determine levels of 2,3,7,8-TCDD and 2,3,7,8-TCDF in a soot sample. Duplicate analysis of a single sample gave 2.8 and 2.9 µg/g 2,3,7,8-TCDD, and 273 and 124 µg/g "2,3,7,8-TCDF". (Unambiguous identification of a particular congener of TCDF requires samples of all 28 possible congeners. In their absence, it cannot be demonstrated that other congeners are not coeluting with 2,3,7,8-TCDF.) The excellent precision obtained in the 2,3,7,8-TCDD analysis reflects the availability of an isotopically labelled internal standard of that compound. At the time of this analysis, no isotopically labelled TCDF standard was in hand. Independent confirmation of the presence of dioxins and dibenzofurans was obtained when a sample of soot was sent to Dr. David Stallngs of the U.S. Fish and Wildlife Service (6). Dr. Stallings extracted the sample and identified numerous GC/MS peaks as tetra- through octachloro-dibenzofurans (total concentration 756 µg/g). Professor Christopher Rappe of the University of Umea, Sweden confirmed these results using

the same extract and reported a total PCDF concentration of 2160 µg/g (7). Although Stalling's limit of detection precluded identification of dioxins, Rappe identified numerous PCDDs at a total concentration of 20 µg/g. In addition, Stalling reported the presence of polychlorinated biphenylenes, at a level of 54 µg/g; at least some polychlorinated biphenylenes exhibit toxicities comparable to the corresponding dioxins.

Although the Center for Laboratories and Research has performed some additional dioxin/dibenzofuran analyses in connection with this project, its major effort has been to develop an analytical procedure that will permit accurate analysis of the broad spectrum of toxic compounds present in these samples. These efforts have includeed securing and purifying appropriate labelled and unlabelled standards (generally not commercially available), modifying clean-up procedures to assure recovery of all compounds of interest, modification of gas chromatographic conditions, and of mass spectrometric data acquisition procedures. Initial efforts have been directed toward analysis of a single sample from each floor of the BSOB to assess the relative degree of contamination. Results are expected imminently.

Biological Assays

Since the cost of chemical analysis for PCDDs and PCDFs is high and very few laboratories are capable of performing the analysis, biological assays have been investigated to screen and prioritize samples for chemical analysis. One approach under continuing study (the "chick embryo assay") involves dosing a fertilized egg with the extract or sample of interest, then waiting 14-18 days and noting lethality (8). Development of this assay is at an early stage and several problems remain unresolved. These include a non-linear dose response curve, uncertainty about the specificity of the test for

PCDDs and PCDFs, and an apparently higher detection limit then a possible alternative procedure developed by Poland (9), the cell keratinization assay. The cell keratinization assay is being evaluated at the Center and has been shown to exhibit behavior and sensitivity (3pg 2,3,7,8-TCDD/ml) fully consistent with literature data. It has been used, in a preliminary study, to assay the "TCDD-like activity" present in benzene extracts of the soot samples taken from above the ceiling panels on most floors of the BSOB. Eventually, these results will be compared to the chemical analysis data for PCDDs and PCDFs to validate the method for use in the detection of "TCDD-like activity" in environmental samples such as BSOB soot.

While these studies indicate a potential use for the in vitro induction of keratinization in the detection of dioxin congeners and isomers, a problem has become apparent. Consistent with the published literature, the magnitude of the keratinization response in these cultures has been found to decrease with time, although the sensitivity of this response to 2,3,7,8-TCDD has so far remained unchanged. Future work with the cell keratinization assay will be designed to solve this problem and to increase its speed, accuracy and reliability.

An observation made here suggests a correlation between the induction of keratin by 2,3,7,8-TCDD and a change in cell morphology. Preliminary experiments suggest that it may be possible to use this altered morphology as a faster, easier and more stable substitute for the cell keratinization assay.

An apparent correlation has been observed between "TCDD-like activity" using the keratinization assay and PCB levels in

the BSOB soot samples. Preliminary results, using the altered morphology as a indicator, suggest that the levels of PCBs in these samples are too low to have themselves induced a response. An alternative explanation postulates a correlation between PCB levels and PCDD/PCDF levels. If this result is confirmed, the relatively straightforward PCB analysis could be substituted for the much more difficult PCDD/PCDF analysis in many cases.

Animal Toxicology Experiments

The dermal toxicities of the soot and the chemicals therein have been assessed by application to the shaved skin of albino rabbits. After 24 hours contact, 500 mg soot/kg rabbit produced no observable dermal effects after 40 days. In contrast, distinct (but reversible) effects were observed when an equivalent dose of soot extract was applied in a similar fashion. Thus, the dermal toxicity of these chemicals is lessened by absorption on the soot.

The acute oral toxicity of the soot administered in an aqueous suspension by gavage to guinea pigs (LD_{50}) was determined to be ca. 410 mg/kg. Since the soot was less toxic than predicted from preliminary chemical analysis, the hypothesis was formulated that the oral "bioavailability" of these chemicals was lessened by their adsorption onto the soot; this concept was supported by a study already in the scientific literature dealing with the toxicity of 2,3,7,8-TCDD adsorbed on carbon (10).

As a test of this hypothesis, a sample of soot was subjected to exhaustive chemical extraction, and the resulting mixture of chemicals was administered in an aqueous suspension to guinea pigs. The toxicity of the extract (LD_{50} of 327 mg soot equivalent/kg guinea pig) was only slightly increased, thus demonstrating that

"bioavailability" was not the principal origin of the soot's unexpectedly low toxicity.

Recently, experiments have been completed which provide an explanation for these effects. The acute oral LD_{50} of authentic 2,3,7,8-TCDD was determined when administered (by gavage) in an aqueous suspension and in corn oil. These values differed markedly; in corn oil, the LD_{50} was 2.5 ug/kg, fully consistent with literature values (11). However, the earlier described experiments all involved administration of the soot in aqueous suspension. This matrix was selected (based in part on the recommendation of the Health Department's expert committee of scientists and physicians with particular knowledge relevant to dioxins and dibenzofurans) because it more closely models the most plausible routes of oral exposure. The acute oral toxicity of 2,3,7,8-TCDD was markedly diminished in an aqueous matrix (LD_{50} of 19 ug/kg). Thus, the lower than expected acute oral toxicity of the soot was in large part attributable to the fact that it was administered in an aqueous matrix. The observed acute oral toxicity of the soot is now consistent with existing chemical data, given the large uncertainties in both the analytical results and the toxicities of individual congeners. This result is encouraging, since it removes any necesity to postulate "unusual" effects on toxicity, and therefore suggests that it may eventually be possible to make more extensive use of literature data in evaluating the hazard posed by reoccupation of the building.

The next step in the Division's animal toxicology program will be a 90-day sub-acute study. Various doses of soot will be incorporated into guinea pig chow, and the animals allowed to eat it for 90 days. Preparation for this important experiment is under way.

As the preceding discussions demonstrate, these areas of research (as well as others not described here) are under continuing investigation at the New York State Health Department. It is already clear, however, that these results will eventually yield data relevant not only to the Binghamton incident, but also to the whole subject of dioxin and dibenzofuran chemistry and toxicology.

DISCUSSION

Q. Are there any observed health effects?
A. 400 people are believed to have been exposed to varying degrees of contamination. To date, there are no documented health effects from that exposure.
Q. What is the New York position on removal of askarel equipment from buildings?
A. At this time, there is no replacement policy.
Q. What type of clinical tests will be run on those exposed?
A. Full range tests will be run on liver function and blood.
Q. Has there been any attempt to check on health effects of past occurrences of building transformer fires?
A. There has not been, to my knowledge.

1. "Toxicology Institute Analytical Handbook," Center for Laboratories and Research, Albany, N.Y. 12201, 1981.
2. Giam, C.S., Chan, H.S., Neff, G.S., Anal. Chem. 47, 2319 (1975).
3. H.R. Buser and C. Rappe, Chemosphere, 6, 454 (1977); H.R. Buser, H.P. Bosshardt, C. Rappe and R. Lindahl, ibid, 7, 419 (1978); H.R. Buser, H.P. Bossshardt and C. Rappe, ibid, 7, 109 (1978).
4. M.Monta, J. Nagawa and C. Rappe, Bull. Environ. Contam. Toxicol., 19, 6654 (1977); C.A. Nilson, K. Anderson, C. Rappe, and S. Westermark, J. Chromatogr., 96, 137 (1974).
5. R.M. Smith, P. O'Keefe, K. Aldous, D. Hilker, and J. O'Brien, Env. Sci. Technol., submitted for publication.
6. D.L. Stalling, Columbia National Fisheries Research Laboratory, Preliminary Report, March 31, 1981.
7. C. Rappe, University of Umea, Sweden, Report, 1981.
8. J. G. Wilson, J. Environ. Path. Toxicol., 2, 149 (1978); D.O.E. Gebhardt, Adv. in Teratology, 5, 97 (1972).
9. J.C. Knutson and A. Poland, Cell, 22, 27 (1980).
10. H. Poiger and C.H. Schlatter, Fd. Cosmet. Toxicol., 18, 477 (1980).
11. E.E. McConnell, J.A. Moore, J.K. Haseman and M.W. Harris, Toxicol. Appl. Pharmacol., 44, 335 (1978).

PCB EQUIPMENT INVENTORY AND MANAGEMENT PLAN FOR STATE OF CALIFORNIA FACILITIES

J. P. Woodyard
SCS Engineers

P. Hypnarowski
Department of General Services

J. Tappa
Power Transformer Services, Inc.

PCB EQUIPMENT INVENTORY AND MANAGEMENT PLAN FOR STATE OF CALIFORNIA FACILITIES

John P. Woodyard, P.E.
SCS Engineers
Long Beach, California

Paul Hypnarowski, P.E.
Office of the State Architect
Department of General Services
Sacramento, California

Jerry Tappa
Power Transformer Services, Inc.
Somers, Wisconsin

ABSTRACT

The State of California conducted an extensive survey of state-owned PCB electrical equipment from March through June 1981. SCS Engineers, under contract to the Department of General Services, inspected over 3,000 fluid-filled transformers at 94 state institutions (hospitals, correctional facilities, colleges and universities, state office buildings, etc.) spanning seven state departments. Moderate and major leakers and imminent hazards were identified, and corrective action plans were prepared and costed out for each installation. Approximately 200 transformers were sampled and analyzed for PCB content. The laboratory results were used to apportion removal/replacement costs for four major corrective action options, ranging from simple replacement of PCB leakers and imminent hazards units to complete replacement of all PCB and PCB-contaminated units regardless of condition.

This paper presents a description of the survey and a summary of the final results. The survey logistics are described, including recordkeeping, data analysis, and data presentation format. The results of the sampling survey are presented by unit size and manufacturer. The cost estimating procedure is described, and the results summarized. State-owned central storage facilities, proposed as an option to on-site storage, are described, and their implementation status is reviewed.

PCB EQUIPMENT INVENTORY AND MANAGEMENT PLAN FOR STATE OF CALIFORNIA FACILITIES

INTRODUCTION

The decision makers and other citizens of the State of California are well aware of the dangers posed by improper management of hazardous waste. Polychlorinated biphenyls (PCB's), in particular, have been a focus of attention for both local media and state regulatory authorities. Almost weekly, incidents of improper PCB management are heavily publicized by the media. Some of these incidents occur locally, and in several cases have involved state-owned PCB equipment.

Several PCB incidents occurring in recent years attracted the interest of the Governor's office and the state legislature. The Department of General Services, Office of the State Architect (OSA), with normal responsibility for state facilities maintenance and engineering, was tasked with implementing a formal management strategy for state-owned PCB equipment. In early 1981, OSA contracted for a major inventory and management plan for PCB equipment at 94 state institutions based on contributions by seven state departments. This paper provides a summary of the results of that survey and future PCB management activities by the State of California.

The objectives of this first survey included the following specific items:

- Provide a detailed inventory of PCB and PCB-contaminated electrical equipment at the 94 state institutions.
- Determine the costs associated with replacing existing PCB equipment or otherwise overseeing its environmentally acceptable operation and storage.
- Present recommendations regarding the disposition of equipment items which pose an imminent hazard.
- Evaluate potential central storage sites for state PCB equipment.
- Determine the necessary electrical system modifications to accommodate PCB equipment replacement.
- Determine the total cost of PCB management at these 94 institutions.
- Provide supplementary information regarding the potential PCB hazard for use in future management action.

The inventory itself is similar to efforts conducted internally by many utilities. Several aspects of the project are

nevertheless valuable to the industry, such as the inventory data base management system, fluid sampling results, and storage site layouts, siting procedures, and cost estimates. These items are highlighted below. The interested reader is referred to the survey report for additional details (1).

PCB REGULATIONS IMPORTANT TO AN EQUIPMENT SURVEY

Under the Toxic Substances Control Act, the State of California is subject to the same PCB management regulations as the rest of the public and private sector. The large inventory of state-owned PCB equipment, coupled with the lack of a formal management plan, results in periodic activities which are not in compliance with the regulations. These regulations prompted the state survey. The regulations are well known to the utility industry. Certain PCB regulations are nevertheless of particular importance when conducting an inventory, and are highlighted below.

One purpose of the survey was to assess the adequacy of the PCB inventory at each of the 94 institutions, and to assist maintenance personnel to properly identify and label PCB equipment. During the early stages of the inventory, many of the institutions were found to possess an inadequate inventory and little knowledge of their PCB equipment and its location. The project team assisted in the labeling of equipment during the course of the inventory. The final report served the dual purpose of informing the legislature of the scope of the problem, and providing each institution with a detailed inventory based on site visits and laboratory sampling and analysis.

Identifying leaking PCB equipment and determining the degree of hazard associated with each proved to be important aspects of the project. A significant number of the equipment items currently on-line and in storage at state institutions have leaked, although a majority of the leaks are minor. Some of the leakers are nevertheless located in sensitive or "imminent hazard" areas (food handling, mechanical rooms, etc.), and were formally identified as such for the first time during the inventory.

Confusion regarding the location, identification, and history of fluid-filled electrical equipment at many state institutions was prevalent. PCB contamination during years of maintenance was expected, but the turnover in maintenance personnel allowed some institution PCB records to become seriously outdated. The inventory provided an opportunity to sample some units and review the records for possible fluid contamination.

The location of imminent hazards among PCB equipment was a key part of the inventory, with remedial action funding expected to be a major focus of 1981 legislative attention. Some PCB equipment installations throughout the state are in sensitive locations (mechanical rooms, etc.), or leaking in the vicinity of personnel activities. The state was notified upon identification

of hazards at such installations, and corrective action was taken immediately thereafter in some instances.

EPA standards for environmental isolation of PCB equipment proved important to the project. The remedial action alternatives posed to the state legislature varied as a function of time, budget, and severity. Several of the less severe alternatives required that most PCB equipment remain on-line for the foreseeable future, and be fitted with appropriate safeguards in the event of a spill or on-line malfunction.

In the same vein, the requirements governing "storage for disposal" (Annex III) were important to the inventory. Temporary approved storage sites were considered for each institution, as well as for one or two central locations in the state as accumulation points for off-line PCB equipment. Limitations on storage time were considered secondary at this point to the overall project goal of removing equipment from operation.

The availability of sufficient commercial capacity for PCB disposal is of concern to any inventory and management plan. Apart from the federal regulations and permit requirements which limit the existing disposal capacity, the State of California also expects to experience a ban of PCB's from the state's Class I landfills as a result of a recent executive order by the Governor (2). The State of California therefore elected to de-emphasize near-term disposal in favor of long-term storage and transfer capacity.

LEGAL IMPLICATIONS OF STATE PCB OWNERSHIP AND DISPOSAL

Within the current legislative framework of PCB management, there are explicit penalties for noncompliance with prevailing regulations and specific responsibilities of the various parties involved in a PCB management program. The State of California, like any public or private agency responsible for PCB management, is concerned with the liability exposure associated with improper PCB management.

The liability which could result if one of the PCB handling steps resulted in damage falls under one of the four following legal categories:

- Common law theories of liability.
- Superfund strict liability.
- The Toxic Substances Control Act (TSCA).
- Citizen suits.

The common law principles of strict liability theory for ultrahazardous activity are the most commonly exercised principles in environmental contamination. These theories apply to any person conducting an activity which may result in harm, no matter how careful the actor is. Even where negligence or fault theories are applied to toxic contamination cases, the negligence

standard is not high. The PCB regulations are specific and often inadvertently violated. The state could be held liable for any damage resulting from failure to meet these regulations (3).

In addition, negligence on the part of the state in selecting a contractor to transfer PCB's for storage or ultimate disposal could result in liabilities being imposed on the state for associated damages. Even where the state is careful in contractor selection, there is some precedent for holding the owner of the material responsible for the actions of a contractor where the actions involved constitute inherently dangerous activity. Contracts of this type should be carefully reviewed by legal counsel for their insurance and indemnity provisions (4).

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (PL96-510), or the so called "superfund" legislation, codified some of the elements of the state common law strict liability rules. Under superfund, any responsible party which causes the release or threatened release of hazardous substances is liable for the cost of removal, or other damages for adverse effects on natural resources. A state government can be held liable for virtually any negligent action regarding PCB management, as superfund liability is joint and several.

The TSCA imposes specific constraints on the use and manufacture of PCB's. The regulations governing PCB management are well known. A specific gravity-based civil penalty structure was also adopted by EPA under TSCA. There is no limitation on the policy that precludes its application to states.

Penalties imposed by federal government on sovereign states are often thought to be inappropriate, so the last course of action in an instance of state PCB mismanagement is civil penalties imposed by citizens suits. While a common defense in many states is government immunity, California is one of several states which have abolished the governmental immunity defense. While citizen plaintiffs suing a state can recover attorneys and expert witness fees, there is no clear precedent regarding money damages and/or civil penalties in such a suit. Nevertheless, a state could face significant liability for failure to prevent PCB discharges.

IMPLEMENTATION OF THE PCB EQUIPMENT SURVEY

The survey of PCB electrical equipment in California state facilities served many purposes. Aside from providing a detailed inventory of fluid-filled electrical equipment, the inventory provided an opportunity to review PCB management requirements with the responsible state employees and to make a firsthand assessment of equipment condition.

The inventory encompassed 94 state institutions within seven state departments. Table 1 lists the departments along with the

TABLE 1. LIST OF STATE DEPARTMENTS SURVEYED AND APPROXIMATE FLUID-FILLED EQUIPMENT COUNT

Department	No. of Institutions Surveyed	No. of Units	
		PCB*	Other
Corrections	12	205	634
Developmental Services	9	238	784
General Services	34	7	6
Mental Health	2	18	118
State Universities and Colleges	19	362	828
Veterans Affairs	1	26	86
Youth Authority	17	77	235
TOTALS	94	933	2,691

* Based on nameplate data only.

estimated number of fluid-filled equipment items on hand within each department.

For the purposes of the survey, the original list of 94 institutions was divided evenly between the northern and southern halves of the state. Separate project task groups were assigned to each half. Each task group then assembled two-man survey teams, consisting of one engineer familiar with PCB management and one electrical engineer familiar with the particular institution's electrical system. The two geographic sections were further subdivided based on clusters of institutions, and crews were assigned to each cluster. During the scheduled 3- to 5-day site visit, the survey crew first briefed the supervising electrical engineer on the purpose of the project and the current status of the regulations. The crew then reviewed the facility's inventory of electrical equipment. An electrician or electrical engineer would then guide the survey crew to the location of each fluid-filled equipment item.

For each equipment location within the institution, the survey crew completed a detailed set of four individual data forms listed below:

- A cover sheet, which identified the location of the facility within the institution, date, team participants, contacts, and the number and code of fluid samples taken.
- A storage and records form, used to inventory all oil-filled equipment in storage and to provide an assessment of the adequacy of the storage facility in accordance with Annex III regulations.
- PCB equipment survey forms, which were filled out for each equipment item (regardless of the name plate fluid), and included name plate information and general comments on equipment condition.
- Installation forms, which described the specific location of each group of equipment items. This form included space for sketches and/or photographs of the installation, including notes regarding spill control and at least one proposed method of equipment removal.

An electrical form was also prepared for tallying necessary information on the electrical aspects of these equipment items. Code violations were noted, and remedial action costs were estimated. Equipment condition and load were noted for later use in specifying replacement equipment.

A minimum of three fluid samples were extracted at each institution from on-line or stored equipment containing non-PCB name plate fluid. These samples were then analyzed for PCB concentration in order to detect possible contamination during manufacturing or topping off during operation. The results of the

analysis were then compiled and correlated with size and manufacturer to determine any trend in PCB concentration among state equipment.

Table 2 shows the correlation between equipment size and PCB concentration, while Table 3 correlates manufacturer with PCB concentration. Over 130 samples were analyzed, but some unit capacities and/or manufacturers could not be identified. Note that a higher percentage of larger units were contaminated. Similar correlations in Table 3 are not appropriate due to differences in unit size between manufacturers.

An approximate PCB/PCB-contaminated/non-PCB ratio of 75%/20%/5% was applied to the balance of oil-filled equipment based on these results. It was recognized that a unit-by-unit analysis must ultimately be performed prior to actual design and implementation of a comprehensive remedial action program.

Once the forms were completed, costs were computed for equipment replacement, code violation repair, environmental isolation, and spill cleanup, regardless of whether the equipment contained PCB's or a non-PCB fluid.

The ultimate user of this information was to be the state legislature, which would set a policy for the first program year and budget the appropriate costs for remedial action in accordance with the policy. To this end, four separate cost scenarios were developed, each in compliance with the current regulations, but varying in degree of remedial action. These first-year options included the following:

a. Replacement of all PCB and PCB-contaminated equipment regardless of condition with new environmentally acceptable equipment.

b. Same as "a" except that equipment in good condition is retrofilled to a non-PCB classification. Equipment containing less than 100 gallons of fluid was not considered for retrofilling.

c. Complete replacement of leaking or otherwise hazardous PCB equipment with new environmentally acceptable equipment, and retention of PCB and PCB-contaminated equipment in good condition with appropriate spill prevention and control measures.

d. Replacement of all leaking or otherwise hazardous PCB equipment with new environmentally acceptable equipment, except where equipment is in good condition, and leaks are minor and repairable. All equipment kept in service was to be retrofilled to achieve a contaminated classification. Units of less than 100 gallons were not considered for retrofilling. PCB-contaminated equipment

TABLE 2. STATE OF CALIFORNIA TRANSFORMER FLUID ANALYSIS RESULTS, BY FLUID CAPACITY

	Test Results (ppm)		
Size (gal)	< 50	50-500	> 500
0 to 49	43	8	1
50 to 124	15	3	0
125+	24	9	4
TOTALS: #	82	20	5
%	77	19	4

TABLE 3. STATE OF CALIFORNIA TRANSFORMER FLUID ANALYSIS RESULTS, BY MANUFACTURER

Company		50	50-500	500
Westinghouse		12	2	0
General Electric		19	10	5
Pennsylvania		4	0	0
Sierra		3	1	0
West		5	2	0
Line Material		2	0	0
Gardner		7	0	0
Hill		6	0	0
Wagner		2	0	0
Other*		19	6	3
TOTALS:	#	79	21	8
	%	73	20	7

Includes: Uptegraff
Pacific
McGraw-Edison
ITE
Marcus
ESCO
Allis-Chalmers

remaining in service was equipped with spill control and its containment.

Based on these cost scenarios, detailed inventories were prepared for each institution, as shown in Table 4. Using the information presented in this fashion, the cost of each policy scenario could be computed directly by moving up and down the cost columns, and including or excluding the appropriate corrective action cost. Cost tables, such as the one shown in Table 5, were then prepared for each institution, summarizing the cost of implementing each scenario for each category of equipment contamination. On-site storage was also included. Summary tables were also prepared for each institution listing the number of units in each PCB category and the associated volume of fluid requiring disposal; an example is shown in Table 6. Each institution write-up also included a description of PCB equipment condition in general, as well as an assessment of the current electrical system.

Once all of the institutions within a department had been surveyed and the data tabulated, tables similar to Tables 5 and 6 were prepared by department as well.

Table 7 summarizes the cost of the corrective action costs by alternative and state department. Table 8 presents a qualitative comparison of the four PCB management scenarios alongside the initial cost for implementation. One of the major benefits of the survey was to show the relative cost of various degrees of PCB management within the state. Alternative C, a version of which was ultimately adopted by the state legislature, was estimated to cost approximately 10 percent of the cost of complete equipment replacement (the most severe option, "a"). Both alternatives meet the current intent of the law. The less expensive alternatives have a higher long-term risk, and will require that supplementary inventories be conducted to update equipment condition and replacement cost each year.

PCB STORAGE FACILITY DEVELOPMENT AND SITE SELECTION

The establishment of one or more state-owned central PCB storage facilities was considered a desirable alternative to present storage and transport methods. Over 200 transformers and other electrical equipment items containing PCB's were observed in unauthorized storage areas during the course of the inventory. A significant part of the PCB management plan, therefore, was to develop a preliminary storage concept and attempt to site such a facility somewhere convenient to all of the state institutions.

Several storage alternatives exist, including development of approved storage facilities at each institution, development of a smaller number of satellite storage facilities serving clusters of institutions, and development of one or two central storage and transfer facilities. Early in the inventory, the state decided to pursue the major central storage facility concept due to

TABLE 4. FLUID-FILLED ELECTRICAL EQUIPMENT
"EXAMPLE OF INVENTORY TABLES,
CALIFORNIA STATE UNIVERSITY, CHICO

	Equipment Description							
Location	Unit Number	Instal-lation	Fluid	Type	Condition	Weight (lb)	Capacity (gal)	Labels
Modoc Hall	18	otdr pad	sus oil	xfmr	NOL	5,145	170	NO
Holt Hall-Bsmt	19	app vault	sus oil	xfmr	mod leak	11,023	385	NO
Plumas Hall	20	app vault	PCB	xfmr	NOL	5,820	164	NO-A
	21		PCB	xfmr	NOL	5,820	164	NO-A
South Gym	22	otdr pad	sus oil	xfmr	NOL	4,333	163	NO
Stadium Lights Transformers	23	pole	sus oil	8 xfmr	NOL	5,640	320	NO
Stadium Parking Lot	24	pole	PCB	xfmr	NOL	745	19	NO-A
Stadium Pole Mounted Switch	25	pole	sus oil	OS	trace leak	50	5	NO
Intramural Field Pole Mount	26	pole	PCB	xfmr	NOL	745	19	NO-A
Langdon Hall-Rm 301	27	LAB	sus oil	6 xfmr	NOL	300	30	NO
Dairy Unit-Location X	28	pole	sus oil	xfmr	NOL	300	15	NO
	29	pole	sus oil	xfmr	NOL	450	20	NO
Horticulture Unit	30	pole	sus oil	xfmr	NOL	395	30	NO
Pump House-Farm	31	pole	sus oil	3 xfmr	NOL	750	45	NO
Meat Lab	32	pole	sus oil	3 xfmr	NOL	1,200	90	NO

TABLE 4 (continued)

Location	Unit Number	Total Replacement Cost Equipment ($)	Removal ($)
Modoc Hall	18	30,000	3,200
Holt Hall-Bsmt	19	52,000	6,600
Plumas Hall	20 21	45,000	6,070
South Gym	22	22,000	3,200
Stadium Lights Transformers	23	5,000	5,000
Stadium Parking Lot-Pole Mount	24	3,000	900
Stadium Pole Mounted Switch	25	incl	incl
Intramural Field Pole	26	12,000	600
Langdon Hall-Rm 30	27	5,000	200
Dairy Unit-Location X	28 29	3,200	600
Horticulture	30	1,500	300
Pump House-Farm	31	2,400	900
Meat Lab	32	3,500	900

for Each Location		Corrective Action Costs for Each Location			
Instal-lation ($)	Total ($)	Retrofill ($)	Isolation ($)	Spill Clean-up ($)	Code Compliance ($)
20,000	53,200	8,500	820	NA	-0-
20,000	78,600	19,250	220	600	-0-
35,000	86,070	8,200 8,200	380	NA	-0-
17,000	42,200	8,150	540	NA	-0-
3,000	13,000	NA	NA	NA	-0-
2,500	6,400	NA	NA	NA	-0-
incl	incl	NA	NA	NA	-0-
9,000	21,600	NA	NA	NA	-0-
1,500	6,700	NA	NA	NA	-0-
1,800	4,600	NA NA	NA	NA	-0-
1,000	2,800	NA	NA	NA	-0-
1,600	4,900	NA	NA	NA	-0-
2,500	6,900	NA	NA	NA	-0-

TABLE 5. SUMMARY OF PCB CORRECTIVE AND MANAGEMENT CONTRACT COSTS: DEPARTMENT OF STATE COLLEGES AND UNIVERSITIES

Alternative	Known PCB ($)	Suspected PCB ($)	PCB Contaminated ($)	Storage Facility ($)	Total ($)
Alt. A - Complete replacement of all PCB and PCB-contaminated equipment regardless of condition with new environmentally acceptable equipment.	13,900,000	450,000	1,000,000	250,000	15,950,000
Alt. B - Similar to Alt. A except equipment (transformers and switches) in good condition shall be retrofilled to a non-PCB classification (EPA - less than 50 ppm). Equipment of less than 100 gallons not considered for retrofilling (not cost effective).	5,300,000	275,000	1,100,000	250,000	6,650,000
Alt. C - Complete replacement of all leaking (or hazardous) PCB and PCB-contaminated equipment with new environmentally acceptable equipment. PCB and PCB-contaminated equipment in good condition shall be retained in service, but with new work added for spill prevention, as required.	1,200,000	25,000	100,000	250,000	1,575,000
Alt. D - Replacement of all leaking (or hazardous) PCB and PCB-contaminated equipment with new environmentally acceptable equipment, except units of over 100 gallons capacity, shall be repaired where leaks are minor and condition is good. PCB equipment (over 100-gallon capacity) shall be retrofilled to meet contaminated classification (50 to 500 ppm). New work as required for spill prevention of all units retained.	3,200,000	75,000	300,000	250,000	3,825,000

TABLE 6. FLUID FILLED ELECTRICAL EQUIPMENT SUMMARY TOTALS
DEPARTMENT OF UNIVERSITIES AND COLLEGES

		Gallon Capacity of Equipment				
	PCB Category	0-49	50-100	>100	NA	Total
Number of Units	Known PCB	104	60	198	0	362
	*Suspected PCB	27	8	6	<1	41
	*PCB Contaminated	107	33	23	1	164
	*Non-PCB	404	123	87	9	623
Gallons of Fluids	Know PCB	49,312 gal				
	*Suspected PCB	2,473 gal				
	*PCB Contaminated	9,912 gal				
	*Non-PCB	37,166.5 gal				

Approximate storage area required: 2,640 ft^2

Estimated Contract Cost: $250,000

* Approximate value based on statistical probability of oil contamination.

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TABLE 7. SUMMARY OF PCB CORRECTIVE AND MANAGEMENT CONTRACT COSTS BY ALTERNATIVE*

Department	Cost by Alternative ($000) (a)	(b)	(c)	(d)
General Services	282	68	3.5	41.5
Development Services	3,790	2,627.5	427.5	810
Youth Authority	1,969.5	1,299.5	201.5	408.5
State Colleges	15,950	6,650	1,575	3,825
Mental Health	837	425	93	173
Corrections	4,175	3,075	495	914
Veterans Affairs	538	458	68.5	94
TOTAL	$27,541.5	$14,603.0	$2,864.0	$6,266.0

* Does not include cost of transportation, disposal, or central storage site.

TABLE 8. QUALITATIVE COMPARISON OF

Alternative	Ease of Implementation	Initial Cost ($000)
(a) Complete equipment replacement.	-	27,542
(b) Complete replacement, except equipment in good condition and greater than 100 gallons will be retained and retrofilled.	0	14,603
(c) Replace leakers and provide spill control for remaining PCB or PCB-contaminated equipment.	+	2,864
(d) Replace moderate and major leakers; repair others. All retained equipment greater than 100 gallons will be retained and retrofilled. Provide spill control for remaining PCB or PCB-contaminated equipment.	+	6,266

SELECTED PCB MANAGEMENT ALTERNATIVES

Initial Risk	Possible Future Costs	Possible Future Risks	Meeting Existing Regulatory Intent	Meeting Possible Future Regulatory Intent
High	None	None	Exceeds	Meets future intent
Mod.	Low	Low	Exceeds	Probably meets future intent
Low	High	High	Meets existing intent	No
Low	Mod.	Mod.	Meets existing intent	No

improved transportation efficiency and assurance of proper PCB management at the state level.

The siting operation proceeded in several phases. The initial screening of potential state-owned sites was based on Resource Conservation and Recovery Act (RCRA) hazardous waste general facilities standards. These include consideration of seismology, location in floodplains and wetlands, endangered species, sole source aquifers, and buffer zones.

Design criteria were also established based on the Annex III storage requirements. A specific list of design criteria was prepared for general storage facilities; necessary permits at the state and federal level were identified; and general site parameters were developed. The conceptual storage facility was designed to accommodate all PCB and PCB-contaminated fluids, equipment, and material identified during inventory of the 94 institutions. Statewide, an estimated 0.5 acres would be required for storage of Annex III waste (contained fluids), and 1 acre for transformer carcass storage.

The primary functions of the facility would be (a) storage for disposal, (b) flushing, and (c) processing for transport to disposal. No treatment or disposal would take place at the facility. Figure 1 shows the conceptual site layout for the single large facility, indicating the major storage areas and necessary support functions. Similar scaled-down versions were also prepared in the event that two or more decentralized facilities were selected.

Table 9 summarizes the detailed cost estimates and sizes developed for each facility. There are obvious economies of scale between one and two facilities, recognizing the fixed cost for office space, laboratories, scales, and semivariable operation and maintenance costs.

Given the facility size and design and siting criteria, the actual site screening commenced. Beginning with a list of all state-owned facilities, initial screening was conducted by eliminating sites with the following characteristics:

- In or near population centers (due to public opposition potential).
- In or near coastal plains (due to prohibitive siting requirements).
- In major agricultural areas (due to potential for environmental contamination impacts).
- In or adjacent to office buildings and complexes (due to lack of adequate space).

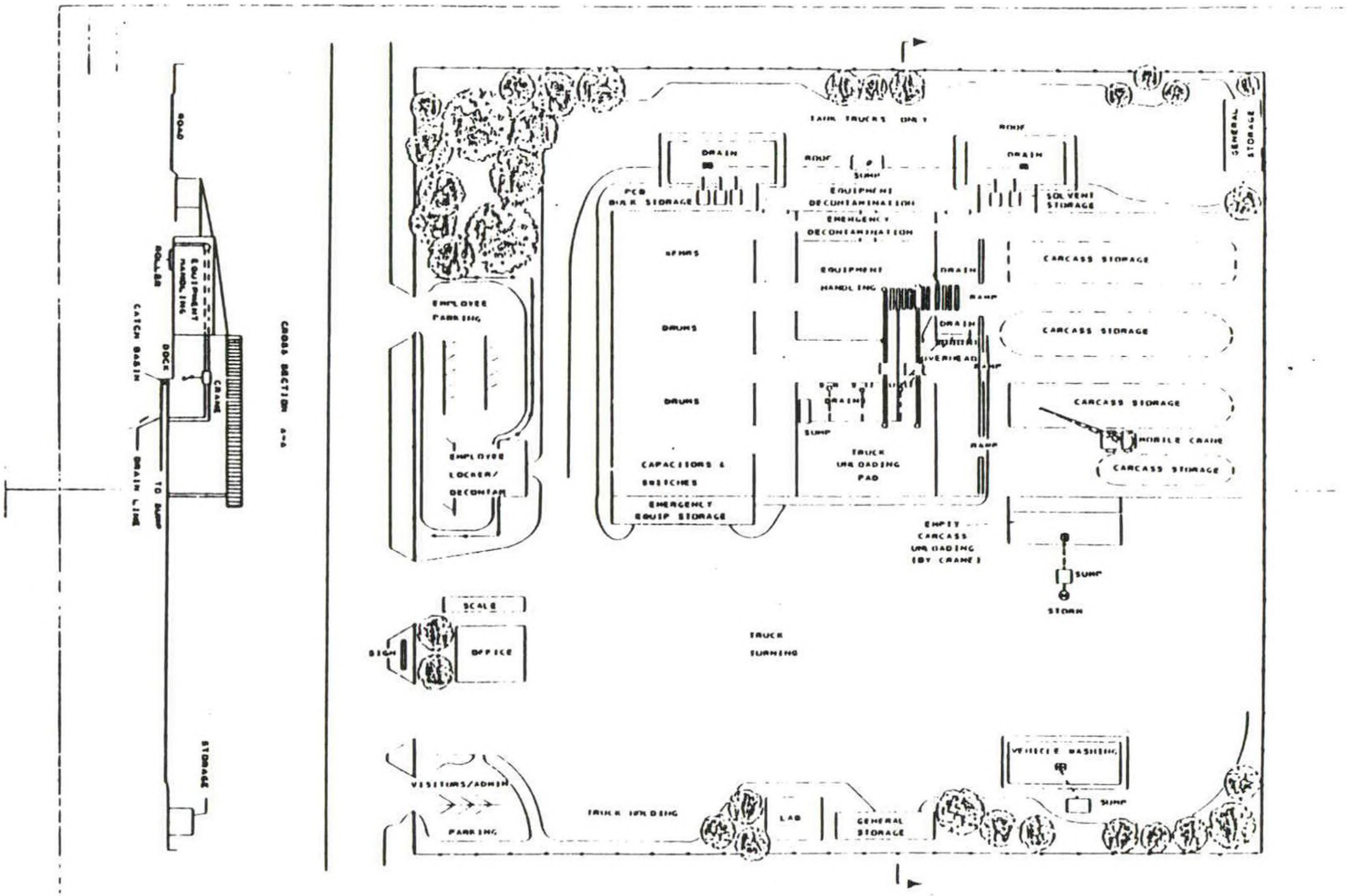


Figure 1. Conceptual storage site layout, large facility.

TABLE 9. COST/SIZE SUMMARY FOR CENTRAL PCB TRANSFER FACILITIES

Facility	Acres/ Facility	Number of Facilities	Total Estimated Capital ($)	Total Estimated Annual O&M ($)
Large	8.3	1	1,563,116	127,030
Small	3.9	2	994,791	101,870

Remote valleys in the east central portion of California were also excluded due to their inconvenient location in relation to the major population centers.

A total of eight counties survived the initial screening. The Department of General Services, Office of Real Estate, was then consulted to determine state holdings in these counties. The next phase screening criteria included exclusion of the following sites:

- Offices, park areas, and historical landmarks (due to incompatibility with PCB storage).
- Sites of less than 1 acre.
- Sites more than 2 miles from a major transportation artery.

The elimination process left 11 candidate state-owned sites. This list was expanded to include several federally owned sites identified during the course of the initial screening. Each of the 15 remaining sites were then investigated to determine their underlying geology, holding agency, general social and environmental impact, and other important siting considerations.

The list was finally narrowed to four sites based primarily on favorable geology. All four sites (Solemint, Soledad, Camp San Luis Obispo, and Hungry Valley) were visited and fully developed for final selection by the state. Existing structures were investigated for PCB storage suitability. Preliminary cost estimates were prepared for upgrading each site for storage facility construction. A detailed collection and transportation analysis was performed for each of the sites to determine which would result in the lowest transportation cost for the 34 institutions. The cost of the large and small storage/transfer stations was then amended for each site, based on the availability of existing structures, the degree of site preparation, and any additional access roads which might need to be constructed.

The storage analysis was intended for use by the state legislature and other state officials to select and implement a long-term storage strategy. The funding bill approved in June 1981 did not include consideration of a central storage facility in the preliminary plans for PCB management, due to anticipated public opposition to any central storage facility. Budget appropriations were instead made for individual storage facilities at the 53 institutions requiring immediate attention. There are no plans to pursue the siting of a storage facility in the next fiscal year.

PCB TRANSPORT AND ULTIMATE DISPOSAL

The final link in the state's first phase of PCB management was a determination of the cost of ultimate disposal of the material, once consolidated at a common storage facility. The status of PCB disposal capacity for liquids and solids was reviewed for the state, including projected facility life, location, and unit cost for disposal. Given this information, transportation and disposal costs were estimated by the state department for both solids and liquids. The results of this analysis are presented in Tables 10 and 11, respectively.

STATUS AND PLANS FOR STATE OF CALIFORNIA PCB MANAGEMENT

The PCB management plan and inventory described in this paper was the result of an intensive 3-month investigation, culminating in the development of a budget change proposal for the California legislature. In June 1981, a budget allocation of approximately $4 million was approved for 1981-1982, based on the least expensive option, Alternative C. Budget items were approved for replacement of major and minor leaking PCB equipment, spill containment and control provisions for on-line PCB equipment, and temporary storage at 53 institutions impacted by the program.

The 1982-1983 budget proposal will include up to $7 million for replacement or repair of minor leakers including retrofilling, spill control, and destruction of PCB fluids generated during the FY 81-82 changeout program.

The state will also be conducting the next phase of inventories at institutions excluded from the initial investigation. The inventory should begin at the end of December 1981, and culminate in a similar budget change proposal for the June 1982 legislative session.

Other actions by the state legislature and regulatory agencies (Department of Health Services, California OSHA) will also impact PCB management by the state and private sector over the next several years. The Governor's office recently issued an executive order banning the disposal of PCB's and selected "extremely hazardous wastes" from California landfills. The Governor has also proposed a toxic waste agency to consolidate various toxic and hazardous waste activities from the different departments possible, including the OSA PCB program. Several incidents within the past year have also brought attention to the state-owned PCB management problem, and have provided legislative incentive both for funding of remedial action and for passage of more stringent regulations governing PCB management. These and other options at the state level can be expected to accelerate PCB management activities in California well ahead of federally required action throughout the United States.

TABLE 10. COST OF PCB MATERIAL TRANSPORT TO DISPOSAL, BY DEPARTMENT

Department	Solids		Fluids		Total
	Volume (m^3)	Total ($000)	Volume (Gal.)	Total ($000)	
Corrections	338	$ 5.0	33,712	$ 8.0	
Developmental Services	337	5.6	33,720	8.0	
General Services	8	0.1	480	0.1	
Mental Health	83	1.2	6,586	1.6	
Universities/ Colleges	1,019	15.1	120,460	28.6	
Veterans Affairs	39	0.6	2,654	0.6	
Youth Authority	145	2.1	9,924	2.3	
Total	2,009	$29.7	207,536	$49.2	

*Assumes $0.11/m^3$-mi and 135 mi/trip avg. = $14.85/$m^3$

+Assumes $0.125/1000 gal. -mi and 1900 mi/trip avg. = $237.50/1000 gal.

TABLE 11. COST OF PCB MATERIAL DISPOSAL, BY DEPARTMENT

Department	Solids Volume, (m^3)	Solids Total ($000)	Fluids PCB, Gal	Fluids Total ($000)	Fluids PCB Cont. Gal.	Fluids Total ($000)	Total ($000)
Corrections	338	$ 67.6	27,864	$ 222.9	5848	$ 46.8	$ 337.3
Developmental Services	337	75.4	24,116	192.9	9604	76.8	345.1
General Services	8	1.6	400	3.2	80	6.4	11.2
Mental Health	83	16.6	4,494	359.5	2092	16.7	392.8
Universities/ Colleges	1,019	203.8	103,872	831.0	16,588	132.7	1,167.5
Veterans Affairs	39	7.8	1,786	14.3	868	6.9	29.0
Youth Authority	145	290.0	7,096	56.8	2,828	22.6	369.4
Total	2,009	$662.8		$1,680.6		$308.9	$2,652.3

*Assumes: $200/$m^3$ Solids, $8.00/Gal. Fluids (1983)
#PCB Rinse = PCB Fluid
PCB Cont. Rinse = PCB Cont. Fluid

REFERENCES

1. SCS Engineers. PCB Study/Survey, California Office of the State Architect, Sacramento, California, June 1981. 765 pp.

2. Executive Order of October 13, 1981, concerning hazardous waste control.

3. McKenna vs. Pacific Electric Railway Company, 286 p. 445, 104 C.A. 538.

4. United States vs. Shell, 549 F2d 587 (C.A. 9th, 1976). Note: U.S. government held liable; contractor's employee killed while undertaking ultra-hazardous activity.

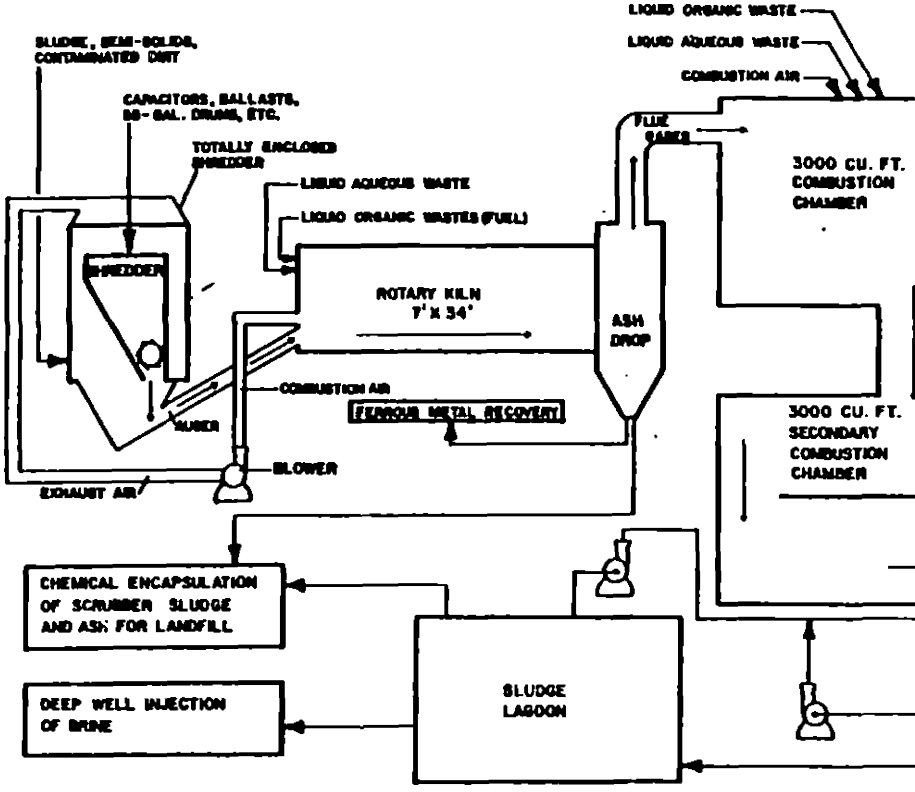
Section 4

ASKAREL DESTRUCTION

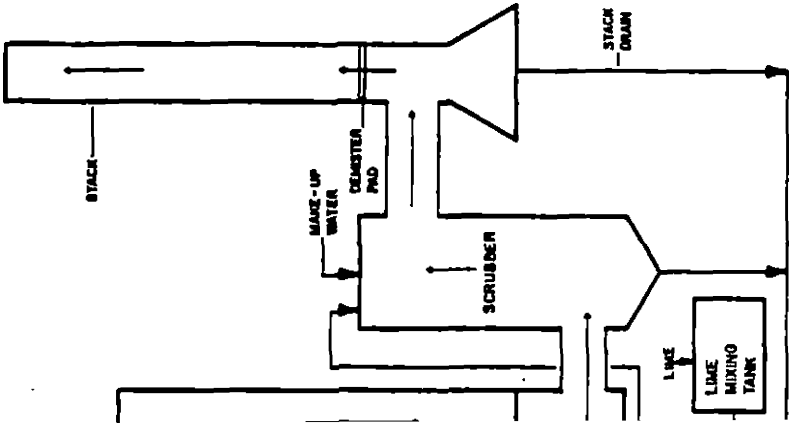
SCHEMATIC OF ENSCO INCINERATION SYSTEM

G. Combs
ENSCO

SCHEMATIC OF ENSCO INCINERATION SYSTEM



G. Combs
ENSCO
El Dorado, Arkansas



DISCUSSION:

Q. What is your present capacity?

A. The limit is now 600 pounds per hour, but we hope to increase that to 2000 pounds per hour soon.

Q. Have you refused material based on heavy metal content?

A. Yes, but we have not found it necessary with PCB waste. Non PCB waste streams are tested prior to shipment, but we have not found this necessary for transformer contaminated oil.

Q. Are you accepting capacitors at this time?

A. Yes; however, the plant was down two weeks before Thanksgiving so there was a delay in disposal.

Q. What is the holding time for capacitors now?

A. We cannot really answer. It will vary depending upon waste streams. However, half of the cash receipt goes into an escrow account until it is burned. When the capacitors are actually destroyed, a written report is provided.

OCEAN INCINERATION

J. E. Campbell
Chemical Waste Management

Ocean Incineration

James E. Campbell

Chemical Waste Management, Inc. is a wholly owned subsidiary of Waste Management, Inc. and the largest company of its type in the field of chemical waste disposal. To date, we have received from the USEPA interim status for 18 treatment and disposal centers and nine transfer facilities in the United States. Two of these facilities, one located at Kettleman Hills, California and the other in Emelle, Alabama, are currently permitted for the disposal of PCB Wastes. In addition, we operate the ocean incineration vessel MT "Vulcanus" in Europe and the United States, for the at sea incineration of chlorinated hydrocarbons and other halogenated wastes. It is this ship, the Vulcanus, which I will be talking about today.

In September of 1980, Chemical Waste Management, Inc. acquired Ocean Combustion Services of the Netherlands, which included the Vulcanus. Through its operation of the ocean combustion vessel Vulcanus, Ocean Combustions Service serves major industrial customers in several European countries and the United States, by utilizing high temperature incineration to burn organochlorine wastes.

The Vulcanus performed the first officially sanctioned ocean combustion of chlorinated hydrocarbon wastes in the United States in 1974 and 1977, meeting the environmental requirements of the USEPA then and again in 1977 when she was brought back to incinerate additional consignments of toxic wastes. The first two burns were conducted at an EPA designated burn site in the Gulf of Mexico, which is approximately 200 miles south of Galveston, Texas. The burn in 1977 was for the incineration of the herbicide Agent Orange, and was conducted at a remote location in the Pacific Ocean, West of Johnston Island. Combustion efficiences of all these burns ranged from 99.9 to 99.999 percent of all organic compounds.

It was the results of these burns that prompted Chemical Waste Management, Inc. to apply for and receive an EPA permit for the at sea incineration of PCB liquids greater than 500 ppm. On October 23rd, of this year we received Research Permit No. HQ-81-002 for the incineration at sea of PCB's. This permit has been issued pursuant to authority granted in section 1412 of the Marine Protection, Research and Sanctuaries Act of 1972.

The Vulcanus is a chemical tanker which was converted in 1972 from a dry cargo vessel complying with international regulations issued by the Intergovernmental Maritime Consultive Organization (IMCO) which is a London based branch of the United Nations dealing with shipping, ship building, ship safety, etc. Prior to being converted into an incineration vessel, it served for sixteen years on regular lines of trade between Europe, the United States, the Great Lakes and the Gulf of Mexico. It was converted within seven months and entered service as an incineration vessel in September 1972. It has now been in service for more than nine years and is the most thoroughly researched vessel of its type in the world today.

The Vulcanus has recently undergone maintenance in Europe and has been certified by Germanischer Lloyd in accordance with IMCO Type 2 standards for transportation of hazadous material. In addition to this certification, the ship was also inspected and cleared by the U. S. Coast Guard when it arrived in port on November 27, last week.

The incinerators were also overhauled and test burns resulted in 99.97 percent average combustion efficiency. The automatic stack monitoring of the Vulcanus is in full compliance with the Final Regulations and Guidelines for Incineration at Sea as adopted pursuant to IMCO regulations. The Vulcanus, as a matter of fact, was used as the model in the development of the regulations which will be incorporated into EPA's regulations.

The Vulcanus is a double hulled ship equipped with two large incinerators capable of burning 4,000 gallons of waste per hour and an array of sophisticated controls which continuously monitor operations to ensure full compliance with international permits. The Vulcanus is approximately 335 feet long, 46 feet wide and contains 15 holding tanks for a total load capacity of about 850,000 gallons. All safety equipment designed for the ship is in accordance with the latest regulations of IMCO and the U. S. Coast Guard. The wastes to be processed must be liquid and pumpable. They may contain solid substances in pieces up to 2mm in size. Halogen content of even more than 70% represents no problem. PH range should be between 4 and 9. Water may also be incinerated, but must be kept in separate tanks and fed into the incinerators along with the wastes.

In May of this year, knowing that the permit was forthcoming, we began accumulating mateial for the first burn, which will take place later this month, in the Gulf of Mexico at the EPA designated burn site approximately 200 miles south of Galveston, Texas. The site has been described in environmental studies as a biological desert and near perfect for ocean incineration. The loading of the Vulcanus began yesterday morning and will continue for approximately 8 to 10 more days. We expect the ship to be fully loaded when it leaves its port facility of Chickasaw in the Mobile, Alabama bay area. There is no storage of PCB material at the port, but only a transfer facility. All storage has been done at our Emelle, Alabama landfill, where we have the capacity to store approximately 900,000 gallons of liquids. The PCB material is currently being transferred from Emelle, Alabama to Mobile, Alabama by tanker at the rate of 20 trucks per day.

The material, before being loaded into the tankers was blended together in 25,000 gallon storage tanks in order to reach the needed physical properties for burning. The permit is for up to 3.6 million gallons of liquid. With each burn consisting of 850,000 gallons, we plan to conduct four seperate burns, the first one taking place this month. The by-products of these burns will be carbon dioxide, water, hydrogen chloride, and trace metal particulates. The natural alkalinity of the ocean neutralizes the acidity of the hydrogen chloride with a buffering and environmentally nominal effect. A large plume spiked with ammonia emanates from the incinerator stacks in the form of long white trailing cloud which allows the ship operators to visually monitor the plume and keep it behind them at all times. The incinerators are located at the extreme rear of the ship.

During the entire trip, the Vulcanus will be capable of 24-hour communication with the 8th District Coast Guard. There are extensive safety procedures and rules that the ship and its crew must adhere to as required in the permit. Also, on board will be a safety officer, a representative of T N O, which is the group that will be monitoring the ship's burn efficiency, a representative of TRW, under contract to EPA, and a representative from EPA. Among other devices, a black box monitoring device will be installed to record carbon monoxide, carbon dioxide, oxygen and wall temperature along with a camera mounted so as to photograph the control panel of the black box every 15 minutes.

Conclusion:

As you know, one of the methods for PCB disposal permitted in the PCB regulations is incineration. Incineration is the preferred method for disposal of a number of chlorinated organic wastes because it is capable of essentially complete destruction of the toxic or hazardous constituents of the wastes and is thus an ultimate disposal technology. An alternative to land-based incineration is incineration at sea.

At-sea incineration of organochlorine liquids has been practiced successfully in Europe for a number of years and there have been several burns in the United States. All U. S. burns were closely monitored by EPA. Monitoring results provided the technical basis for concluding that at-sea incineration is an environmentally acceptable alternative to land-based incineration of organochlorine wastes. At-sea incineration is a technology which has the potential to increase PCB disposal capacity nationally, thereby, relieving some of the expected shortfall in capacity. Although at-sea incineration is a proven technology, Chemical Waste Management, Inc.'s planned burn this month will be the first attempt to demonstrate that PCB's can be effectively disposed of by incineration at-sea.

Questions and Answers:

Q. What are your environmental discharge restrictions?

A. We must meet the same discharge levels and results as for a landbased destruction plant.

MOLTEN SALT DESTRUCTION OF PCBs

J. Johanson
Rockwell International

MOLTEN SALT DESTRUCTION OF PCBs

by

J. Johanson

Environmental and Energy Systems Division
Rockwell International
8900 De Soto Avenue
Canoga Park, California 91304

Abstract

The application of molten salt technology for destruction of hazardous wastes such as PCB is being demonstrated at Rockwell International. The Molten Salt Destruction (MSD) process is based upon the submerged injection of combustible waste and air into a sodium carbonate molten salt mixture at 800 to 1000°C. The salt, which neutralizes acidic pollutant gases, is stable, nontoxic, inexpensive, and an excellent heat transfer media.

Bench-scale and pilot-scale test results of the MSD process applied to HCB, a simulant of PCB, are described. Waste destruction removal efficiencies (DRE) exceeded minimum RCRA requirements for all design test conditions. Results for DRE ranged from more than seven 9s to more than eleven 9s.

DISCUSSION:

Q. Will Rockwell provide disposal service?

A. No. Rockwell is offering the process and will sell equipment, but will not go into the waste disposal service business.

PLASMA PYROLYSIS OF TOXIC WASTES

T. G. Barton
Associate Professor

Department of Civil Engineering
Royal Military College of Canada
Kingston, Ontario K7L 2W3
(613) 545-7395

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Province of Ontario

PLASMA PYROLYSIS OF TOXIC WASTES

PLASMA PYROLYSIS OF TOXIC WASTES

INTRODUCTION

The disposal of toxic materials is an emotionally charged issue in which technology is castigated and bound by political and social displeasure. It is no longer sufficient to show that a toxic material being destroyed is not present in significant quantity in the effluent from the destruction technology. The public and the administrative guardians of the environment have focused attention on the possible production of potentially more toxic compounds during the destruction of wastes.

Polychlorinated biphenyls (PCB's) present a difficult problem for conventional waste disposal systems. Since they are very stable organic molecules, they require long dwell times at high temperature to effect thermal destruction. Present incineration guidelines are difficult to achieve, yet are extremely conservative for plasma systems for three reasons. First, since radiative heat transfer proceeds as a function of the fourth power of the temperature differential, a plasma system is capable of radiating energy up to six million times faster than a conventional flame. Second, organic chlorides are known to dehalogenate when excited by ultraviolet radiation which is abundant from thermal plasmas. Third, inorganic materials often present in contaminated waste are rapidly melted and slagged to promote exceptional decontamination. Thus, it may be conceived that a plasma system possesses unique properties which may adequately address the ultimate destruction of organic halide wastes such as PCB fluids and PCB contaminated capacitors.

PLASMAS

Plasmas have been referred to as the fourth state of matter since they do not always behave as either a solid, liquid or gas. A plasma may be defined as consisting of charged and neutral particles, having an overall charge of approximately zero, all exhibiting collective behaviour.(1) Within the universe, as much as 99 percent of matter, including stars and interstellar space, is in the plasma state.(2) On earth, plasmas are much less prevalent, but the Aurora Borealis, lightning bolts, fluorescent and neon lights, and arc welding are common examples. They all exhibit a collective property of plasmas, an ability to readily conduct electricity.

The most common method of plasma generation is electrical discharge through a gas. The plasma may thus be regarded as a finite resistance between a cathode and anode in an electrical circuit. Convection currents shift the plasma arc, creating a larger area for radiative losses and making the plasma difficult to sustain.(3) Energy lost to areas outside the plasma by molecules, ions, electrons or electromagnetic radiation (photons) must be replaced in order to sustain the plasma. The high currents and voltages required to replace the dissipated energy can lead to electrode destruction. Arc welders are characterized by very short arcs of this type and by electrodes which are beneficially destroyed by the plasma created.

In order to create longer, more stable arcs, an innovation was required. The plasma torch used in our research overcomes the convective disturbance by collimation of the plasma arc. Collimation is accomplished by tangentially injecting a gas into

the arc space in the hollow, cylindrical electrode thus creating a strong recirculation vortex. This large resistance to convective disturbance ensures a dimensionally stable plasma column along which the electrical discharge takes place.

The plasma arc, when applied to waste disposal, can best be understood by thinking of it as an energy conversion and transfer device. A low pressure gas is used as a medium through which an electrical current is passed. The type of gas used is relatively unimportant in creating the discharge, but will ultimately affect the products formed. In passing through the gas, electrical energy is converted to thermal energy by absorption by the gas molecules, which are activated into ionized atomic states, losing electrons in the process. Arc temperatures up to 50 000 K may be achieved along the centreline recirculation vortex. Ultraviolet radiation is emitted when molecules or atoms relax from the highly activated states to lower energy levels. Waste materials are atomized and ionized as they interact with the decaying plasma species. The products which result are simple because their activated states are atomic. Figure 1 shows a sustained, well collimated 250 kW transferred plasma arc.

The power available in the plasma discharge can be varied from approximately 80 kW to 350 kW, although additional power is available by increasing the output from the power supply system. Thus the plasma power can be widely varied to suit the needs of the waste being destroyed.

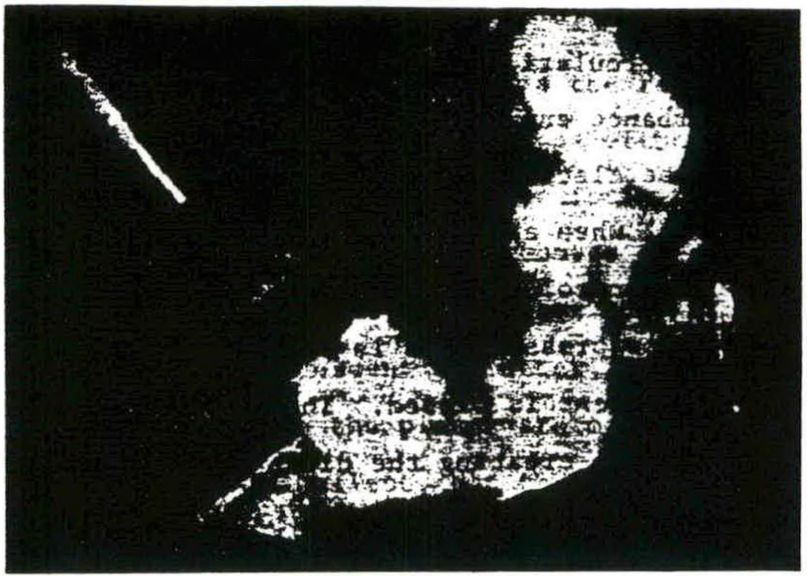


FIGURE 1. TRANSFERRED PLASMA ARC

COMPUTER SIMULATIONS

An integral part of the application of plasma arc technology is the computerized pyrolytic simulation model. If plasma forces a rapid atomization of organic compounds, then recombinations of new molecules from the activated atomic species should be predictable based on kinetic equilibrium. This computer model is used to predict the composition of products formed from waste feedstocks as well as the quantity of plasma energy required to force the pyrolysis.

Equilibrium and material balance equations are used to determine the concentration of product species formed over a range of equilibrium temperatures for selected operating conditions. Undesirable products can be eliminated by the

computer simulation by altering the operating conditions. Changes in enthalpy between the feedstock and the output products are used to predict the quantity of plasma energy required adiabatically for the pyrolysis of the waste being considered. This computer simulation has been tested and supported with experimental data.[4] Suitable experimental test conditions are predetermined using this computer simulation for each test.

EXPERIMENTAL TEST APPARATUS

A schematic of the plan view of the test apparatus used during the destruction of liquid wastes is shown in Figure 2.

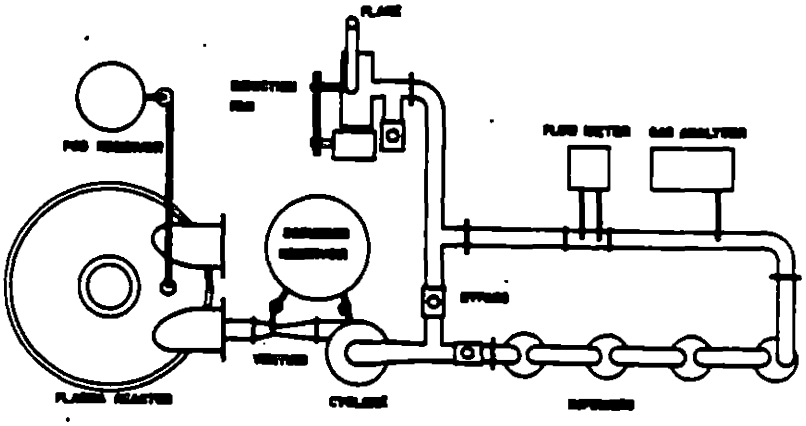


FIGURE 2. PLAN VIEW OF TEST APPARATUS

The plasma reactor is fabricated from stainless steel and is refractory lined with kaowool-22 to limit heat loss to less than ten percent of the applied power. The water cooled, T-shaped

plasma torch is inserted through the top of the reactor and a transferred arc is struck between the torch and a graphite electrode located in the hearth of the reactor. Incident radiation from the arc to the walls of the reactor is approximately 200 to 300 kW/m^2, and is indicative of the much more energetic nature of this type of destruction technology. Liquid wastes are pumped into the reactor through a water walled injection tube using a variable speed Master-Flex pump. The stream of waste, exiting the tube, is aimed to strike the hearth at the impingement point of the transferred plasma arc. The torroidal vortex created in the hearth of the reactor by the plasma discharge ensures excellent entrainment and atomization of the waste in the plasma.

The atomized entities are allowed to recombine, forming products in the upper equilibrating zone of the reactor. Plasma power and waste feed rate are predetermined by computer simulation to ensure a suitable equilibrium temperature in this upper zone. A temperature of approximately 1100 K has been found to be suitable for most organic chloride wastes. The plasma reactor is shown in Figure 3.

The gas scrubbing system consists of a water injected venturi scrubber, a wet cyclone and a closed circuit scrubbing water reservoir as shown in the schematic of Figure 2. Chilled water from the scrubber reservoir is injected through two spray nozzles into the venturi. Water is sprayed at 8 L/min through the upstream nozzle ahead of the venturi throat. The wetted gas is hit with a second spray of 7 L/min as it exits the

FIGURE 3. PLASMA REACTOR

venturi throat. The gas is chilled from 1100 K to 300 K in less than 10^{-3} seconds thus minimizing any shifts in the high temperature equilibrium concentrations of the product gas. Better than 99 percent of the water is extracted from the wetted gas in the cyclone and is returned to the scrubbing water reservoir. Acid gases are trapped by the scrubbing water and neutralized by the addition of suitable basic solutions.

The entire gas stream passes through a series of glass impingers designed to capture organic compounds which may be present in the product gas. Both 10 cm and 23 cm diameter impingers have been used and a series of four 23 cm impingers are shown in Figure 4.

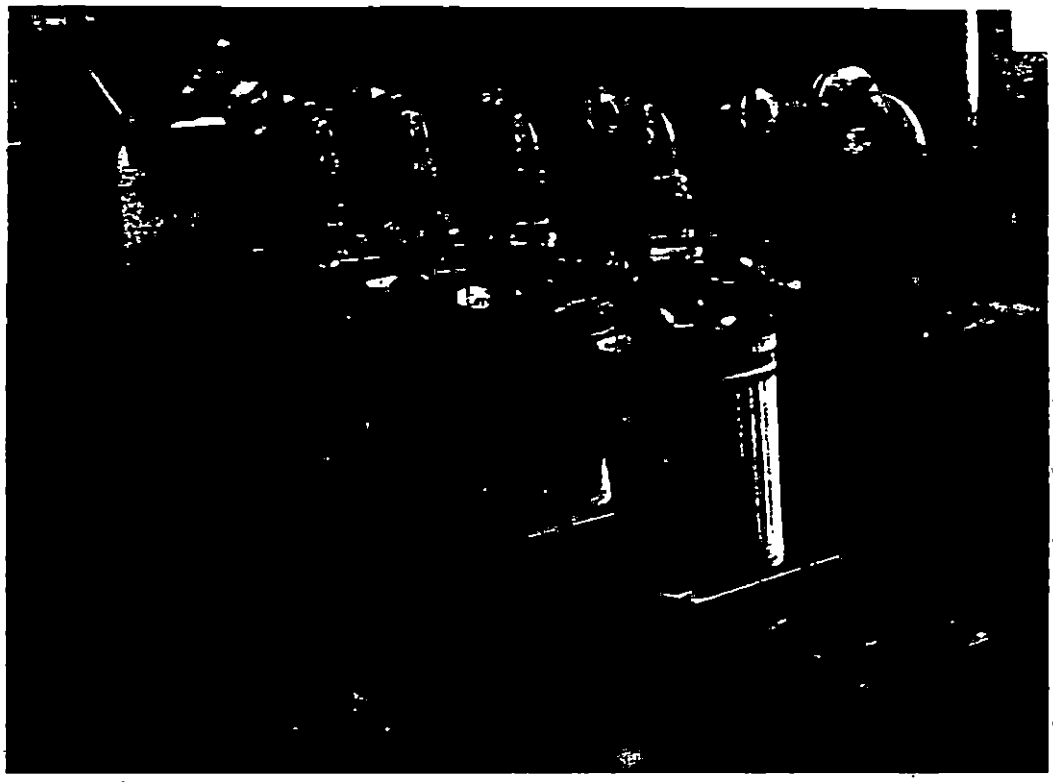


FIGURE 4. GLASS IMPINGER NETWORK

The glass impingers are filled with 20 mm Raschig Rings and wetted with ethylene glycol. The impinger network is bathed in an ethanol-dry ice mixture to promote excellent trapping of organic residues in the product gas.

TESTING PROGRAM

A series of tests has been conducted to demonstrate the performance of the plasma system and to establish the degree to which energy and material balances could be accomplished. The initial use of PCB's in an elaborate test program was judged to

not be in the best public interest and unnecessary until an assessment of all of the experimental parameters was completed. Instead, the twelve chlorobenzenes were selected as simulating or mimicking compounds because they have a wide range of solubilities and vapor pressures, and can be mixed to give elemental compositions identical to commercial PCB preparations. Furthermore, two of the three trichlorobenzenes (TCB's) are present in the aroclors.

Simulated waste solutions were prepared by mixing 300 grams of TCB with three litres of methanol. Computer simulations based on waste atomization and kinetic equilibrium reformations were conducted prior to each test to establish suitable test conditions. The reactor was preheated and the simulated waste material was injected according to the predetermined test conditions. The waste reservoir and injection system was then triple rinsed with methanol to ensure that all the TCB had entered the reactor and that no residue was left on the injection system. According to the computer simulation, the products formed during the destruction of this simulated waste at a reactor equilibrating temperature of 1100 K are listed in Table 1.

TABLE 1. COMPUTER SIMULATION OF THE DESTRUCTION OF A TCB/METHANOL SOLUTION

Product	CH_4	CO	CO_2	HCl	H_2	H_2O	N_2
Mole Percent	0.6	22.54	3.79	1.42	40.12	6.86	25.20

Plasma Energy Required is 0.35 kWh/kg feed.

An additional 61 products were considered by the computer model including 15 chlorinated compounds, but were predicted to have

molar concentrations of less than five ppm.

Although many chlorinated waste destruction demonstrations have shown a reduction in concentration of the waste of interest in the test effluent, few have been able to complete, even on a macroscopic basis, a chlorine balance. Hydrogen chloride extraction in the venturi scrubber was accomplished with the injection of sodium hydroxide at a rate slightly in excess of a stoichiometric amount. Measurement of the pH in the scrubber reservoir during each test gave an indication of the capture of acid gas, mainly hydrogen chloride. At lower pH values, carbonic acid interference is minimized. Specific chloride ion concentration in the scrubber reservoir was determined by titration using Mohr's method.

The first two impingers were chilled to -20°C and the last two impingers were chilled to -70°C to promote high capture efficiency of organic compounds entrained in the product gas. For internal calibration of each test, a known amount of mono-bromobenzene was slowly injected upstream of the impingers to simulate the presence of organic compounds in the gas stream. The amount of mono-bromobenzene extracted from each impinger served to provide a profile of the scrubbing efficieny of the impinger network. After completion of each test, a known amount of ortho-dibromobenzene was added to each impinger. The efficiency of extraction of organic residues from each impinger was directly related to the recovery of the ortho-dibromobenzene

Chromatographic separation of the various benzene compounds used was easily aacomplished using capillary column gas chromatography. A Varian 3700 chromatograph, equipped with

an electron capture detector and temperature programmer was used for all work associated with mimicking compounds. Residual samples were injected in 2,2,4-trimethyl-pentane using a Varian 8000 Auto Sampler, with hydrogen as the carrier gas. The capillary column was fused silica, 25 metres long with a 0.2 mm inside diameter, and coated with dimethyl silicone gum on siloxane. A Varian CDS 111 was used to integrate the gas chromatographic peaks and to give accurate retention times. Identification of peaks was made by retention times.

TYPICAL TEST RESULTS

The concentration of TCB detected in the scrubber reservoir has varied from zero to a maximum of 2.4 ppb. Chloride ion determination when converted from concentration to total mass showed a capture of more than 98 percent of the chlorine. Less than 800 ml of water passes through the cyclone to be trapped in the chilled impinger network. A series of four 23 centimetre diameter impingers are shown in Figure 5.

The gradual transition in colour of the impinger fluid from left to right gives a visual indication of the trapping effectiveness of the impinger system. The small amounts of carbon which escape removal in the scrubbing system became trapped in the impinger fluid, and concentrate in decreasing amounts through impingers one to four.

Recovery of ortho-dibromobenzene from each impinger during extraction was approximately 100 percent complete. Impinger scrubbing efficiency based on mono-bromobenzene recovery showed the impingers to be better than 90 percent effective in retaining this compound. This high retention of

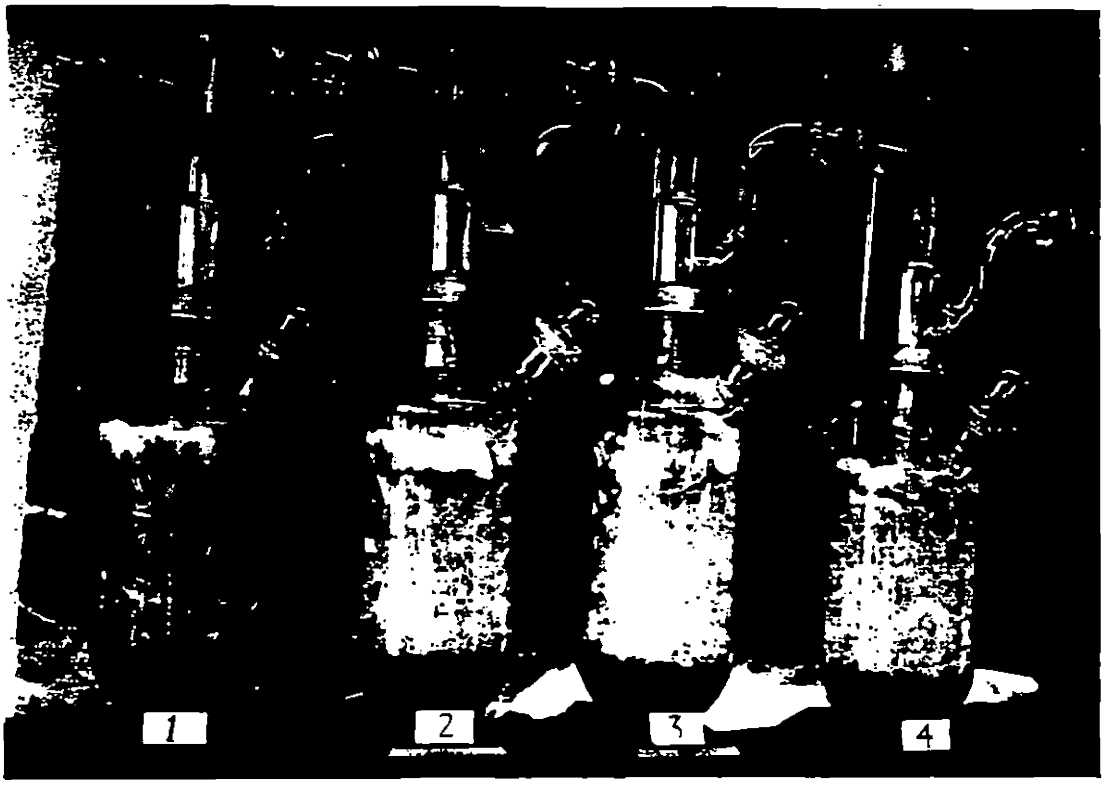


FIGURE 5. PROFILE OF USED IMPINGERS

a relatively volatile compound with a vapor pressure comparable to low molecular weight PCB implies little risk of escape of organic compounds from the impinger system.

Total recovery of 1,2,4-trichlorobenzene from the impinger network amounted to less than 63×10^{-6} percent of that injected into the plasma reactor. This mass of TCB is attributed to short circuiting of feed material during startup and shut down of the system. An additional recovery of 1,2,3-trichlorobenzene was also recovered and could possibly have been synthesized in the reactor from a portion of the short

circuiting material. Quantities however were so small as to be undetectable in the scrubbing reservoir, and a total mass of 6×10^{-6} grams was found in the impingers.

Quantities of other compounds, believed to have higher molecular weights than TCB have also been detected in the impinger. However the total mass was estimated to be in the microgram range and more than 94 percent of it was concentrated in the first three impingers. Such finite quantities and their trapped locations suggests little risk of large molecular weight compounds being released to the environment during testing of more hazardous or toxic materials.

PROGNOSIS

1. A testing protocol has been developed which minimizes the risk of environmental contamination during the evaluation of the destruction of organic chloride compounds.
2. The atomization and recombination hypothesis for plasma destruction has been supported with experimental data for organic chlorides.
3. Demonstration of this destruction technology should be completed for PCB's by early in 1982.
4. Commercial scale of this technology should be portable and accommodate both organic wastes and inorganic compounds contaminated with organic residues.

REFERENCES

1. Chen, F.F.
"Introduction to Plasma Physics", Plenum Press, New York, 1974.

2. Kamenetskii, D.A.
"Plasma, The Fourth State of Matter", Plenum Press, New York, 1972.

3. Hellund, E.J.
"The Plasma State", Rheinhold Publishing Corporation, New York, 1961.

4. Barton, T.G.
"An Introduction to Waste Disposal by Plasma Arc Heating", Civil Engineering Research Report No. CE80-1, March, 1980.

Section 5

CAPACITORS

CAPACITOR RUPTURE AND INCIPIENT FAILURE DETECTION

R. Tackaberry
Electric Power Research Institute

CAPACITOR RUPTURE AND INCIPIENT FAILURE DETECTION

Robert Tackaberry

EPRI PCB SEMINAR

ABSTRACT

Capacitors manufactured prior to the ban on the use of PCBs and now in service are a problem. Upon removal they require proper disposal, and, should they rupture in service, they present a spill clean-up situation as well. We have estimated that there are approximately 2,800,000 such units in service. EPRI has a project underway to develop instrumentation that is most suitable for detecting incipient failure and/or the approach of the end of service life for capacitors in service. In the phase I effort the objective is to assemble all possible instruments that will be effective in measuring capacitor characteristics, including temperature, corona, capacitance, resistance, leakage, and physical dimensions. Each will be tested, modified as necessary, and calibrated in preparation for an extensive field evaluation of tests on 1200 capacitors on two utility systems. Following field tests and data collection, the various instruments will be evaluated, singly and collectively, as to the contribution of each instrument to predict failures, their simplicity of operation and performance reliability, first cost and operating and maintenance costs, and convenience and safety in use. Finally, a conceptual design will be developed for a composite instrument for ultimate field use.

FIELD INSPECTION, REMOVAL AND DISPOSAL OF PCB CAPACITORS

V. S. Harper
Georgia Power Company

V. S. Harper
Georgia Power Company

FIELD INSPECTION, REMOVAL AND DISPOSAL OF PCB CAPACITORS

INTRODUCTION:

In 1976 the Toxic Substances Control Act was enacted requiring that measures be taken to protect the environment from PCB discharges. Since most power capacitors manufactured before that date contained various types of PCB liquids, power capacitors were addressed directly in subsequent EPA regulations. Electric utilities had begun to adopt special operating practices for PCB capacitors even before the EPA published proposals, but with the promulgation of the EPA regulations certain practices became mandatory. While the specific methods of compliance varied from one utility to another, practices are generally similar. The basic requirements for capacitors were as follows:

- Locate, mark with approved PCB Label, and maintain a record of each PCB unit.
- Remove failed units and transport to a designated storage facility while awaiting disposal.
- Dispose of PCB units in EPA approved disposal facility.
- Clean up PCB liquid around ruptured or leaking units and dispose of waste and failed units properly.

Georgia Power Company initiated other specific practices to reduce the exposure risk for PCB units. Improved fusing practices were developed to reduce the number of ruptured units, a test program was initiated to check questionable units, and a phase-out program for distribution circuit capacitors was recently approved.

Perhaps the most pressing problem facing PCB capacitor users at this time is the limited number of EPA approved disposal facilities for capacitors. This has resulted in a stockpile of failed units. In addition, the substantial cost of disposal must be considered as a major portion of any replacement program.

FIELD INSPECTION

The initial regulations required that utilities locate, label and maintain a record of all PCB capacitors. In our case, locating and marking 70,000 units was not a minor undertaking. Operating districts had historically installed distribution capacitors at their discretion. Location records were practically non-existent. A company-wide capacitor survey was conducted early in the program and individual units were labeled at that time. These records were transferred to computer files, and a location program is now available for all units. (See Exhibit I). These files are updated from disposal records as units are removed from service.

Periodic inspections are made on all capacitor banks. Any unit leaking or damaged is replaced and transported to the storage facility. In addition, all other units in that bank are tested electrically. This test is made with a portable LCD C-Meter. The capacitance reading is compared to a previous reading marked on each individual can, and a deviation of 10% or more in the readings is an indication of internal pack failure. Any unit showing this deviation is replaced and transported for storage. Of all the failed units removed annually, approximately 5% are detected with the C-Meter. Capacitor bank fusing policies were changed to reduce tank ruptures and assist in the field inspection program. Individual trip-o-link fuses were installed on each PCB can. Also, current limiting fuses were installed in each phase on each capacitor bank where fault currents of 5000 amps or more were available. (See Exhibit II). Our field test program requires that all units in the bank are tested prior to reenergization for a blown fuse condiiton. These fusing and field test policies have improved our capacitor rupture rate from 10% in the early 1970's to less than 1% in 1980.

Our failure rate of all film capacitors is less than 0.25%, and no tank ruptures have occurred. Therefore, our current practice is to fuse all film distribution capacitor banks with one group fuse per phase.

REMOVAL AND TRANSPORTING FAILED UNITS

Individual intact PCB units removed for disposal are handled and transported to the storage facility in a routine manner. Leaking units or ruptured units are placed in approved removable head drums with proper labels attached. Operating personnel are provided with disposable aprons or coveralls, gloves, boot covers, and safety shields for use during the removal process. Any PCB contamination on the capacitor bank, distribution pole, or ground under the bank is cleaned up and the waste material is put in the drum. The protective clothing is then included in the drum along with sufficient oil soak material to absorb the free PCB liquid in the capacitor. In the event that all the capacitor fluid is spilled on the ground, several drums may be necessary to hold the contaminated soil. Each drum is then marked to show its contents and transported to the storage facility. A log is maintained at the storage facility to record each drum and individual capacitor unit. (See Exhibit III).

DISPOSAL

EPA regulations required that a permanent storage facility be constructed by each PCB user. Georgia Power Company modified an existing building at our Underground Network Facility to meet the specific requirements of the regulations. This building serves as the central storage facility for the entire company. Drums containing PCB liquids, wastes, and leaking capacitors are stored inside the building, and intact capacitors are stored on pallets on a concrete slab immediately adjacent to the building. An attendant is assigned to maintain the disposal records and supervise the operation of the facility during normal working hours.

A considerable inventory of PCB liquid in drums and capacitors on pallets has accumulated at this facility, due to the lack of an EPA approved disposal facility for PCB liquids and capacitors during much of 1981. This condition necessitated the construction of a second permanent storage building in mid 1981. The additional building was designed to be utilized solely for storage of drums containing PCB liquid. This facility is inspected periodically and maintained by the supervisor of the permanent storage facility.

Recently, a facility in Eldrado, Arkansas has been licensed by the EPA to burn capacitor tanks. This facility will accept capacitors in wooden crates, provided the crates are lined with polyethylene and hard fiber board and contain sufficient oil-soak material to absorb the free liquid in the capacitor units. Georgia Power Company has contracted with the facility and is presently shipping units for disposal. The cost of this method is high and the handling and packaging requirements are time consuming.

Another facility in St. Louis, Mo. has obtained an interim license for a volume reduction process for power capacitors. Discussions are presently underway with this alternate supplier.

SUMMARY:

Georgia Power Company has initiated several operating practices to comply with the EPA regulations for continued PCB capacitor usages. These practices are meant to reduce the risk of PCB exposure. The long term solution to the PCB capacitor question appears to be an accelerated change out program, and many utilities, including Georgia Power Company, are taking this approach. However, budgetary limitations and manufacturing capabilities will limit the number of units replaced per year. Even this reduced change out program will generate a considerable number of PCB units for disposal. Alternate disposal methods are of considerable interest to us.

DISCUSSION

Q. Is your meter used for failure detection or quality control?

A. It is used for both. Tests are made as received for Q.C. and after service. A 10% difference is used as rejection criteria.

Q. Is the Georgia Power shipping container EPA acceptable for non-leaking capacitors?

A. Yes.

Distribution Capacitor Status Reporting System

_____ Division _____ District

Bank Size _____ KVAR Individual Unit Size _____ KVAR

Voltage _____

Substation Name _____ Feeder No. _____

Cap Bank Location No. _____ Address _____

Type Bank ☐ Fixed ☐ Switched Type Control _____ (Temp., Voltage, Time, etc.)

EXHIBIT 1

Bank Status

Date Checked _____ ☐ PCB ☐ Non-PCB

Bank ☐ Energized ☐ De-Energized Controls ☐ Operable ☐ Inoperable

Date	Remarks (Record counter readings on Controls)

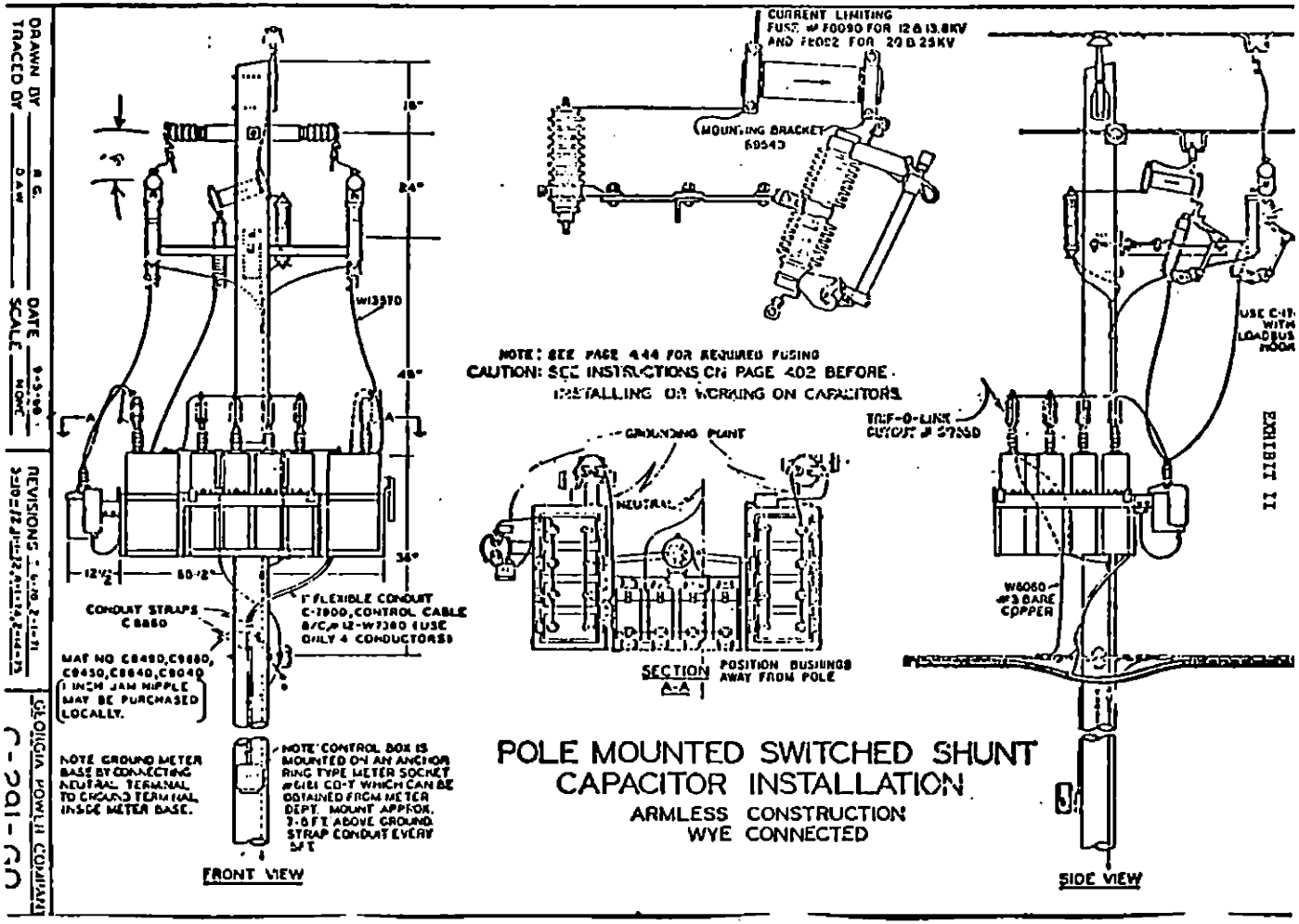


EXHIBIT III

PCB ARTICLES AND PCB CONTAINERS

DATE_____

COVERS YEAR_____

DISPOSAL AGENCY_____

I.D. CODE	DATE REMOVED	DATE STORED	DATE TRANSPORTED	LOCATION	IDENTIFICATION OF ITEM AND CONTENTS	QUANTITY OF PCB-Kg.

1 POUND = 0.4536 Kg.
1 GALLON PCB = 5.8913 Kg.

Sample of log sheet to be used only at the Permanent Storage Facility - 271 Maple Street. Available from General Office.

CAPACITOR PROTECTIVE SCHEMES INVESTIGATED BY NORTHEAST UTILITIES

L. R. Rancourt
Northeast Utilities Service Company

Leo R. Rancourt

Northeast Utilities Service Company
Berlin, Connecticut

CAPACITOR PROTECTIVE SCHEMES INVESTIGATED BY NORTHEAST UTILITIES

INTRODUCTION

The prevention of tank rupture in polemounted distribution capacitor banks is the subject of much utility discussion. Considering the relatively high failure rate of capacitor units and federal regulations concerning the spillage of PCBs, utilities are faced with an urgent need to reevaluate traditional protection practices of group fusing overhead distribution capacitor banks or face the real possibility of mass replacing PCB cans with newer non-PCB units. Capacitor tank rupture will occur if the total energy input to the capacitor under failure is greater than the ability of the tank to withstand such input. The protective scheme must detect the failing capacitor can and remove the individual can or entire bank from service before tank rupture occurs.

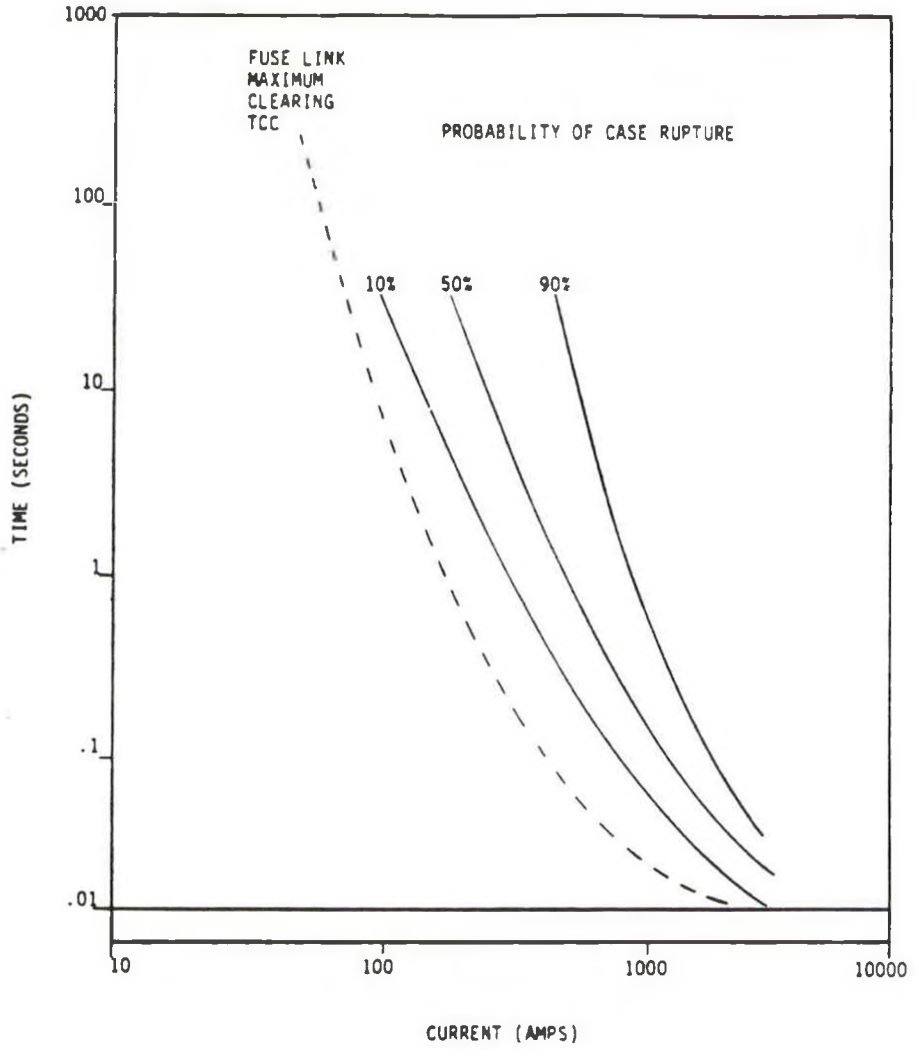
This paper will present an overview of NU's study on polemounted capacitor protection which involves an evaluation of all known protective schemes, both fused and relayed types. However, specific scheme costs and recommendations included in the NU study are excluded from this paper.

NORTHEAST UTILITIES COMPANY (NU)

Northeast Utilities attempted to minimize tank rupture problems in 1976 by installing an expulsion link with faster, more sensitive clearing characteristics. The violent tank ruptures decreased but the rupture rate did not. Recently a comprehensive study was completed which investigated all available polemounted capacitor bank protective schemes and evaluated their effectiveness in preventing or minimizing tank ruptures.

Northeast Utilities experienced an increase in polemounted capacitor failures beginning in 1971. Of the total failures, 52% ruptured.

The NU polemounted capacitors are group fused in the less than 10% probability of tank rupture zone. The probability of tank rupture curves are published by NEMA Standards CPI-1973. See Figure 1. Fusing below the 10% probability of capacitor tank rupture is in the predicted safe zone where no greater damage than slight swelling of the tank should occur. Further, NU polemounted capacitors are installed in locations where the available fault current is less than 5000 amperes.

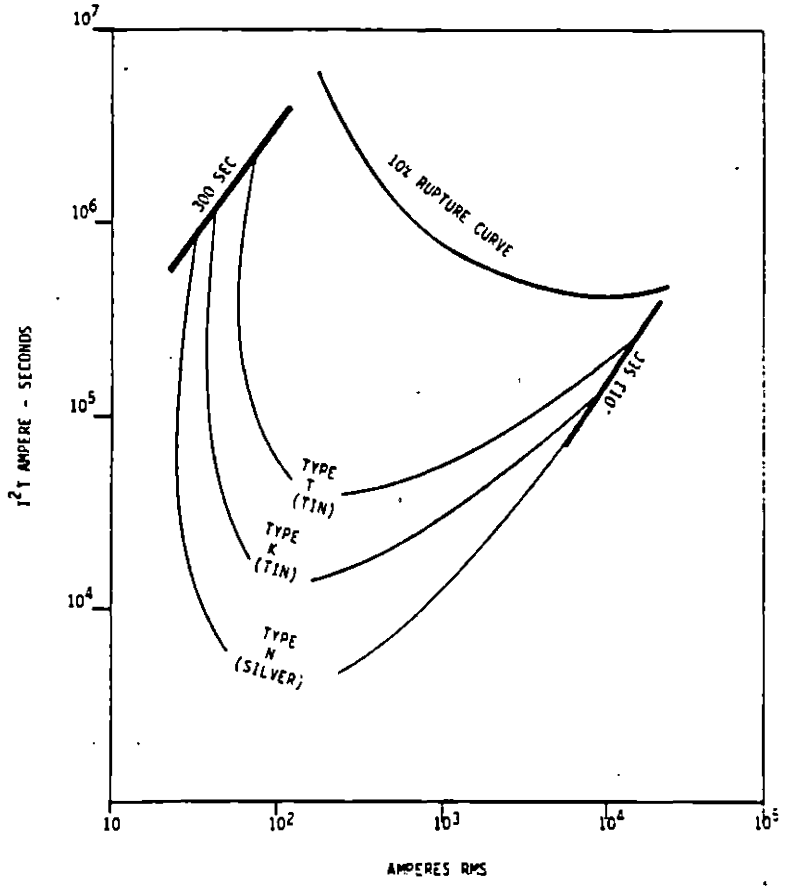


FUSE CLEARING VS PROBABILITY OF CASE RUPTURE

FIGURE #1

In 1976, the Chance type H fuse was introduced into the Northeast Utilities System (group-fusing of both grounded and ungrounded-wye 15 and 23kV capacitor banks) as a method to limit capacitor tank rupture. The total fuse clearing I^2t let-thru energy of the type H fuse was considerably less than the previously used types K and T fuses.

Mechanical problems developed with the Chance type H fuse. The S&C Silver type N fuse was determined comparable to the Chance type H fuse in regard to I^2t energy let-thru. In 1977, the S&C Silver type N fuse replaced the type H fuse on the Northeast Utilities System. See Figure 2.



I^2T LET THRU OF VARIOUS FUSES VS I^2T OF CAPACITOR 10% RUPTURE CURVE

FIGURE #2

In 1979 and 1980, a study was made of polemounted capacitor failures (from late 1976 to early 1980) which indicated approximately 50% of paper-film capacitor banks group fused with either the type H or N fuse were still experiencing tank rupture. The violent tank ruptures had decreased using H and N fuses, but the capacitor tank rupture rate had not changed significantly.

Because of the PCB problem, rupture prevention of capacitor banks over the last four-five years has become extremely important. An obvious but very expensive solution, would be to replace all PCB capacitors with non-PCB units. Before being forced into complete replacement, NU decided to investigate all known methods of capacitor protection to determine if a scheme was available which would prevent or minimize tank rupture. The scheme not only had to be cost effective, but defensible if litigation should occur.

AVAILABLE PROTECTIVE METHODS

The capacitor can failure modes must be known before a protective scheme is selected which will provide the best possible protection against capacitor can rupture. Although there are two or three basic modes of capacitor failure identified by industry, utility people generally agree that the most common mode of capacitor tank rupture results from pack-to-pack failure. The pack failure process continues until the tank ruptures from either internal gas pressure or the sudden release of fault current energy.

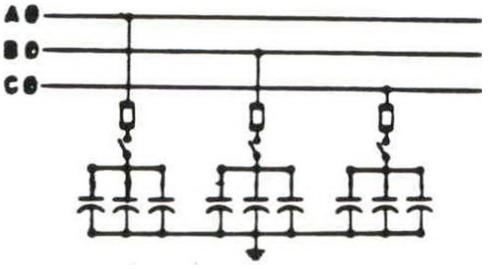
Because capacitor can failure is a gradual process, the protective device must respond to an early stage of progressive pack failure and isolate the can or the bank before rupture occurs.

There are two available protective methods for preventing or minimizing capacitor can rupture: fusing and relaying.

Fusing - Proper application of fuses require that the maximum I^2t let-thru of the fuse must always be less than the minimum rupture I^2t of the capacitor tank. See Figure 2.

There are two basic methods of protecting capacitor banks for can rupture: group fusing of a capacitor bank and individual can fusing, or a combination of both.

Group Fusing



GROUP FUSING

FIGURE #3

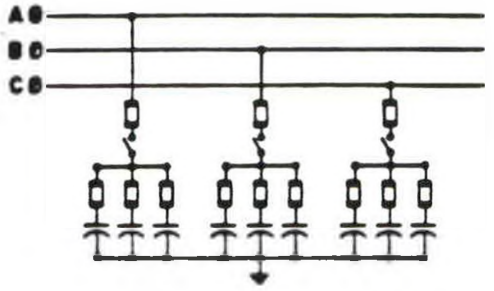
The group fuse scheme consists of either expulsion or current-limiting fusing or a combination of both. The combination expulsion-current-limiting fuse scheme consists of installing an add-on current-limiting fuse in series with an existing expulsion fuse.

Since the group fuse must be sized according to full bank current plus tolerances, it is difficult to respond to the gradual current build-up of pack-to-pack failures before tank rupture. The probability of tank rupture in the event of a capacitor fault can be minimized by using a group fuse with faster, more sensitive, minimum-melting characteristics, or by sizing closer to normal bank load.

The advantage of group fusing is that group fuses are the most desirable and economical method for protecting against possible can failures. The current-limiting fuse protects against high I^2t let-thru current.

The disadvantage of group fusing is that no group fuse can give satisfactory protection against pack failures that generate gas sufficiently to rupture the tank prior to the can progressing to a complete short. This is especially true for floating-wye banks, where the fault current is inheritly limited to three (3) times normal current, and the fuse might take several minutes to clear the failure. Also, not all CL fuses are available in the high voltage, larger ampere sizes.

Individual Fusing



COMBINATION GROUP-INDIVIDUAL FUSING

FIGURE #4

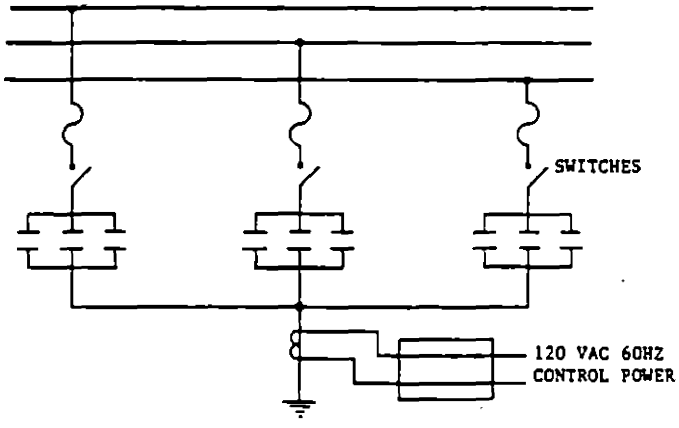
The individual capacitor fuse scheme consists of a low-profile bushing mount which holds an expulsion fuse link (one manufacturer's model includes a current-limiting fuse mount) that can be installed on the bushings of new or existing capacitor cans. Individual can fusing offers increased protection against tank ruptures. The optimum fuse is the smallest, fastest fuse which will not result in nuisance operation and which will meet the voltage, fault current, and energy requirements of the locations. Unlike the group fuse, which must carry full bank current plus tolerances, the individual fuse need only be sized for the full can current, greatly reducing the fuse size requirement.

The individual fuse scheme can be installed on the bushing of all capacitor bank sizes, regardless of voltage or connection. However, when installed on floating-wye cans, the installation must have four or more parallel cans per phase or the neutral of each group isolated to limit over voltage when an individual fuse clears.

A combination individual fuse-group CL fuse scheme provides a high degree of protection against both pack failure and high fault current locations. When an individual fuse blows, the failed can is readily identified, eliminating costly field testing to locate the problem can.

Although individual fusing will greatly decrease the probability of a tank rupture, no fuse scheme can completely eliminate pack failures that gas sufficiently to rupture the can prior to a complete short. Another disadvantage is that the cost of an individual fuse scheme is quite high especially when retrofitting existing capacitor banks. Further, the capacitor installation may require expensive CL group fusing due to the individual fuse holder's low interrupting capability.

Relay Protection



INSTALLATION DIAGRAM

RELAY SCHEME

FIGURE #5

Relay schemes consist basically of either a voltage or current sensing device and a relay with adjustable time delay and current or voltage pick-ups. The neutral current device is installed with grounded-wye banks and the neutral voltage device with floating-wye banks. These schemes can detect a fault as low as a two-pack failure and operate to prevent capacitor tank rupture. When a capacitor can begins to fail, there is an increase in either the neutral current or a rise in neutral potential, depending on the capacitor connection. When the neutral current and/or voltage rises to the selected pick-up levels, and after a time delay, the relay activates a controlled switch to isolate the bank.

Relay schemes, which must detect a failing capacitor bank, are one of the most sensitive devices. Disadvantages are their susceptibility to operate for certain circuit disturbances, the need to determine which capacitor can is in the failing mode, not intended for detection of sudden high current faults, and the requirement of a switched bank. Also, the relay scheme may require current-limiting group fusing to protect the switches in the event of high current faults.

OTHER PROTECTIVE CONCEPTS

Pressure Switch

The pressure switch concept is a device which detects a gradual internal pressure build-up and disconnects the faulted can when a predetermined level is reached to prevent capacitor tank rupture. The pressure switch would be wired into the control circuit to open the capacitor tank switching device.

Individual Pack Fusing

The individual pack fusing concept probably provides the optimum in capacitor tank rupture due to internal pack failure. This concept provides an individual fuse for each capacitor can pack. When one pack fails, it is removed from the series-parallel group to prevent a progressive pack-to-pack failure, internal arcing, and the generation of gas. This fuse concept not only prevents tank rupture from arcing pack failures, but also allows the can to remain in service with reduced KVARs.

SUBSTATION CAPACITOR BANKS

In order to get an idea what protection individual fusing (both expulsion and current-limiting) or overvoltage or overcurrent relay schemes would provide against capacitor can rupture, a study was made of NU substation capacitor banks equipment failures. Substation capacitor banks are normally protected with individual fuses and some type of overvoltage or overcurrent scheme.

During a three-year period (1/77-12/79) the substation capacitor rupture rate was approximately forty percent.

Individual can fusing and/or relay schemes can reduce the probability of, but no present protection scheme has yet to demonstrate a 100% reliability in preventing capacitor tank ruptures. A 10-20% tank rupture rate would still be expected if these schemes were installed on pole-mounted capacitor banks.

AVERAGE CLEAN-UP COST FOR NU OVERHEAD PCB CAPACITOR BANK SPILLS

The average clean-up cost per rupture on the NU system was calculated to be $1,000.

The costs included only that labor and material which was incurred for the clean-up of contaminated soil, materials, or equipment and the disposal to a chemical waste site. The costs do no include the replacement or disposal of the ruptured can(s) or any liquid PCBs remaining in the can.

The present worth of clean-up costs over the remaining service life for all system voltages was calculated as approximately $230,000 in 1981 dollars.

THE INSTALLED COST TO PROVIDE RUPTURE PROTECTION TO NU OVERHEAD PCB CAPACITOR BANKS

The installed cost to retrofit an effective protective scheme on all PCB polemounted capacitors was estimated between $900,000 and $2,000,000.

In order to compare the total installed cost of the protective equipment with the total cost of PCB clean-up, it was necessary to present worth the total installed cost of the protective equipment, including carrying charges, O&M, and taxes over the remaining service life of the PCB capacitors. The present worth investment costs in 1981 dollars was estimated between $1,450,000 and $3,780,000, depending on the scheme selected.

CONCLUSION

A NU study was undertaken to investigate all known protective schemes which would prevent or minimize tank rupture of distribution polemounted PCB capacitor banks, and to perform a cost/benefit analysis of each scheme.

The two basic schemes available for prevention of capacitor can rupture are fusing and relaying. There are several methods of fusing capacitor banks: Group fusing of an entire bank, individual can fusing, or a combination of both. The relay schemes for detecting a failing capacitor bank consists of either a voltage or current sensing device in conjunction with an adjustable trip level and time delay relay. Other protective concepts are in development.

There is no question that individual fusing or relay schemes are far superior for minimizing tank rupture and PCB spillage than group fusing. However, because of the uncertainties of the dielectric system under fault conditions and the amount of gas generated, complete assurance against rupture cannot be provided. Regardless of available protective schemes, it is estimated that 10-20% of all PCB capacitor failures would still result in tank rupture.

Further, it was concluded that on the Northeast Utilities System there was no cost/benefit in retrofitting existing PCB capacitor installations with either a sophisticated relay or fuse scheme when compared with total PCB clean-up costs.

However, because PCBs have become such a public concern, each company must evaluate what capacitor safety means to them. The decision must be made whether to accept the potential risks and consequences of a PCB spill, spend the amount of money necessary to either minimize tank rupture by installing more sensitive protective devices, or eliminate PCB spills altogether by replacing all PCB cans with non-PCB units.

At Northeast Utilities, the jury is still out.

BIBLIOGRAPHY

1. L. M. Burrage, "Capacitor Tank-Rupture Prevention - I^2t Considerations," IEEE Meeting, July 17-22, 1977, Paper No. F-77-567-1.

2. J. E. Harder, "Optimum Shunt Capacitor Group Fusing," IEEE Transaction PAS Vol. No. 96, No. 2, March/April, 1977.

3. B. Lageman, E. W. Schmunk, and C. E. Shaw, "Fundamentals of Fusing to Minimize Case Rupture in Distribution Capacitor Banks," IEEE Meeting, July 16-21, 1978.

4. R. A. Pratt and W. W. Oliver, "Two-Fuse System Protects Capacitors," Electrical World, June 15, 1977.

5. P. Marston, "Power Factor Capacitors," Presented at Continental Telephone Service Corporation, 1980 Noise & Service Improvements Seminar, Dallas-Texas, February 2-5, 1981.

6. L. E. Brock and G. R. Newcomb, "Use Tank Pressure to Protect Capacitors," Transmission and Distribution Publication, February, 1978.

APPENDIX

Group Fuse Manufacturers

There are many manufacturers of group fuses, both expulsion and current-limiting. Following are a few of these manufacturers and their products:

A. McGraw-Edison Company - The McGraw-Edison Company manufactures both expulsion and current-limiting fuses.

1. Expulsion - The expulsion fuses manufactured are EEI-NEMA type K and T tin element fuse links.

2. Current-Limiting - The current-limiting fuses manufactured can be added to new or existing distribution capacitor banks to provide energy-limiting protection and are the McGraw NX Companion Fuse. The NX Companion Fuse is limited to a 40 ampere size and can be installed on 8.23kV phase-phase applications.

B. Kearney Company - The Kearney Company manufactures both expulsion and current-limiting fuses.

1. Expulsion - The expulsion fuses manufactured are EEI-NEMA type K and T tin element fuse links, as well as type KS fuses.

2. Current-Limiting - Kearney manufactures both an add-on "B" type CL fuse and a "B" type CL fuse mounted in their own cutout. The CL fuse sizes are available to 100 ampere through 19.9kV line-neutral voltage.

C. S & C Company - the S & C Company manufactures both an expulsion type fuse for pole cutout applications and a SM power fuse.

1. Expulsion - The expulsion fuses manufactured are EEI-NEMA type K and a type N silver element fuse link.

2. The SM Series Power Fuse - The SM Series Power Fuses are installed in their own fuse holders.

D. Chance Company - The Chance Company manufactures both expulsion and current-limiting fuses.

1. Expulsion - The expulsion fuses manufactured are the EEI-NEMA type K and type T copper-alloy fuse link, as well as a type H fuse.

2. Current-Limiting - The Chance Company manufacturers the "K-MATE" CL fuse family. The "K-MATE" 40 is the largest size available for 15.5kV line-ground applications and the "K-MATE" 80 is the largest size available for 8.32kV line-ground applications.

E. RTE Company - The RTE Company manufactures a type "ELO" back-up current-limiting fuse which can be retrofitted to existing or new

systems. The largest fuse size available is the K40 used up to 15.5kV phase-phase systems, and the K25 for the 23kV phase-phase systems.

F. General Electric Company - The General Electric Company manufactures a type "SURE GUARD-ETP" current-limiting fuse for installing with existing or new distribution cutout expulsion fuses. The "ETP" CL fuse can be installed on 8.3 - 23kV phase-neutral applications.

INDIVIDUAL FUSE MANUFACTURERS

A. Kearney

The Kearney Company is marketing a retrofit scheme (Trip-o-Link) for fusing individual overhead capacitor cans. The individual can fusing scheme can be used in conjunction with either existing group expulsion fuses or new Kearney current-limiting group fuses.

If current-limiting group fuses are not used, the "Trip-o-Link" individual cutout must be limited to its 1200 amperes asymmetrical rating.

B. McGraw-Edison

The McGraw-Edison Company has a retrofitting concept for fusing individual overhead capacitor cans with either current-limiting (NXC) or expulsion (K) fuses. The concept is basically that offered for substation type capacitor banks. Arc extinction is done within the fuse tube and expels downward through a single vent.

The interrupting rating is 50,000 amperes symmetrical for the current-limiting fuse holder and 5000/3600 amperes asymmetrical/ symmetrical for the 7.96 and 14.4kV (phase-neutral) expulsion fuse holder.

CAPACITOR RELAY MANUFACTURERS

Square D (Capacitor Fault Relay Type CFR)

The capacitor fault relay, when used with switched, shunt connected, grounded neutral capacitor banks, provides a means of disconnecting the bank when a can begins to fail and before rupture occurs. The CFR relay trips after a time delay at a value of neutral current above normal.

Fisher-Pierce

Fisher Pierce offers both a current and a voltage sensing package (1527 series) for determining failing capacitor packs.

a. Neutral Overcurrent Relay - The Fisher Pierce neutral current relay was designed primarily for detecting low magnitudes of current as exists in the neutral conductor of grounded-wye connected capacitor banks. Detection of neutral current is sensed by a customer supplied current transformer or a Fisher Pierce series overhead current sensor fastened directly to the neutral conductor.

When the current in the neutral conductor exceeds the trip control setting and after a time delay, the relay signals the switch controls to operate the switches to lockout. This relay scheme was originally designed for station type capacitor bank protection.

b. Neutral Overvoltage Relay - The voltage package includes only a relay to operate on a rise in voltage of floating-wye banks. The sensing device (PT or transformer) must be supplied by the user. The voltage scheme can be installed on both 13.2-13.8 and 23kV floating-wye banks. However, on 23kV floating-wye banks, a contact from the capacitor neutral switch must be installed in series with the capacitor line switches to prevent the phase-to-ground rated line switches from closing (into a phase-to-phase condition) before the neutral switch closes.

American Switchgear

American Switchgear has a combination neutral relay and "smart switch" plus a neutral relay as separate packages.

a. "Smart Switch" - Neutral Relay Combination - The "smart switch," a development of Bell Labs, is a solid-state device which is polemounted and inserted into the ground lead of a wye connected capacitor bank. During normal conditions, the capacitor bank acts as a floating-wye connected bank. During switching and fault conditions, the voltage at the common wye starts to rise, the "smart switch" turns on at a predetermined level, allowing the passage of current to ground. If conditions return to normal before a specific time delay, the voltage falls below the trigger value and the circuit will again revert to the floating-wye connection. However, if the levels persist after an adjustable time delay, the device will signal a control to lock open the capacitor bank switches.

b. The neutral relay can be installed on both 13.2-13.8 and 23kV grounded-wye banks to sense a rise in neutral current and to lock open the capacitor switches.

TRI-MAG Company (Capacitor Unbalance Sensing Relay)

The TRI-MAG Company located in Visalia, California, has several solid-state devices which can detect incipient capacitor failure and remove the bank from service before tank rupture occurs. The capacitor unbalance sensing relay (CUSR) can be installed on station, or polemounted switched capacitor banks. Several models are available which can detect voltage (ungrounded banks) and current (grounded banks) rise.

When an increase in voltage or current above a predetermined level occurs, and after a time-delay, the CUSR will lock open the bank switches and activate a lockout indicator light.

S & C Electric Company

a. Bankgard Relay Type LUC - The S&C type LUC relay is a solid-state electronic device designed for ungrounded-wye connected capacitor

banks. The unit designed for small to medium-sized station type banks can be used for polemounted capacitor banks.

The relay detects neutral-to-ground voltage rise and when a predetermined value is exceeded, signals a switching device to disconnect the entire bank.

b. Polemounted Capacitor Protective Device - The S&C Company is interested in developing a relay protective device for polemounted capacitor banks. They have the necessary technology from existing substation equipment for both grounded- and floating-wye connected banks.

   At this time, S&C is interviewing utility companies to determine whether there is a need for such a unit. There are no drawings or estimated prices available.

RTE Company

The RTE Company has a device, still in the design concept stage, which will detect a failing capacitor bank before case rupture.

At this time, they do not have available drawings or estimated prices.

OTHER PROTECTIVE CONCEPT MANUFACTURERS

General Electric Company

The GE Pressure Switch concept is a device that detects internal pressure build-up and disconnects the faulted can to give maximum tank rupture protection. The device is installed on individual capacitor cans and can be used to open the bank switches.

Sangamo Company

The Sangamo Company is investigating an internal fusing scheme which would fuse individual capacitor can packs. A failed pack would be isolated from the remaining good packs which could continue to operate.

Section 6

TREATMENT OF PCB CONTAMINATED MINERAL OIL-LABORATORY

EQUILIBRIUM STUDY OF PCBs BETWEEN TRANSFORMER OIL AND TRANSFORMER SOLID MATERIALS

B. Ro
M. A. Thompson
RTE Corporation

EQUILIBRIUM STUDY OF PCBs BETWEEN TRANSFORMER OIL AND TRANSFORMER SOLID MATERIALS

Bentsu Ro and Mac A. Thompson, RTE Corporation
EPRI TPS 81-788

INTRODUCTION

According to the estimates in the EPA "Economical Impact Analysis" (April, 1979) there are 3,000,000 transformers, containing over 400,000,000 gallons of oil, that are contaminated with PCBs above 50 ppm. Because of the potential liabilities involved in keeping these PCB contaminated transformers in service, it would be highly desirable to have a method for removing the PCBs from the transformers.

The most attractive method for cleaning up these transformers would probably be a "one shot" process, by decontamination of the existing oil or by direct oil replacement. There is a possibility, however, that PCB Contaminated Transformers may not be converted into Non-PCB units by a simple refill process. When a PCB Contaminated Transformer is refilled, the contaminated bulk oil is replaced with a PCB-free transformer oil, but the rest of the solid materials which are contaminated with PCBs remain in the transformer.

If the solid materials in the transformer strongly adsorb PCBs, then at relatively low temperatures (light loading of the transformer), the PCBs would be partially removed from the oil, accumulating in the solid materials to concentrations substantially higher than would be indicated by testing the oil. At relatively high temperatures (heavy loading of the transformer), the adsorption could be reversed, with the heat driving the PCBs out of the solid materials and back into the oil. Although the PCB concentration in the new oil would be less than the PCB concentration in the original oil, it could still be above 50 ppm. Therefore, the transformer would still be classified as PCB Contaminated.

One of the major implications of a cyclic adsorption/desorption of PCBs, is that any determination of PCB concentration in the oil of a transformer would necessarily be dependent upon the load on the transformer (and the ambient temperature) at the particular time that the sample was taken. Another implication of this phenomenon is that in order to clean up a transformer it might be necessary to refill it with clean oil several times or to continuously clean the oil for an extended period of time. Therefore, the object of this EPRI Feasibility Study was to determine the magnitude of the fluctuations in PCB concentration that could be produced by an adsorption/desorption phenomenon.

APPROACH

The ultimate test of any adsorption/desorption hypothesis would be to monitor the PCB concentration in the oil of a variety of transformers for at least one year, to look for fluctuations under normal operating conditions. However, in a field test there are

often so many variables that it is difficult to isolate and to quantify the significant parameters. By the use of controlled laboratory experiments, the impact of different variables can be carefully measured, and the results can then be used to predict the behavior under operating conditions. This, therefore, was the approach used for the subject feasibility study.

This study was restricted to four commonly used transformer materials:

1. "Dicy" paper (Dicyandiamide treated Kraft paper)
2. Core steel (with magnesium silicate coating)
3. Magnet wire ("Formvar" coated copper wire)
4. Diamond paper (Phenolic epoxy coating)

These four materials were chosen because they each represent a very large surface area in an operating transformer, and because there is reason to believe that they may have some affinity for PCBs. The magnesium silicate coating on core steel, for example, is a glass; it is known that PCBs have an affinity for glass. Both the Formvar and the diamond coated paper contain phenolic structures, which could be expected to have an affinity for PCB. The experiments were run using virgin, uninhibited transformer oil and "Inerteen 70-30" (70% Arochlor 1254, 30% Trichlorobenzene).

The adsorption/desorption experiments were all run at two different temperatures, 50°C and 110°C. These temperatures simulate the lightly loaded and fully loaded conditions of an operating transformer. Although transformers experience daily and weekly fluctuations in load, the average operating temperature may be high or low for longer periods of time due to broad seasonal variations. It is these sustained periods of relatively high and low temperatures that are considered to be most significant with respect to overall adsorption/desorption of PCBs.

This study was designed to determine the adsorption and desorption equilibrium relationships of the PCBs between the transformer oil and the solid insulating materials, the rate at which the equilibrium is established, and then to apply this information to the siutation in a typical transformer.

PARTITION COEFFICIENT FROM DESORPTION EQUILIBRIUM

The desorption equilibrium experiments were carried out by immersing different weights of Inerteen soaked solid materials in PCB-free transformer oil, at 50°C and 110°C. The weights of the four solid materials were chosen to yield a broad range of PCB concentrations in the oil at equilibrium. The solid-material/oil systems were kept in constant temperature ovens for 14 days. During this time, they were removed twice daily and shaken for one (1) minute to accelerate establishment of equilibrium conditions. At the end of this time, the oil was sampled for PCB concentration analysis and the residual PCB content in the solid materials was extracted with heptane and analyzed.

The PARTITION COEFFICIENT (K) is defined as the ratio of the PCB concentration in the solid material (C_s) to the PCB concentration in the oil (C_o) at equilibrium.

$$K = C_s/C_o \qquad \text{Equation (1)}$$

Table 1 gives the partition coefficients for the four materials at various PCB concentrations and temperatures.

PARTITION COEFFICIENT FROM ADSORPTION EQUILIBRIUM

The adsorption equilibrium experiments were carried out by immersing constant weights of the dried solid materials in transformer oils containing five (5) different PCB concentrations covering the range from 50 ppm to 2,000 ppm, at 50°C and 110°C. The solid-material/oil systems were kept in constant temperature ovens for 14 days. During this time, they were removed twice daily and shaken for one minute to accelerate establishment of equilibrium conditions. At the start and at the completion of these experiments, oil samples were taken for PCB analysis. The amount of PCBs adsorbed by the solid material was calculated from the difference in the PCB concentrations. Table 2 gives the nominal partition coefficient for the four materials at various PCB concentrations and temperatures.

The nominal partition coefficients from the adsorption experiments are much larger than the partition coefficients from the desorption experiments. This may be attributed to a difference in the methods. In the desorption experiments both the concentration of the PCBs in the solid material and in the oil were determined analytically, but in the adsorption experiments the concentration of PCBs in the solid material was inferred from the concentration difference in the oil. This assumes that all PCBs removed from the oil were adsorbed by the solid materials. However, it is known that the glass containers used to hold the systems would have adsorbed some PCBs also. Since the amounts adsorbed by the solid materials is small, the adsorption by the glassware presumably made a large contribution to the nominal partition coefficient.

ADSORPTION ISOTHERM

The partition coefficients from the desorption experiments were used to calculate adsorption isotherms for the solid materials. The data in Table 1 shows that the partition coefficient increases when the PCB concentration in the oil decreases. This is typical of a Freundlich type of adsorption, and is characterized by the equation:

$$\frac{X}{M} = k\, C_o^{1/n} \qquad \text{Equation (2)}$$

where X = mass of PCB adsorbed, M = mass of solid material, k and n

are constants for the particular system, and C_o is the PCB concentration in the oil, at equilibrium. Taking the logarithm of equation (2) gives:

$$\ln \frac{X}{M} = \ln k + \frac{1}{n} \ln C_o \qquad \text{Equation (3)}$$

Therefore, a plot of ln (X/M) versus ln C_o will give a straight line with slope 1/n and intercept ln k. Linear regression techniques were used to calculate the slope and intercept values for each of the materials. The results are presented in Table 3, and the adsorption isotherms for these materials at 50°C and 110°C are shown in Figure 1.

It is readily apparent from Figure 1 that, in terms of the total quantity of PCB adsorbed by solid materials, the paper adsorbs far more PCB than either the wire or the core steel. This would seem to contradict the data in Table 1, which shows that the partition coefficient for core steel is much higher than that for paper. However, while the core steel adsorbs PCBs strongly on its surface, the total quantity of PCBs adsorbed by the core steel is limited by the fact that the steel is not permeable. In contrast, the paper only weakly adsorbs PCBs, but since it is lower in density, it adsorbs a large volume of oil. As a result, there is a larger total quantity of PCBs adsorbed by the paper than by the core steel.

DESORPTION RATE

Inerteen impregnated Dicy paper was immersed in transformer oil at 50°C and at 110°C, with constant stirring. Oil samples were taken at predetermined time intervals and analyzed for PCB concentration. At the end of the experiment, the residual PCB content in the paper was solvent extracted and determined. From the time-concentration data, the rate of PCB desorption and the diffusion coefficient of the PCB through the paper were calculated. The time required to reach equilibrium is shown in Table 4, and the results of the diffusivity analysis are shown in Table 5.

ADSORPTION RATE

Two sets of eight containers of transformer oil containing approximately 2,000 ppm PCBs were prepared and placed in constant temperature ovens - one set at 50°C, the other at 110°C. Essentially equal weights of dry Dicy paper were impregnated with transformer oil and then immersed into the PCB contaminated oil. At predetermined intervals, one container was removed from each oven and the paper was immediately removed from the contaminated oil. The PCB content in the paper and in the oil were then determined. From this data, the rate of PCB adsorption by the paper and the diffusion coefficient of PCB into the paper were calculated. The time required to reach equilibrium is shown in Table 4, and the results of the diffusivity analysis are in Table 5.

DIFFUSION COEFFICIENT

The rates of desorption and adsorption exhibit a non-linear dependence upon the concentration gradient in the paper-oil boundary, which is a function of time, geometry, and the oil-to-paper ratio. The diffusion coefficient, or diffusivity, was determined for the desorption/adsorption rate experiments, and is given in Table 5. Although these numbers are specific to the particular system tested, some generalizations may still be in order.

The diffusivity, at half-time, is very small for the desorption experiments compared to the adsorption experiments. This would seem to imply a long half-time for the desorption equilibrium, yet the half-time is about the same for desorption/adsorption at 50°C, and significantly better for desorption at 110°C. This phenomenon is apparently due to the fact that the concentration gradient is so high for the desorption experiments versus the adsorption experiments. Diffusivity is a measure of PCB movement within the paper, which would be slow when the internal PCB concentration is high. The rate at which equilibrium is established, however, is driven by the concentration gradient at the oil-paper boundary so the rate will be much faster for desorption of concentrated PCBs into oil than for adsorption of PCBs from a dilute solution.

Both the diffusivity and the half-time shown in Table 5 apply specifically to the oil-paper systems used for the experiments. In a transformer, the paper is not exposed to the oil on all sides; typically, only the edges of the sheets of paper contact the oil directly. For a contaminated oil transformer, the low diffusivity of PCB into the paper implies that it would take a very long time for any PCBs to diffuse down deeply into the coil.

In the situation where an askarel filled transformer is drained and refilled with clean oil, the extremely low diffisivity of PCBs through the paper imply that the migration of PCBs out into the oil (leaching) can be expected to take a very long time, probably at least several years. If the transformer were lightly loaded, the fact that the half-time at 50°C is ten (10) times the half-time at 110°C implies that the leaching time would similarly be extended by a factor of 10.

APPLICATION

In order to apply the results of this study, the approximate material composition of a typical 500 kVA transformer was calculated (see Table 6). Using these values and the adsorption isotherms, the approximate PCB concentration in the various materials was calculated for 50°C (Table 6) and 110°C (Table 7). The results are also shown graphically in Figure 2. The calculations assumed that all paper in the transformer was Dicy paper, since the adsorption/desorption of the diamond pattern paper is so similar.

The impact of the adsorption/desorption phenomenon was calculated for a refilled transformer initially containing 500 ppm PCB. If less than 5% of the original oil were left in the transformer, then the concentration of PCB in the new oil would remain below 50 ppm, even if all the PCBs adsorbed by the solid material were desorbed into the new oil. If more than 5% of the original oil were left in the transformer, then a second refill with new oil should bring the final PCB concentration down below 50 ppm, after any desorption.

CONCLUSIONS

Formvar wire and core steel show some tendency toward PCB adsorption; however, their adsorption is limited to only the surface, so the total PCB content in these two solid materials is small.

Paper has little affinity for PCBs; however, since paper soaks up a greater amount of oil, the total PCB content in the paper is higher than in the other solid materials.

Solid materials adsorb very little PCB in comparison with the total PCB content in the oil.

The equilibrium constant for Dicy paper is independent of temperature between 50°C and 110°C. The equilibrium constants for diamond paper and Formvar wire are slightly temperature dependent, and the equilibrium constant for core steel is very temperature dependent.

For a typical 500 kVA transformer, about 97.5% of PCBs are in the oil; only 2.5% of the PCBs are unevenly distributed among papers, core steel, and Formvar wire. Among these three solid materials, papers adsorb a majority of the PCBs.

An oil temperature fluctuation between 50°C and 110°C can cause a maximum of 0.6% PCB concentration fluctuation. This fluctuation is due to the PCB adsorption/desorption by solid materials. At an initial PCB concentration in the oil of 2,000 ppm, a 0.6% fluctuation represents a change of only 12 ppm.

DISCUSSION

Q. What attempts have been made to verify your model?

A. We believe the model is generally adequate but may have seasonal variations because of possible changes in flow patterns.

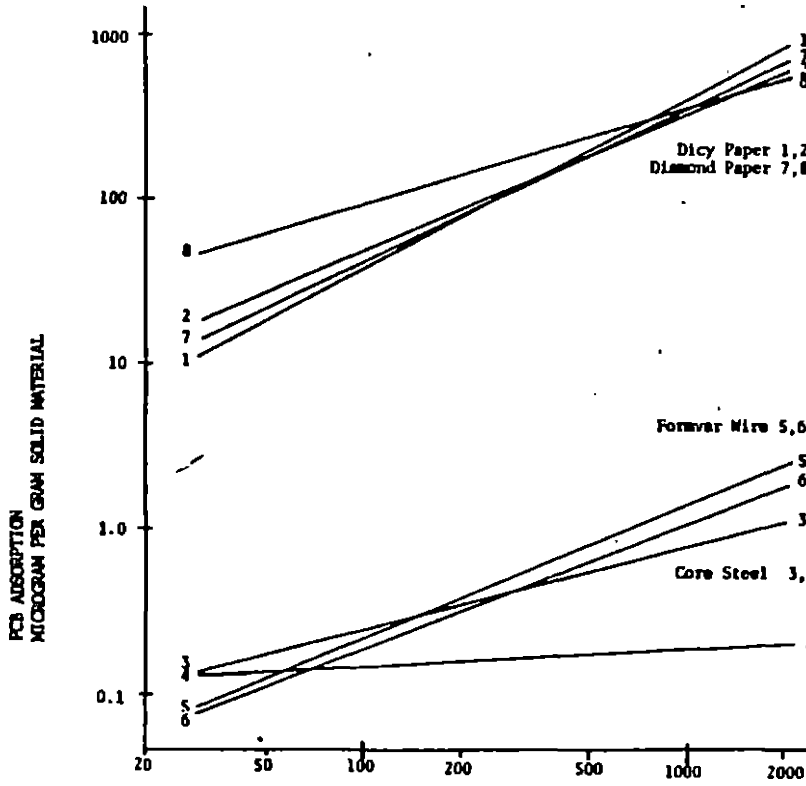


Fig. 1. ADSORPTION ISOTHERM FOR TRANSFORMER SOLID MATERIALS

	50°C	110°C
Dicy Paper	1	2
Core Steel	3	4
Formvar Wire	5	6
Diamond Paper	7	8

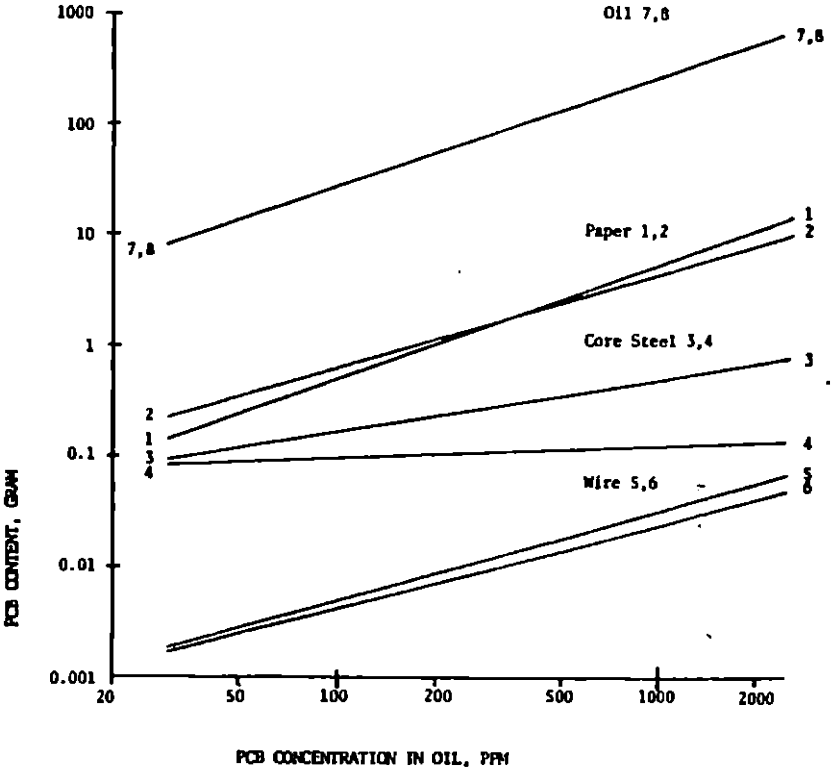


Fig. 2. ADSORPTION OF PCB IN A TYPICAL 500 kVA TRANSFORMER

	50°C	100°C
Dicy Paper	1	2
Core Steel	3	4
Formvar Wire	5	6
Oil	7	8

TABLE 1
PARTITION COEFFICIENT
FROM DESORPTION EQUILIBRIUM EXPERIMENT

Solid Material	Temperature, °C	PCB Concentration in the oil at Equilibrium, ppm	Partition Coefficient	Average ± Standard Deviation
Dicy paper	50	2200	1.30	
		905	1.31	
		400	1.26	1.29 ± 0.02
	110	2530	0.97	
		957	1.10	
		371	1.03	
		130	1.54	
		54	1.73	1.28 ± 0.30
Core steel	50	358	7.7	
		82	7.2	
		34	19.9	11.6 ± 5.9
	110	644	0.8	
		266	1.9	
		95	2.6	
		52	7.5	3.2 ± 2.6
Formvar Wire	50	1560	1.20	
		578	1.17	
		183	1.83	
		85	2.29	1.62 ± 0.4
	110	1510	0.97	
		590	0.93	
		195	1.07	
		96.5	2.06	1.26 ± 0.46
Diamond Paper	50	1970	1.10	
		747	0.88	
		276	1.21	1.06 ± 0.14
	110	2100	0.85	
		772	1.05	
		291	1.96	
		117	2.97	
		52	3.51	2.0 ± 1.0

$K = C_s/C_o$ Equation (1)

K = Partition Coefficient
C_s = PCB concentration in solid material
C_o = PCB concentration in oil

TABLE 2
NOMINAL PARTITION COEFFICIENT
FROM ABSORPTION EQUILIBRIUM EXPERIMENT

Solid Material	Temperature, °C	PCB Concentration in the oil at Equilibrium, ppm	Nominal Partition Coefficient	Average ± Standard Deviation
Dicy paper	50	2165	3.81	
		812	0.78	
		324	2.23	
		130	2.26	2.3 ± 1.1
	110	787	1.70	
		315	2.54	
		128	2.61	2.29 ± 0.41
Core Steel	50	787	75	
		315	95	85 ± 10
	110	787	173	
		315	290	
		128	219	228 ± 48
Formvar Wire	50	795	45	
		318	57	51 ± 6
	110	787	37.3	
		315	39.3	
		128	69.7	
		49	8.93	39 ± 22
Diamond paper	50	795	0.91	
		318	1.25	
		129	1.35	1.17 ± 0.19
	110	1969	0.16	
		787	1.14	
		315	1.55	
		128	2.32	
		49	0.03	1.04 ± 0.86

TABLE 3
CONSTANTS FOR FREUNDLICH ADSORPTION ISOTHERM

	k		1/n		Coefficient of Correlation	
	50°C	110°C	50°C	110°C	50°C	110°C
Dicy Paper	0.3705	1.0163	1.0187	0.8439	0.9999	0.9970
Core Steel	0.0282	0.0976	0.4760	0.0988	0.8562	0.2736
Formvar Wire	0.0053	0.0057	0.8123	0.7621	0.9850	0.9720
Diamond Paper	0.5883	0.0513	0.9240	0.5937	0.9832	0.9908

$$\frac{X}{M} = k\, C_o^{1/n} \qquad \text{Equation (2)}$$

$$\ln (X/M) = \ln (k) + 1/n \ln C_o \qquad \text{Equation (3)}$$

X = Mass of PCB adsorbed
M = Mass of solid material
k = System constant
n = System constant
C_o = PCB concentration in oil

TABLE 4
TIME TO REACH QUASI-EQUILIBRIUM

Experiment	Oil to paper ratio	Temperature °C	Time to reach quasi-equilibrium, min.
Desorption	190	50	183
		110	33
Adsorption	2.70	50	3500
		110	490

TABLE 5
RESULTS OF DIFFUSIVITY ANALYSIS

Experiment	Half-Time Min.	Initial PCB Concentration, ppm In paper	In oil	D at Half-Time cm^2/sec
Desorption at 50°C	36.14	689000	0	2.6×10^{-11}
Desorption at 110°C	3.733	689000	0	7.6×10^{-10}
Adsorption at 50°C	31.8	0	2042	7.7×10^{-7}
Adsorption at 110°C	18.0	0	2042	1.3×10^{-6}

TABLE 6
PERCENT OF PCB CONTENT IN A TYPICAL
500 KVA TRANSFORMER AT 50°C

	PCB Concentration In Bulk Oil, PPM				
Material	50	250	500	1000	2000
Dicy Paper	1.703	1.762	1.787	1.811	1.835
Core Steel	0.775	0.335	0.233	0.162	0.113
Formvar Wire	0.019	0.014	0.013	0.011	0.010
Sub Total	2.497	2.111	2.033	1.984	1.958
Oil	97.503	97.889	97.967	98.016	98.042

NOTE:

1. In a transformer, assume all papers are dicy paper.

MATERIAL	QUANTITY
Oil	318 liters (about 85 gal.)
Paper	12 Kg (about 26 lb.)
Core Steel	611 m^2 (about 6600 $ft.^2$)
Formvar Wire	14 m^2 (about 145 $ft.^2$)

TABLE 7
PERCENT OF PCB CONTENT IN A
TYPICAL TRANSFORMER AT 110°C

	PCB Concentration in Bulk Oil, PPM				
Material	50	250	500	1000	2000
Dicy Paper[1]	2.346	1.843	1.659	1.492	1.341
Core Steel	0.611	0.145	0.078	0.042	0.022
Formvar Wire	0.017	0.012	0.010	0.008	0.007
Sub Total	2.974	2.000	1.747	1.542	1.370
Oil	97.026	98.000	98.253	98.458	98.630
Percent PCB increase (decrease) with respect to 50°C for oil	(0.489)	0.113	0.292	0.451	0.600

NOTE:

1. In a transformer, assume all papers are dicy paper.

DESTRUCTION OF PCB's IN TRANSFORMER OIL

D. J. Brunelle
D. A. Singleton
General Electric Company

DESTRUCTION OF PCB's IN TRANSFORMER OIL

D. J. Brunelle*
D. A. Singleton*

We have recently been investigating the phase-transfer catalyzed reactions of various nucleophiles with unactivated aromatic halides in non-polar media. As a result of this investigation, we have found that potassium hydroxide and polyethylene glycol (PEG) react with polychlorinated biphenyls (PCB's) in non-polar solvents such as transformer fluid. The reaction takes place at moderate temperatures: complete removal of up to 1% PCB's from transformer oil occurs in less than two hours at 100°.

The reaction is very tolerant of air and moisture. We have carried out all of our reactions using 85% KOH containing 15% water. The polyethylene glycol was used as received from the distributor. The presence or absence of air (oxygen) has no effect on the rate or outcome of the reaction. However, to retain the oxidative stability of transformer oil, we recommend carrying out the reactions under an inert atmosphere (nitrogen or argon).

The reaction is operationally very simple: one merely mixes commercially available polyethylene glycol, potassium hydroxide, and the contaminated oil for up to 2 hours at 100°C. Upon cooling, washing with water, or filtration, the glycol phase separates from the transformer oil, which is currently being evaluated for reuse. No special precautions need be taken to exclude moisture from the system or from the oil.

The products from the reaction have been identified as a mixture of aromatic alcohols and polyglycols, which are in the glycol phase. No PCB's, dioxins, or polychlorodibenzofurans have been detected in either the transformer oil or in the glycol phase. Preliminary acute toxicity screening of the neutralized glycol phase indicates it to be a mild eye irritant, but non-toxic by oral ingestion or dermal absorption.

* General Electric Company

The reaction proceeds by a nucleophilic aromatic substitution mechanism, with phase-transfer facilitated by the polyether chain. Subsequent substitution or elimination on the intermediate aryl polyglycol affords biphenyl alcohols and polyglycols. Reactivity of the PCB increases with higher degrees of chlorination. Thus, Arochlor 1260 will react at 60°C, whereas Arochlor 1242 requires heating at 100°C.

Stirring is crucial to the success of the reaction; unstirred reactions do not proceed at all. Use of sodium hydroxide in place of potassium hydroxide leads to an approximate 10-fold drop in rate. We observe an approximate 3- to 5-fold increase in rate using mono-capped polyethylene glycols (e.g., polyethylene glycol monomethyl ether). Using these capped PEG's, arochlor 1260 is completely destroyed in 1-2 hours at 80°C. We are currently pursuing engineering considerations and scale-up of this process.

Discussion

Q. Have you checked for trichlorophenol at partial completion?

A. We do not find trichlorobenzene in the reaction. Temperatures are not high enough to form dioxins or furans.

Q. Do you only get one replacement?

A. No. You will have two replacements.

Q. What is the destruction limit?

A. It will destruct to less than 1 ppm.

Q. Is there any upper limit on the process?

A. It has been tested to 20,000 ppm in the laboratory and still results in zero after processing.

Q. Do you find organic chlorine in residue?

A. Yes. We do find organic chlorine.

Q. How is the contaminated glycol disposed of?

A. The residue is less than 1% of the original volume and is disposed of in a chemical landfill.

PCB REMOVAL FROM TRANSFORMER OIL

F. J. Iaconianni
A. J. Saggiomo
S. W. Osborn
Franklin Research Center

PCB REMOVAL FROM TRANSFORMER OIL

EPRI PROJECT NO. 2028-2

Presented at

EPRI PCB SEMINAR
Dallas, Texas
December 3, 1981

F. J. Iaconianni, A. J. Saggiomo and S. W. Osborn

Franklin Research Center
The Benjamin Franklin Parkway
Philadelphia, PA 19103

The discovery of PCBs as toxic, environmental contaminants has led to strict regulations for the maintenance, operation and disposal of the following classes of transformers, defined according to their PCB content:

- Below 50 ppm PCBs: Noncontaminated Transformer
- 50-500 ppm PCBs: PCB Contaminated Transformer
- Above 500 ppm PCBs: PCB Transformer

As a result, a multitude of transformers on utility systems have been classified under these regulations as PCB Contaminated Transformers.

The primary objective of our contract program is to develop a treatment process for PCB Contaminated Transformers (50-500 ppm PCBs) that will lower PCB concentration below the current acceptability limit of 50 ppm. Processes under investigation involve PCB removal by solvent extraction and by adsorption. Test oils for this study are Texaco 55 Acid Refined, Shell Diala AX Furfural-Extracted, a current Chevron, Exxon Univolts 60 and N-60 transformer fluids. These oils were mainly spiked with Aroclor 1254 (50-500 ppm), the latter considered to be a representative PCB commonly used in transformers.

After PCB-removal treatment, the Noncontaminated oils will undergo several ASTM test procedures (Part 40) to evaluate their reusability as transformer fluids:

1. Aniline Point (D611)
2. Interfacial Tension (D971)
3. Kinematic Viscosity at 40°C (D445)
4. Specific Gravity (API) (D1298)
5. Power Factor at 100°C (D924)
6. Dielectric Breakdown (D1816)
7. Oxidative Stability in presence of di-t-butyl cresol (D2112 & D2440)
8. Acid Number (D974)

In order to facilitate the selection of candidate solvents and adsorbents, an automated literature search was conducted for the period from 1974. Over 1100 citations were examined, 80 of which dealt directly with the solubility, extraction and adsorption of PCBs.

Approximately fifty compounds have been evaluated as solvents for the extraction process. Criteria employed were immiscibility with transformer oil, ability to solubilize and favorably distribute PCBs, relative volatility and non-toxicity. Three solvents emerged that met most of these requirements: polyethylene glycols, average molecular weights 400 and 600 (PEG 400, PEG 600) and methyl cellosolve. The PEGs are non-toxic solvents of low volatility used in many food and cosmetic formulations. In contrast, methyl cellosolve is a relatively toxic solvent employed in fast-drying varnishes, stains and enamels.

In the one solvent, multi-extraction process the efficiency of removing PCBs from transformer oil can be conveniently measured by the distribution coefficient K, a ratio of PCBs in the solvent vs. PCBs in the extracted oil. Typical K values determined in the extraction of Texaco 55 oil were: 0.78 (PEG 600), 0.66 (PEG 400) and 0.98 (methyl cellosolve). These solvents lowered PCB concentration well below the 50 ppm Noncontaminated level. Maximum recovery of oil was achieved with the PEG extractants. Preliminary results indicated that initial PCB concentration and higher extraction temperatures have little effect on extraction efficiency.

Although PEGs have been found to be suitable extractants of PCBs from transformer oil, they possess low volatility. Therefore, it seemed reasonable to transfer PCBs from the PEGs (Solvent A) to a volatile Solvent B, remove the latter for reuse (by distillation) and chemically destroy the PCB residue. Investigation of this exchange-solvent method of PCB-removal yielded as the best Solvents B, cyclohexane and hexane. Cyclohexane provided 90-100% recovery of PCBs from PEG 400 extracts of spiked Texaco 55 oil.

All extracted oil samples from the above work exhibited a noticeable decrease in the amount of aromatic components. Oils treated with recycled PEG 400 were found to contain considerable cyclohexane.

In screening various types of adsorbents for the decontamination of spiked transformer oil, neutral alumina gave best results. Conditions are currently being examined to maximize oil recovery.

Analyses for PCBs have been carried out by gas chromatography using an electron capture detector. Quantitation was effected by comparison of the resulting chromatogram with that of a Standard Aroclor of known quantity. Procedures have been in conformity with the most recent EPA and ASTM approved modifications.

PCB REMOVAL PROCESS DEVELOPMENT: DISTILLATION

W. H. Mink
J. R. Longanbach
R. K. Smith
H. E. Carlton
Battelle Columbus Laboratories

PCB REMOVAL PROCESS DEVELOPMENT: DISTILLATION

by

William H. Mink, James R. Longanbach,
Russell K. Smith, and Herbert E. Carlton

Paper Presented at the EPRI PCB Seminar,
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INTRODUCTION

Several researchers have studied various disposal and destruction techniques for PCBs but distillation is neither. It is a separation technique. But it may have a place in the overall scheme of PCB handling by the electric utilities. Incineration and landfilling are expensive. Large quantities of mineral oil and wash solvents will be used as expensive fuels or landfilled at rates determined by the volume of the material to be burned or buried. If the concentration of PCBs in these materials could be decreased to less than 50 ppm, they could be recycled, and if the concentration of PCBs could be decreased to less than 500 ppm, they could be incinerated in utility boilers at less cost and with recovery of their heating values. Also the PCBs might be concentrated in much smaller volumes of material, which could be incinerated in EPA-approved facilities at lower cost. This may be an option which could save the utilities money in storage, transportation (to the disposal facilities), materials and disposal costs.

Distillation is not universally applicable. For instance, it is not applicable to capacitor dielectrics because these are typically applications where pure PCBs were used.

The applications for which distillation may offer savings include

- Separation of PCB transformer fluids.
- Separation of PCB contaminated mineral oils (containing over 50 ppm of PCBs) which result from topping or draining and refilling of transformers.

- Separation of PCBs from wash solvents.

PCB transformers typically contain 60-70 percent PCBs (usually Aroclor 1254, bp range 365-390 C) and 30-40 percent chlorinated benzene (typically 1,2,4-trichlorobenzene, bp 213 C). The chlorinated benzenes could be separated by distillation and burned to recover their fuel value in a utility boiler. The smaller volume of purer PCBs obtained from the separation process could be burned in an EPA-approved facility at the expense of lower transportation, storage and incineration costs. The separation should be excellent.

Mineral oil (typically boiling between 286-400 C) used to top or drain and refill PCB transformers can be separated from the PCBs (typically Aroclor 1254) and could be recycled after the replacement of stabilizers (typically 2,6- dibutyl p-cresol, bp 97 C). The very small volume of PCBs obtained could be incinerated in an EPA-approved facility. The separation in this case might recover about 85 percent of the mineral oil from Aroclor 1254 and about 90 percent from Aroclor 1260.

PCB transformers must be drained, filled with solvent, typically toluene (bp 110 C), xylene (bp 138-144 C) or kerosene (bp 175-325 C), allowed to sit for 18-19 hours and then drained. The PCBs in the used solvents could be separated and incinerated and the solvent recycled. The separation, even with kerosene, should again be excellent.

There may be other applications but these appear to be practical based on the boiling point ranges, vapor pressures and thermal stabilities of the components.

This paper describes the steps which were followed in the development of a distillation-based process for the removal of PCBs from hydraulic oils.

BACKGROUND

Prior to 1972, polychlorinated biphenyls (PCBs) were widely used as a fire-retardant additive in hydraulic oils employed in foundry die casting machines. When the sale of hydraulic fluids containing PCBs for non-closed-loop applications was stopped in 1972, existing PCB-laden hydraulic oil stocks were recycled with losses replaced with PCB-free hydraulic oils. In 1976, when it became illegal to recycle oils containing more than 50 ppm PCBs, contaminated oils were removed from foundry operations and stored. However, a problem experienced by many foundries was that PCB residuals tended to remain in die casting machinery and in oil storage reservoirs even after repeated flushings of the equipment with uncontaminated oil. The result has been the continued leaching of PCBs from equipment and sumps and a gradual accumulation of PCBs in replacement hydraulic oil stocks to levels in the range of 500 to 3000 ppm. Thus, the amount of PCB-contaminated hydraulic oil generated by die casting operations has continued to increase long after their ban from industrial markets.

Given the high cost of hydraulic oil, a method was needed for the reduction of PCB concentrations in oil stocks to below 50 ppm to allow this valuable fluid to be recycled, to reduce storage costs and to decrease the risk of accidental leakage or spills of PCBs into the environment.

Purpose

The purpose of this study was to identify and test a PCB separation technique that could be used by foundries to convert large stocks of PCB-contaminated hydraulic oils into a product suitable for reuse in the die casting operation. A PCB separation process developed for contaminated hydraulic fluid treatment and recycle had to be capable of producing high yields of an oil product that meets industry standards for acidity, clarity, viscosity and ignition resistance. These standards suggest the need for the selection of processes capable of efficient PCB separation without employing extreme treatment conditions which could result in the degradation of the hydraulic oil matrix.

Some of the corresponding standards which must be met for electrical utility fluids are flash point, viscosity, dielectric breakdown voltage at 60 Hz, power factor, oxidation stability, etc.

LABORATORY STUDIES

The procedure used in the laboratory phase of the study consisted of obtaining a sample of PCB-contaminated hydraulic oil from waste-oil stocks stored at a foundry and screening various candidate separation techniques according to their ability to remove PCBs while retaining the desirable characteristics of the oil product. Several criteria were used to select processes for screening.

- Must not chemically destroy the oil
- Must reduce the PCB concentration to below 50 ppm
- Should be applicable to large scale operation
- Should be relatively simple and inexpensive.

The candidate techniques included:

- Vacuum distillation
- Steam distillation
- Azeotropic distillation
- Solvent extraction
- Foam extraction
- Filtration
- Adsorption.

Hydraulic Oil

The PCB-contaminated hydraulic oil consisted of an isomeric mixture of trisopropyl phenyl phosphate esters containing 2300 ppm Aroclor 1242 and contaminated with particulates, water, mineral oil and phenols.

Results and Discussion

On the basis of the preliminary screening tests, it appeared that vacuum distillation had the greatest potential for application to hydraulic oil decontamination and recovery. Aroclor 1242 boils between 325-365 C and the hydraulic oil boils above 400 C. Thus the PCBs were distilled from the oil.

A complete vacuum distillation was performed in which 12 fractions of distillate were taken. Distillation temperatures ranged from 264 to 278 C at 10-16 mm Hg absolute pressure. Most of the PCBs were in the hydraulic oil removed in the first few distillate fractions: Fraction 1 contained 7200 ppm, Fraction 2 contained 31,000 ppm, while Fraction 8 contained only 5 ppm PCBs. The bench-scale vacuum distillation system achieved PCB reductions of more than 98 percent with a decontaminated oil product yield of more than 90 percent. These data suggested that a vacuum distillation process had considerable potential in the efficient extraction of PCBs from hydraulic oils while minimizing product loss.

Performance Characterization of Vacuum Distillation

After selecting vacuum distillation as the most promising process, two additional series of vacuum distillation experiments were conducted. The first involved high vacuum distillation (0.14 to 0.35 mm Hg) applied to a number of different hydraulic oil samples. The second set was done to obtain data at low vacuum conditions (10-15 mm Hg) for pilot-plant design purposes. The advantage of operating at higher vacuums is the capability of carrying out distillations at lower temperatures with the objective of reducing oil degradation.

For the stored hydraulic oils, a vacuum distillation treatment system must include a filtration step prior to distillation. Solids removal is vital in an overall treatment scheme to avoid desorption of PCBs from solids into PCB-free oil after distillation.

In the bench-scale tests, each of the samples was filtered.

Samples from seven different PCB-contaminated hydraulic oil sources were subjected to high-vacuum distillation, keeping the maximum distillation temperature below 244 C. Concentrations of PCBs in these samples ranged from 600 to 2500 ppm and they contained various amounts of solids before filtration. Each of the samples was filtered before distillation.

Samples of hydraulic oil distillation residue were taken after removal of 5, 10, and 15 percent of the initial oil volume. Distillation was carried out in a 13-inch x 1/2-inch diameter insulated Vigreaux column. The results of the PCB analysis of the samples taken after distillation of 10 percent of the oil show that reductions of PCBs in contaminated oils to levels below the allowable EPA limit of 50 ppm can be consistently achieved with vacuum distillation, even when applied to a wide variety of hydraulic oils.

Four laboratory distillations were carried out at 10 to 15 mm Hg to obtain data for the design of a pilot plant. In these experiments, two distillation columns were used. One was an unpacked, uninsulated 2-inch x 1/2-inch diameter tube. This column provided approximately one plate of fractionation and the PCB level was reduced to only 435 ppm.

The second column was the insulated Vigreaux column. At 90 and 85 percent yield at 10 mm Hg pressure, the PCB content in the distillation residue was 60 and 32 ppm, respectively. Comparison of data at various levels of vacuum indicate that more fractionation is required as vacuum is decreased. Thus, 40 ppm PCBs could be obtained at 90 percent yield using a distillation pressure of 1 mm Hg; whereas at 20 mm Hg, the yield to obtain the same PCB level would be only 85 percent.

These operational data indicated a high likelihood that acceptable levels of PCBs could be achieved in hydraulic oils through the application of higher vacuums to distillation.

The laboratory study also showed that vacuum distillation had the capability of achieving consistently high PCB removal efficiencies with a variety of hydraulic oils containing a wide range of PCB concentrations.

Reductions of PCBs from as high as 2500 ppm to below 50 ppm could be achieved with losses of only 10 to 15 percent of the oil product. The data generated in the laboratory provided a basis for the design of the distillation system at the pilot scale.

The laboratory study also suggested a relationship between distillation vacuum and rates of product degradation which had to be incorporated in the design of the pilot system. The application of higher vacuum to distillation should allow lower distillation temperatures and less product degradation. This implied a tradeoff to be defined for the design of the pilot plant: higher capital and energy expenditures for higher vacuum distillation versus improved product yield and quality.

This study provided direction and an information base for a pilot plant study on the vacuum distillation process for the removal of PCBs from hydraulic oils.

PILOT STUDIES

Using data developed in the laboratory studies, a distillation curve of percent versus temperature was prepared for 15 mm Hg pressure. These data are depicted in Figure 1. Specific heat and latent heat of vaporization were estimated. Sufficient data were then available for system design.

Process Description

Figure 2 is a Flow Diagram of the PCB separation process. Contaminated oil feed (containing 500 to 5,000 ppm PCBs) is pumped through a heat exchanger (against hot product oil at about 500 F) and further heated by a Dowtherm heater. The oil at about 320 F is fed into a stripping column. Water and low boiling organics are flashed off, condensed, and sent to waste storage. The stripped oil is heated to about 500 F and pumped to the distillation column which is maintained at 10-15 mm Hg. PCBs are distilled over, and partially condensed in, an air-cooled condenser. A portion of the condensed material is returned to the distillation column as reflux. The remainder is further cooled and added to the water-condensed material from

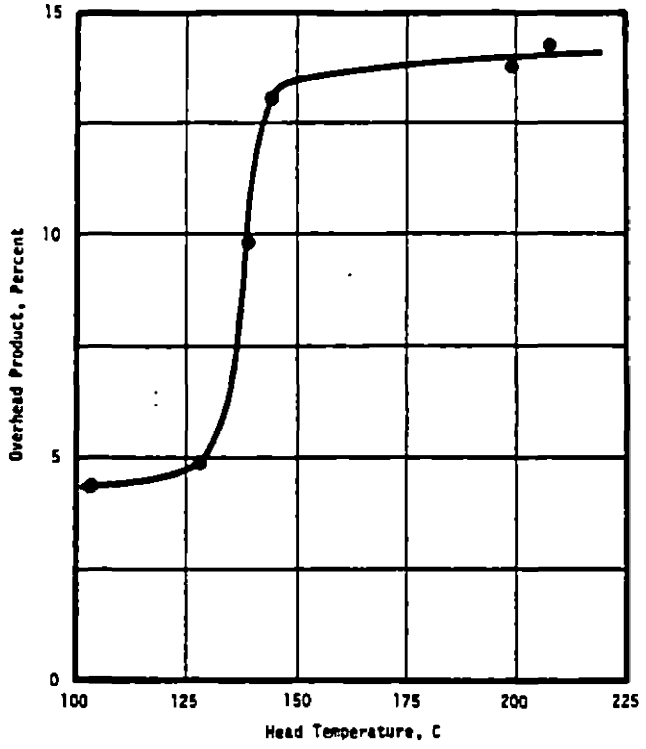

FIGURE 1. MATERIAL TAKEN OVERHEAD AS A FUNCTION OF HEAD TEMPERATURE

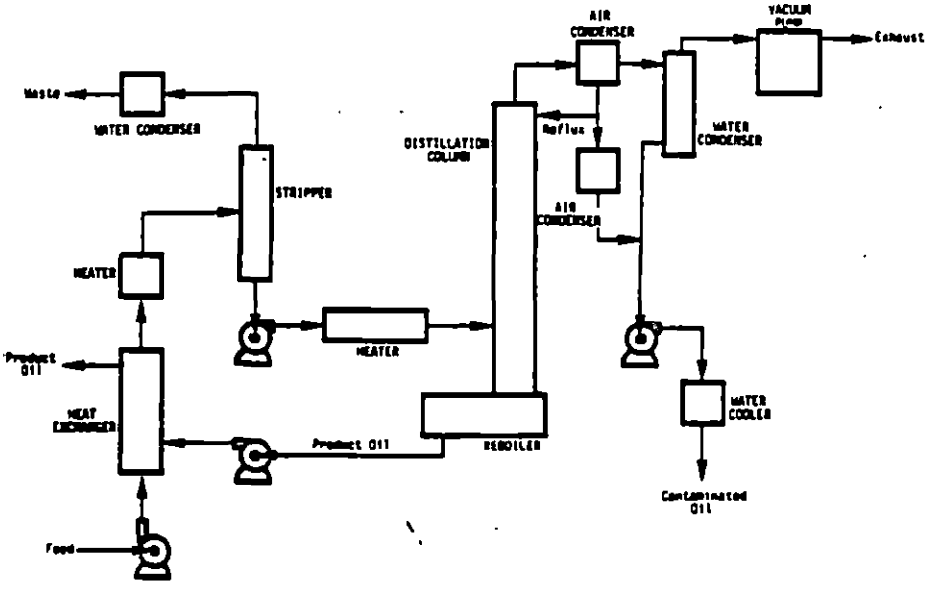

FIGURE 2. PROCESS FLOW DIAGRAM

the air-cooled condenser. This combined PCB material (containing 10,000 to 50,000 ppm PCBs) is pumped through a cooler to contaminated storage. Stripped material flowing down the distillation column is reheated in the reboiler. A portion of the reboiler material (containing < 50 ppm PCBs) is pumped through the heat exchangers to preheat the feed oil and sent to product storage.

Plant Operation

The pilot plant was started up on clean oil (with no PCBs). The process was leak-tested at temperature, and clean oil distilled overhead. Following shakedown and testing, the system was filled with PCB-contaminated oil and tests with PCB-containing oil were then conducted in Battelle's special materials pilot plant area which is designed to permit such hazardous chemicals testing.

A total of 16 tests were carried out in the equipment. (Table 1 summarizes the data obtained.) PCB concentrations in the product ranged from 775 to less than 1 ppm with feed concentrations ranging from 360 to 1150 ppm. In some tests (for example, Test 6), the product PCB concentration was above or near the feed concentration. In these cases, the analyses were performed on samples obtained either before steady state had been reached or where operating conditions selected were such that an upset occurred. The bulk of the tests resulted in a product with an acceptable PCB concentration (below 50 ppm).

Figure 3 presents distillation data as a function of product yield and column overhead temperature. If the overhead temperature is maintained above about 230 F, it appears from an extrapolation of the data of Figure 3 that a product containing less than 50 ppm PCBs at yields over 90 percent can be realized. It should be pointed out that yields given in Table 1 and Figure 3 are based on the contaminated feed, which contains among other things, water and mineral oils. The yield based on the phosphate ester would probably be well over 95 percent.

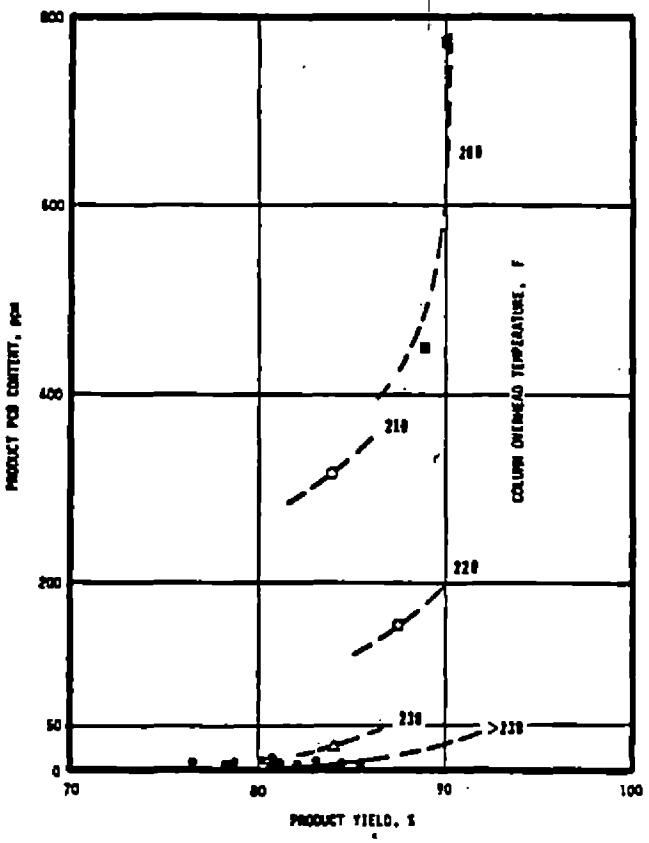

FIGURE 3. EFFECT OF OPERATING PARAMETERS ON PRODUCT QUALITY

TABLE 1

Run	Overhead Temperature F	Feed Rate GPM	Product Yield %	Product PCB Concentration ppm
1	343	1.5	85.3	8
2	461	2.8	78.6	13
3	339	1.7	76.5	8
4	267	2.3	78.3	<1
5	220	4	87.5	155
6	202	5	90.0	755
7	201	5	89.0	447
8	357	5	83.0	12
9	366	5	82.0	6
10	230	5	84.0	30
11	234	5	84.6	2
12	210	5	84.0	320
13	328	3.5	80.9	<1
14	337	3.5	80.9	1
15	321	3.5	80.9	<1
16	335	3.5	80.9	1

CONCLUSIONS

PCBs can be removed from hydraulic oil with a vacuum distillation process. Oil cleanup by this method affords two cost avoidances. First, the bulk of the contaminated oil can be reclaimed for reuse. Second, the volume reduction of waste results in transportation cost savings. It also saves disposal costs, which are generally based on the quantity of material, and not on PCB concentration. In fact, the cost savings (in this case) are so dramatic that a payout time of less than one year is anticipated for the project.

The plant, built by Battelle on skids, was shipped to the foundry and is successfully processing contaminated oil.

DISCUSSION

Q. After distillation, how was PCB content determined?

A. We used various gas chromatographs.

Q. Are there any permit problems?

A. No. Air monitoring is done. It is a sealed system. We are working with the State EPA.

Comment: Since hydraulic oil and PCB have a boiling point spread of 40° and transformer oil has a boiling point the same as PCB, it was suggested that the process cannot work with transformer oil.

Q. Is there any PCB left in the stripped fluid?

A. No.

REMOVAL OF PCB FROM TRANSFORMER OIL

T. O. Rouse
General Electric Company.

REMOVAL OF PCB FROM TRANSFORMER OIL

T.O. Rouse, General Electric Co.

PROGRAM DESCRIPTION

The mineral oil contained in many transformers is contaminated with measurable amounts of polychlorinated biphenyls (PCB). The handling, maintenance and disposal of these transformers would be simplified if these PCB were eliminated. Because of the general chemical inertness of PCB and because of their similarity to many of the hydrocarbons in transformer oil, removal is a difficult task. Not only must a successful process efficiently and reliably eliminate PCB, but the processed oil should be suitable for continued use as a dielectric fluid and it should not present a hazard to the environment. The Electric Power Research Institute believes that removal of PCB from transformer oil leaving a reusable liquid is an important goal to be reached and therefore is sponsoring work to meet this goal. This report describes that part of the sponsored work to be performed by the General Electric Company and its collaborators.

The General Electric Company has considered many possible processes as part of internal programs or in collaboration with other investigators. Four are particularly promising. They are: (a) liquid-liquid extraction, (b) reaction with organo-sodium compounds, (c) irradiation with electrons, and (d) super-critical fluid extraction. All reduce PCB levels in transformer oils. There is not sufficient information available now to determine if the oil treated by one or the other process can be reused in long-term operation in electrical insulation systems. There is not sufficient information available now to determine the cost effectiveness of each process. In short, there is not sufficient information available now to determine which will do the job most effectively.

The first step in the present program is to evaluate the four processes and the resulting oils in sufficient depth in the laboratory to choose the process most effective in providing a reusable oil.

The second step is to demonstrate that the selected process will produce acceptable oil on a larger scale. A scaled-up process unit will be

built and operated. Process parameters will be evaluated and operating procedures will be developed. Oil treated by the selected process will be more fully evaulated to determine if it is suitable for long-term use as a dielectric fluid.

The urgency of the PCB removal problem is great and it would be very desirable to complete the demonstration of a full-scale process unit or a completely engineered pilot scale unit very quickly. However, the consequences of selection of a process leading to unusable oil and possible transformer malfunction are equally great. The goal of selection and demonstration of the most effective and reliable process in a year is considerable, but, we believe, a realistic challenge. The appropriate resources of the Apparatus Service Business Division and the Power Transformer Department of General Electric, the High Voltage Research Laboratory of the Massachusetts Institute of Technology together with the New England Aquarium and the High Voltage Engineering Corporation, and the Critical Fluid Systems Corporation (from A.D. Little Company) have been assembled to reach this goal. The Apparatus Service Business Division will be responsible for assessing the prospects for commercialization of the demonstrated process. The technical work will be coordinated in the Power Transformer Department. Work on the liquid-liquid extraction and organo-sodium processing will be done at the Power Transformer Department. The High Voltage Research Laboratory of MIT and its collaborators and the Critical Fluid Systems Corporation of the A.D. Little Company will provide particular expertise and work on the electron irradiation and super-critical fluid extraction processes, respectively. Determination of the reusability of oil also will be done at the Power Transformer Department.

DISCUSSION

Mixtures of chlorinated biphenyls and trichlorobenzene have been used as dielectric fluids in transformers and other electrical apparatus since the 1930's. PCB have been judged to be harmful in the environment, and their manufacture, use and disposal have been subject to Government regulation since 1978. This regulation extends not only to transformers containing these mixtures alone, but also to the large number of mineral

oil-filled transformers which have been contaminated with PCB during manufacture or service.

Specifically, the most recent regulation defines three categories of transformers*:

A. A PCB transformer is one filled with liquid containing 500 ppm or more PCB whether initially designed for PCB-containing fluid or not. Liquid taken from PCB transformers must be disposed of in an EPA approved high temperature incinerator.

B. A PCB-contaminated transformer is one filled with liquid containing 50 to 500 ppm PCB. Liquid taken from a PCB-contaminated transformer may be disposed of in an approved chemical waste landfill or high temperature incinerator, in high efficiency boilers approved by EPA and by alternate methods proposed to and approved by EPA.

C. A non-PCB transformer is one filled with fluid containing less than 50 ppm PCB. The only restriction involving non-PCB transformers is that fluid from the transformer may not be disposed of through such uses as road sealants or dust control agents - if any detectable PCB is present.

Present regulations do not require the removal of PCB and PCB transformers from service earlier than would normally be the case. (Consideration is being given to different limits on PCB concentrations in defining maintenance and disposal requirements.) The regulation presently in force does permit the servicing of transformers to reduce the PCB content. If the PCB level is found to be below 500 or 50 ppm following three months use after such servicing, the transformer may be recategorized as a PCB-contaminated or non-PCB transformer. The less stringent maintenance, repair and disposal requirements of the new category then apply.

The only well-demonstrated method for reducing the level of PCB in transformers is retrofilling, i.e., draining and refilling the transformer with oil containing no PCB. It has been estimated that careful draining will reduce the amount of liquid in the tank to 1-2% of the initial value. An additional 2-4% of the liquid remains in the coil-core structure. Over roughly three months, this is leached out into and equilibrated with the fluid used to refill the unit. Transformers containing as much as perhaps 1000 ppm PCB might be converted to non-PCB

*Railroad transformers present a special case.

transformers by retrofilling a single time. There is an economic trade-off to be considered: the cost of retrofilling versus the reduced cost of maintaining, servicing and disposing of the retrofilled unit. The relative consequences of leaks and spills from a particular transformer with and without retrofilling must be considered. Finally, the drained fluid must be disposed of. Retrofilling is not being done extensively yet. Only two high temperature incinerators have been approved and appropriate landfills and high efficiency boilers do not seem to be widely used. In general, PCB and PCB-contaminated liquids are simply being accumulated and stored.

There is a major limitation even if these facilities were available. It is estimated that there are approximately three quarters of a billion gallons of oil containing 50 ppm or more PCB in transformers. Production capacity of transformer oil in the U.S. is approximately one hundred million gallons per year and the bulk of present production is used in the manufacture of new transformers. Unless the drained oil can be processed for reuse, a concerted effort to eliminate PCB from oil-filled transformers even over the next ten years would lead to a major transformer oil supply disruption.

There are two aspects to reuseability. First, the treatment to remove the PCB must neither convert them to environmentally hazardous materials nor leave other environmentally hazardous residues of the process.

Secondly, the oil must still perform satisfactorily for many additional years in service as an electrical insulating liquid. Any products of or residues from the PCB removal process must not adversely affect the dielectric properties of the liquid nor can they affect the aging behavior either of oil or of the paper and other materials in contact with the oil. Oil is a complex mix of hydrocarbon molecules, many of which may react or be removed under the conditions under which PCB are affected. The formation of hydrocarbon reaction products or the removal of stabilizing materials may also make an oil unusable.

Because of the complex make-up of transformer oil, it will be difficult to determine reusability of oil. IEEE guides provide recommended values

for a few properties of oil in or being reintroduced into transformers. These, however, demonstrate the quality of oil that was produced by tried and accepted processes or reclaimed or reconditioned by simple and well-demonstrated processes. ASTM standards provide recommended values for a number of properties of oil fresh from the refinery. Again, these demonstrate the quality of oil that has been treated by tried and accepted processes. These standards and guides and the test procedures on which they are based may not effectively address the effect of the PCB-decontaminated oil on the overall insulation system. The decontamination process can alter the composition and properties of the oil in ways not normally encountered in transformer oil production and reuse. Very thorough evaluation of the treated oil must be done to be sure that there will be no reduction in life and overloadability of transformers filled with the reused oil.

The treated oil must be evaluated by the standard methods to be sure that it meets the standard functional requirements. In addition, material compatability tests must be made. Oxidation kinetics must be determined because the removal process may leave behind catalysts for oxidation or may remove inhibitors. Cellulosic insulation is the material most vulnerable to thermal degradation in a transformer. The PCB removal process may leave products or residues that will speed up paper degradation and limit life and overload resistance. A lack of effect of the treated oil on the rate of degradation of wire enamel and other materials of construction must be demonstrated. The compositional changes occurring in the oil should be measured to minimize the possibility that there are subtle undesirable changes occurring which are outside the realm of the standard tests.

Because it is probable that the oil itself will be affected by the PCB removal process, it also is probable that additional steps will be required to return the oil to reusability. A careful evaluation of the oil from the decontamination step will be needed to determine what post-treatment is needed. Further evaluation of the oil will be needed to assure that any post-treatment has been effective. Final demonstration of the oil reusability will require iterative oil evaluations.

PCB ELIMINATION METHODS

Processes for the elimination of PCB from oil fall into two general categories. One is separation - the removal of PCB from the oil into another phase which is then disposed of. The second is in situ destruction - conversion of the PCB into innocuous materials in the oil directly. In principle at least, an in situ destruction process could also be applied to the PCB-rich phase formed by a separation method. Potential separation processes include extraction of the PCB into fluid phases immiscible in oil. The fluid could be normally condensed liquid or the super-critical fluid formed by compression of a gas above its critical temperature. (Distillation is also a separation process. It does not appear to be feasible here because the boiling ranges of mineral transformer oil and PCB overlap.) Potential in situ destruction processes include dechlorination by electron irradiation and by reaction with organo-sodium compounds. (Combustion processes such as incineration or use as engine fuel are also destructive processes but destroy the oil also.) These processes are discussed below.

Solvent Extraction

PCB can be removed from a transformer oil by mixing it with an oil-immiscible PCB-free liquid in which PCB are soluble. PCB will be removed from the oil into an extraction liquid until equilibrium is established. The partition coefficient defines the ratio of the equilibrium concentration in the extraction liquid to that in the oil. If the partition coefficient is one, one-half of the PCB in oil will be dissolved into an equal volume of extraction liquid initially containing no PCB. Ninety percent of the PCB will be extracted on mixing the oil with ten volumes of the second liquid - and so on. Oil-liquid systems with higher partition coefficients will require less extraction liquid to reduce the PCB content of oil by a given amount. Unfortunately, partition coefficients much greater than two are unlikely on thermodynamic grounds for PCB-oil systems. The amount of extraction solvent needed to remove PCB will be large. Any practical process will require reuse of the solvent after removal of the previously extracted PCB. This is done most simply by using an extraction liquid which has a boiling point well below that of PCB ($\sim$ 275°C and up). The solvent can be recovered by

distillation, leaving the accumulated PCB in the still pot for eventual disposal.

Solvent extraction with solvent recovery by distillation has many attractions. The process is widely used in industry. Transformer oil itself is often refined using one or another solvent extraction step. The processing can be done with a mobile unit and the extraction process itself can conceivably be done on a side stream from an operating transformer. There are no chemical reactions occurring and no undesirable products are formed. No side reactions occur to destroy the oil molecules. The rate of extraction is limited only by the rate of mixing the liquids. The most promising solvents are commonly used in industry and their health and environmental hazards are well-defined. The PCB can be highly concentrated for ultimate efficient disposal. (A transformer filled with 10,000 gallons of oil contaminated at the 100 ppm level contains only one half-gallon of PCB.)

There are two major questions about the use of solvent extraction. A liquid with good extraction capability may not be completely immiscible with transformer oil and small amounts of solvent may remain with the oil. If the residual solvent makes the oil unusable, it would have to be removed. Secondly, the fact that solvent extraction is used in the original refining of the oil raises the possibility that a liquid which effectively extracts PCB may also extract some of the natural ingredients of the oil. If these ingredients are necessary to continued use of the oil, the process may be unusable unless they or other satisfactory alternates can be added back to the decontaminated oil.

Organo-Sodium Reactions

Sodium reacts with PCB to strip chlorine from carbons in the biphenyl molecule. The chlorine is replaced by hydrogen atoms removed from other molecules or the carbon couples with other molecules. When all the chlorines have been replaced, the PCB is converted to biphenyl products. The chlorine molecules form sodium chloride - "salt" - in the process. The reaction occurs with finely-dispersed sodium metal but is very slow because the PCB must reach the surface of the metal particles in order to react. Large excesses of sodium metal must be used to provide suffi-

cient surface area for even moderate reaction rates. The rate of the process can be increased greatly if reactive sodium can be distributed on a molecular basis.

Metallic sodium can react with aromatic hydrocarbon molecules to form sodium salts. These salts can then dissolve in oil and can react with the PCB to form biphenyl products and sodium chloride. The aromatic hydrocarbon reverts to its original form. In order to build up quantities which will give attractive PCB removal rates, the organo-metallic salt must be stabilized by the presence of additional molecules - ligands. The ligand serves to solvate the sodium salt and increase its stability. The recently announced Goodyear process for removing PCB from heat transfer oils, for example, employs naphthalene to form the sodium salt and tetrahydrofuran (THF) as the stabilizing ligand. Other salt-forming reactants and other ligands are known. Organo-sodium reactions of this sort have been used for decades to dechlorinate hydrocarbons, although their use with PCB is recent.

The major advantage of organo-sodium reactions is that they do destroy PCB molecules in situ. Given a sufficient excess of sodium reagent, PCB can be removed to any desired level. The primary products are innocuous salt and hydrocarbon coupling products. The reaction is rapid.

There are two major areas of concern with the organo-sodium destruction approach. Oil reusability is the first. In order to function in the sodium reagent, an oil soluble salt former and ligand must be used. If these soluble materials cannot be removed and are detrimental to continued use of the oil, the attractiveness of the process is reduced. THF and other ligands might be removed by vacuum distillation or an extraction process fairly readily. Naphthalene removal would be more difficult. It is often overlooked that transformer oils contain measurable amounts of aromatics including alkyl and naphthenic substituted naphthalenes. It may be that the addition of naphthalene will be unnecessary to destroy the PCB in transformer oil at reasonable rates because the naturally occurring aromatics will form sodium salts and serve as the carrier for the sodium.

A second problem with reusability is unwanted side reactions. Sodium reactions were used in refineries as early as the 1920's to refine thiophenes (a class of aromatic hydrocarbons containing sulfur) out of oils. One school of thought has it that thiophenes improve the oxidation resistance of oils. Oil properties such as oxidation resistance would need careful evaluation before oils treated with organo-sodium reagents could be accepted for reuse. Finally, the organo-sodium materials may react with the normal contaminants - oxidation products, etc. - found in used transformer oil. The products of these reactions may reduce the life of the insulation system. It is also possible that the products of these reactions will be appreciably more hazardous in the environment than the PCB themselves. Ultimately oils treated with organo-sodium reagents should be subjected to at least preliminary toxicity testing before the process can be judged to be acceptable.

Electron Irradiation Destruction

Another means of destroying PCB is irradiation with ionizing radiation. Machine accelerated electrons possess energies far in excess of the binding energies in any molecule. Such electrons can penetrate into a target material - whether solid, liquid or gas - distributing energy by random collisions with the atoms and molecules in their path. An electron dosage of 20 megarad (1 megarad = 10 joules/gram absorbed energy) will excite over 10^{19} atoms per gram of liquid and produce about 4×10^{19} ionizations. Profound chemical changes - the stripping of chlorine atoms from PCB; the cleavage of carbon bonds in rings - could take place in such high energy transfers.

Electron irradiation has been evaluated briefly by personnel of the High Voltage Laboratory of the Massachusetts Institute of Technology and the General Electric Company. PCB are indeed destroyed; a dosage of 15 megarad reduces the PCB concentration from $\sim$ 500 ppm to $\sim$ 50 ppm.

PCB destruction using electron radiation offers many advantages. There is no need to mix the oil with chemicals and no need to strip the oil of reactants. The process is potentially very clean. It also may be relatively inexpensive.

There are also several major areas of concern here. The first has to do with the fate of the chlorine atoms once removed from the PCB. In the organo-sodium process, the chlorines react stoichiometrically with the sodium reagent to form sodium chloride. In the irradiation case, the chlorine can abstract a hydrogen atom from a neighboring hydrocarbon or water molecule and form hydrogen chloride or it can replace a hydrogen atom on a carbon structure. Chlorination of an aromatic carbon in another aromatic molecule could result in a material with a higher toxicity than the original PCB. Chlorination of a benzyl carbon can result in molecules which, as skin irritants, later react with water to form hydrogen chloride. The hydrogen chloride is undesirable not only because of its irritant character, but because traces of it can substantially increase the rate of aging of the paper in transformer insulation systems.

A second area of concern is the effect of the irradiation process on other qualities of the oil. There is no reason to expect that only carbon-chlorine bonds in PCB will be attacked and every reason to believe that other molecules will be altered. It may be necessary to remove unwanted side reaction products or to add back materials to obtain oil suitable for reuse.

Super-Critical Fluid Extraction

This process is fundamentally a liquid-liquid extraction process which is based on the significant changes in the dissolving power of a super-critical fluid solvent that occur with changes in pressure or temperature.

The removal of PCB from several contaminated transformer oils using super-critical carbon dioxide has been recently demonstrated on a laboratory scale by A.D. Little personnel. The major product was a low PCB content fraction with the PCB concentrated in a smaller volume co-product. The oil was extracted into the carbon dioxide phase and the PCB was left behind in the residual fraction (raffinate). Carbon dioxide was chosen because it is the material most commonly used to date in super-critical fluid extraction. It is readily available and inexpensive. Other super-critical fluids may extract the PCB from the oil rather than the reverse.

Super-critical fluid extraction is potentially the cleanest of the available PCB removal processes. The possible extraction fluids - carbon dioxide, ethane, propylene, etc. - are well-known and readily handled. They can all be easily removed from transformer oil by simple vacuum treatment Like simple solvent extraction, there are no products of PCB reaction or side reactions to be dealt with.

The selectivity of the PCB removal process is the major concern to be addressed in evaluating this process. It is important that the carry-over of oil with the PCB raffinate be minimized for two reasons. First, the amount of material which ultimately must be accumulated and destroyed should be minimized. Secondly, the loss of oil constituents needed for reuse should be minimized.

SUMMARY

Widespread reduction of PCB in oil-filled transformers in the next decade will require that a method be found which eliminates PCB from mineral oil efficiently and reliably. The process should leave behind an oil whose continued effectiveness as a dielectric liquid is unimpaired. The process should leave behind an oil which is not objectionable in the environment. The process must be acceptable to EPA. Further, it is very desirable that the process operate on-site or on-unit to minimize transporting large volumes of oil containing PCB.

A number of approaches can be taken to the removal of PCB from transformer oil. The chemistry of these processes are such as to raise concern that the treated oil will not be reusable. The program described above is directed toward the selection and demonstration of a PCB removal process which will result in reusable oil.

DISCUSSION

Q. What permits do you have?

A. EPA Region 1 has given permission for the test program.

Section 7

TREATMENT OF PCB CONTAMINATED MINERAL OIL - FIELD TRIALS

CHEMICAL DECOMPOSITION OF PCB's IN TRANSFORMER FLUIDS: The Acurex Process

G. J. Miille
Acurex Waste Technologies, Inc.

CHEMICAL DECOMPOSITION OF PCB's IN TRANSFORMER FLUIDS: The Acurex Process

G. James Miille, Acurex Waste Technologies, Inc.

ABSTRACT

Three general methods for PCB disposal exist today: landfilling, incineration, and chemical detoxification. Public opposition has caused close scrutiny of PCB disposal with primary concern for public exposure and surety of PCB destruction. This report presents the various methods of PCB destruction and highlights the Acurex Waste Technologies, Inc. process.

INTRODUCTION

Polychlorinated biphenyls (PCB's) are a general class of chemical compounds containing varying amounts of chlorine atoms attached to a biphenyl molecule. PCB's are found in varying quantities in electrical transformers and capacitors, and now, unfortunately, in the environment. Their use in transformers and capacitors stemmed from their excellent dielectric properties and chemical stability. This chemical stability is the reason why PCB's have been labeled a hazardous material (reference 1).

PCB's were first introduced in 1929 by Monsanto Company. Their widespread use and lack of controls lead to the contamination of the environment. Investigation into the toxicity of PCB's showed that they are not highly toxic; however, their inherent hazard is produced by their tendency to accumulate in the environment.

Once in the environment, PCB's enter the food chain. By the time PCB's reach the human body through the air and diet, their concentration can increase manyfold (reference 2). As PCB's build up in the body they gather in the fatty tissues. Over an extended period of time these accumulated concentrations can cause organ disorders and potentially fatal illnesses.

The presence of PCB's in the environment is only one part of the problem. Control of PCB's still in industrial use, namely utility transformers, is another major problem. Over the years, the noncontrolled use of PCB's and the practice employed in transformer rebuilding resulted in large numbers of transformers being contaminated with PCB's. Either a PCB-filled transformer was filled with a non-PCB fluid, or vice versa, but in either case the resulting transformer contained concentrations from a few parts per million to a high percentage of PCB's.

REGULATIONS

The first regulation to control PCB's was the Toxic Substance Control Act (TSCA) of 1976. TSCA, which took effect January 1, 1977, set forth guidelines for the Environmental Protection Agency (EPA) to enact regulations governing disposal and labeling of PCB's. In addition, TSCA instructed EPA to promulgate rules to govern manufacturing, processing, or distribution in commerce of PCB's, except for use in totally enclosed environments. These rules were published in the May 31, 1979 Federal Register and took effect July 2, 1979 (reference 3). Moreover, these regulations defined levels of PCB contamination and the methods of disposal for each level and type of PCB item. Rules for temporary storage of PCB's were also defined.

Landfilling was the most common method of disposal, especially for PCB capacitors. On March 1, 1981, EPA disallowed landfilling of PCB capacitors, requiring them to be stored until they could be incinerated. These capacitors must be removed from storage and disposed of by January 1, 1984. PCB transformers (PCB content greater than 500 ppm) may be disposed of by rinsing the casings and landfilling them. The liquid must be incinerated or chemically detoxified by an EPA-approved method.

PCB-contaminated transformers and their liquid can be landfilled, incinerated, or chemically detoxified. A summary of the current regulations governing disposal of PCB articles is shown in table 1.

METHODS OF DISPOSAL

The three most prominent methods of disposal are landfilling, incineration, and chemical treatment (references 4 to 13). Incineration may include special incinerators, high-efficiency boilers, cement kilns, or other methods relying on retention of the PCB molecule in a high-temperature atmosphere. Chemical treatment methods include various new processes; most of these methods are based on an active sodium reaction with PCB's.

Landfilling PCB's and PCB articles was the most practical alternative to storage in uncontrolled areas. However, over the years, public opposition to landfilling has grown tremendously. Recent disposal site incidents bear witness to this.

As an option to landfilling, incinerators were developed to destroy the PCB molecule at elevated temperatures. As with landfilling, public opposition grew because of the possible contamination of the environment by nonreacted PCB emissions (references 14 and 15). Strict controls, such as flowrates, oxygen and carbon monoxide mixtures, and temperature, are enforced to ensure complete breakdown of the PCB structure. Nevertheless, certification of an incinerator today is a long and costly process that is carefully scrutinized by the general public. Other high-temperature methods, namely high-efficiency boilers and cement kilns, use similar theory and must meet comparable standards.

Chemical treatment methods are relatively new in the PCB disposal market. The method most commonly promoted is the so-called "sodium

Table 1. Disposal of Failed PCB Articles[a]

	Store[b]	Rebuild	Disposal	
			Landfill	Incinerate or Treat[c]
Failed PCB capacitor	Until 1984[b]	Not practical	No	Yes
Failed PCB transformer (greater than 500 ppm)	Until 1984[b]	No	Rinsed casing	Liquid
Failed PCB-contaminated transformer (50-499 ppm)	Until 1984	Yes	Yes	Yes

[a]Functioning PCB articles can be left in service indefinitely
[b]Federal Register, May 31, 1979
[c]Treat by EPA-approved method

Note: PCB transformer can be rinsed by EPA method, and if less than 500 ppm can rebuild, if less than 50 ppm unregulated (remove label).

process" which incorporates the strong reducing agent, sodium, to dechlorinate the PCB molecule (references 16 and 17). The original sodium method research was performed by Goodyear (reference 4). This information was made available to the general public, and from this, several firms developed their own processes.

ACUREX PROCESS

Acurex Waste Technologies, Inc. (AWT) a subsidiary of Acurex Corporation, has developed a chemical treatment process (AWT Process) using sodium, but with some major changes and additions to the original "sodium process" (reference 18). This process, as with all new technologies, must be approved by EPA. This approval is now pending.

The AWT process unit is mobile and therefore able to treat PCB's onsite. PCB's or PCB-contaminated transformer oil enters the AWT system at one end where it is filtered and batch sized. As the oil is transferred farther downstream, the active sodium reagent is added and the mixture is allowed to react. After complete destruction of PCB's is shown by gas chromatography analysis of a batch sample, the excess reagent is quenched. The PCB-free oil is then filtered and returned to the customer.

One of the major concerns of PCB chemical treatment methods is the possibility of side reactions that might produce harmful byproducts. Several controls have been added to the AWT process to prevent such byproducts from forming. First, the complete PCB destruction process takes place under an inert nitrogen atmosphere. Since no oxygen is present, harmful oxidation products cannot form. Second, all reaction steps are performed at ambient temperature. This prevents possible thermally induced breaking of the biphenyl bond to form benzene and its hazardous chlorinated derivations.

The AWT process design is simple to ensure the best control. The PCB-laden oil is treated a batch at a time to allow analysis of the treated oil before it is transferred from the process unit. Immediate analysis is possible by using a gas chromatograph located on the process unit.

Another change that AWT made was to replace the original sodium reagent mixture. Napthalene, a priority pollutant, was a component of the original mixture. This was replaced by a nonpriority pollutant (proprietary).

The AWT process was tested under the auspices of the EPA on September 9, 1981 in Cincinnati, Ohio to gain approval and an operating permit. Several conclusions can be made from the demonstration. First, the process is effective in destroying PCB's. PCB's at a 1,000-ppm concentration were destroyed to less than 2 ppm, the detection limit of analysis. Second, no harmful byproducts were produced. Harmful byproducts are commonly agreed to be chlorodibenzodioxins and chlorodibenzofurans (products of PCB oxidation). Analysis for these components in the before-treatment oil and after-treatment oil showed no formation of these or similar substances. Third, no substantial air emissions of PCB's were recorded.

There has been considerable discussion about the reusability of chemically treated transformer oil (reference 18). To most, the risk in reusing treated oil with questionable dielectric properties clearly outweighs the minimal cost savings. One major reason for reusing transformer oil is the suspected shortage of replacement fluids. It was originally thought that if a large number of PCB-laden transformers were rebuilt, there would not be enough replacement fluid to supply all

requirements. However, it has been found that the estimate of PCB-laden fluid in service was high. Therefore, the need for reprocessing transformer fluid is diminished.

CONCLUSIONS

Recent fast-paced growth and development in PCB-destruction processes has lead to close public scrutiny of the methods. Public opposition is based on fear of future exposure to PCB's, an inability to verify destruction during normal operation, and fear of pollutant emissions (reference 19).

Sodium-based mobile processes incorporating controls to avoid emissions and harmful side reactions, offer a safe method of PCB destruction. Acurex Waste Technologies, Inc. has such a process.

DISCUSSION:

Q. What is the permit status?

A. The first unit is completed. The demonstration has been done. We have filed with all Regions and expect approval within a month. A second unit is now under construction.

Q. Do you recommend re-use of treated transformer oil?

A. Not at this time.

REFERENCES

1. Cal-Osha Reporter, pg. 00-2623-00-2625, September 7, 1981

2. "TMI Evaluates: What to Do About Askarel (PCB) Transformers," Transformer Maintenance Institute, 1980.

3. "Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce and Use Prohibitions," Federal Register, May 31, 1979; Volume 44, No. 106.

4. Plant Engineering Magazine, Technical Publishing Company, pg. 133-134, August 21, 1980.

5. Weitzman, L., and L. Pruce, "Disposing Safely of PCBs: What's Available, What's on the Way," Power, pg 78, February 1981.

6. Hazardous Waste Report, Vol. 2, No. 25, pg. 5.

7. Electric Week, McGraw-Hill, pg. 9-16, October 6, 1980.

8. Design News, pg. 36-38, September 21, 1981.

9. Chemical Regulation Reporter, Vol. 5, No. 24, pg. 525.

10. Power Magazine, pg. 150, April 1981.

11. Chemical Engineering Magazine, pg. 37-41, August 10, 1981.

12. Electrical Week, McGraw-Hill, pg. 5, June 22, 1981.

13. "Disposal of Polychlorinated Biphenyls (PCBs) and PCB-Contaminated Materials, Vol. 1," Electric Power Research Institute, October 1979.

14. Chemical Week Magazine, pg. 24, April 29, 1981

15. Hess, L. Y., "Reprocessing and Disposal of Waste Petroleum Oils," Pollution Technology Review, No. 64, Chemical Technology Review No. 140, Noyes Data Corporation, 1979.

16. N. D. Scott, J. F. Walker, and V. F. Hensley, Journal of American Chemical Society, Vol. 58, pg. 2422-2444, 1936.

17. "Handling Metallic Sodium on a Plant Scale, U.S.I.," Industrial Chemicals Company, 99 Park Avenue, New York, NY 10016.

18. Weitzman, L., "Treatement and Destruction of PCBs and PCB Contaminated Materials," Paper presented to the Division of Environmental Chemistry, American Chemical Society, August 1981.

19. Electrical World Magazine, pg. 30, October 1981.

SUNOHIO PCBX PROCESS AND FIELD EXPERIENCE

O. L. Norman
SunTech

Sunohio PCBX Process
and
Field Experience

O. L. Norman, SunTech

About three years ago, Sunohio set out to help its customers by developing a process to provide a better solution to the PCB problem than that of burial or incineration of valuable dielectric fluids and electrical devices. The result of the development program is the EPA-approved PCBX process which will be described today.

First, however, you should know that Sunohio is a partnership between a subsidiary of the Ohio Transformer Company and a subsidiary of Sun Company. Thus, Ohio Transformer brings to the organization expertise in the engineering and servicing of electrical devices while Sun contributes its knowledge from the manufacturing and servicing of mineral oil dielectric fluids. Sunohio was thus established in 1976 to provide a service to industry and electric utilities for testing, reconditioning and reuse of transformer insulating and cooling mediums.

It wasn't long, of course, before Sunohio's customers began asking for help in solving their PCB problems. Sunohio, in turn, contracted with SunTech, the R&D arm of Sun Company, to search out a process which could meet most, if not all, of the objectives given in the first slide.

The research phase was carried out in the Sun labs in Marcus Hook, PA, while the larger scale development was done at the Ohio Transformer facilities in Canton, OH.

The initial request for EPA approval was made with the EPA headquarters in Washington in June, 1980. A demonstration was held in Canton in October, 1980, for a team of EPA representatives from Washington and each of the ten regional offices. At the same time, technical data was submitted to support the basis of the chemistry involved in the PCBX process. EPA approval was announced in May, 1981.

The PCBX equipment is mounted in a standard trailer forty feet long and is accompanied by an auxilliary trailer containing recovery and test equipment. The second slide shows the rig alongside a transformer and connected to it by two hoses to permit oil to be pumped from, and to, the transformer after processing. The next slide shows an internal view of the rig - taken at the time of the EPA demonstration.

PCBX is a continuous process in contrast to a batch operation, and a simplified flow diagram is given in the next slide. As can be seen, the oil is pumped from a transformer, or storage tank, through a heater to a mixer where reagent is metered in. From there, the mix flows to a reactor and then to a recovery system consisting of heat exchangers, filters, centrifuge, and vacuum evaporator before returning to the transformer or clean storage tank. The chemical reactions take place at temperatures below the flash point of transformer oil and at pressures only enough to pass the oil through filters.

As was indicated earlier, one of the main objectives of PCBX was to deliver the decontaminated oil with a quality sufficient to permit its reuse for normal dielectric purposes. Oil processed by PCBX meets all the specifications for reclaimed oil and, in many cases, meets the NEMA specs for new oil.

Earlier this summer, Sunohio was taken to task for not releasing information pertaining to long-term stability of processed oil. We would like to correct that situation at this time by sharing with you, as we did at an IEEE meeting in Chicago in October, data pertaining to oxidation stabilities as measured by ASTM D2440 and D2112 tests. The next slide shows data on three different samples of oils processed by the PCBX rig in the storage yard of Ohio Transformer. These runs were made during a latter portion of the development work. Please note that the inhibitor levels are at a minimum value for the three samples. Even so, the sludge and acid concentrations, as measured by TAN, meet the specification levels for new and used oil. In the worst case the samples are at a just fail level. If inhibitor had been added to the permitted levels, the oils would have easily passed this accelerated test.

Another laboratory test was used to demonstrate the effect of PCBX on the straight mineral oils which can be described as the base oils for manufacturing NEMA I and II oils. The Rotating Bomb Oxidation Test, D 2112, was modified by running the test at 110°C instead of the usual 140°C. In the next slide are test results with oils which could be inhibited to meet NEMA Type I and II specifications. You see the data would indicate that PCBX actually improves the quality of oil, as indicated by the greater length of time it takes for the pressure drop in the test. However, we will not go so far as to claim quality improvement over that of new oil, but we strongly believe that PCBX is not harmful to the stability characteristics of the oils themselves. Again, note that these results were obtained with oils which contained no added inhibitor.

Additional tests of a longer term nature are in progress. We have under evaluation transformers filled with oil which has been processed by PCBX. These transformers are energized and are being carefully monitored. The results are excellent.

Depending on the PCB contaminants in the dielectric fluid, a transformer under the current regulations can be classified either as a PCB contaminated item or as a PCB item. A transformer classified as a PCB item

causes a special concern to its owner. The transformer cannot be repaired if it has problems requiring servicing; it must be replaced. It must be carefully emptied, rinsed, and hauled away to an approved burial site. The fluid and solvent must also be disposed of by incineration or solidification and buried in an EPA-approved land fill. This represents a considerable cost in operational expenses, a loss of capital in the buried equipment, and an additional capital expenditure for the new equipment. Regardless of the problem, PCBX can be used to decontaminate a contaminated transformer or for the reclassification of a PCB transformer to a non-PCB item.

Sunohio has been operating its PCBX process commercially for the past three to four months. Its mobile rigs have operated successfully at large public utilities and industrial organizations during that period. There will be five rigs on the road by the end of 1981, operating in the EPA regions which have approved the PCBX process. Sunohio has the capability of constructing and fielding several new rigs each month to satisfy the market.

Sunohio has been cooperating with Environment Canada, the equivalent of the United States EPA, while they examine the PCBX process for approval in Canada.

Discussion

Q. What is the cost of processing contaminated transformer oil?

A. $3. to $7. a gallon, depending upon volume, contamination level, type tank, handling requirements, etc.

Q. What are the by-products?

A. Inorganic salt - non-toxic material. Sunohio is responsible for disposal of waste and process by-products.

Q. What are the power requirements for your trailer?

A. The trailer is not self-contained. It requires a 440 volt-100 amp. service connection.

Q. Do you accept askarel?

A. No; Mineral oil only. The process would be satisfactory for destruction of askarel but not with this trailer. Sunohio is not now planning to treat pure askarel. The current permit is for treating "mineral oil containing PCB's" only.

Q. How high contamination level have you processed?

A. Commercially, about 1300 ppm. The limit for the current trailer is not established, but it probably is not in the 10,000 ppm range, as the unit is now operated.

Q. What EPA regions have granted approval?

A. Regions 1, 4, and 7 have approved. We expect all Regions will have approval soon.

Slide 1

Process Objectives
for
PCB Elimination

-- Chemical destruction of PCB's
-- Environmentally safe waste products
-- Non-destructive to the dielectric fluid
-- Maintain electrical insulating qualities of the fluid
-- Portable process which can be mobile rig mounted

Slide 2

Exterior View of Mobile Rig (Not Included)

Slide 3

Interior View of Mobile Rig (Not Included)

Slide 4

Flow Diagram (Not Included)

Slide 5

Stability of PCBX Treated Oils
Development Sample Analyses

Test	Test Method	Sample No. 1508	1539	1546	New Oil Limits I	II	Used Oil Limits
Inhibitor	D2668	0.02	0.02	0.04	0.08	0.3	0.3
Oxid. Stability	D2440						
72 Hours							
Sludge %		0.063	0.064	0.051	0.15	0.10	-
TAN		0.452	0.456	0.442	0.50	0.30	-
164 Hours							
Sludge %		0.116	0.125	0.153	0.30	0.20	0.25
TAN		0.552	0.525	0.622	0.60	0.40	0.50

Slide 6

Oxidation Stability*

PCBX Treated Oils
(Non-Inhibited)

Oil Type		Minutes at 110°C 1	2
I	Before Treatment	307	415
	After Treatment	330	427
II	Before Treatment	130	120
	After Treatment	165	152

*Modified Rotating Bomb Oxidation Test (RBOT) (D2112)

PHILADELPHIA SOLUTION TO A NATIONAL PROBLEM

J. J. Garland
PHILADELPHIA ELECTRIC COMPANY

Philadelphia Solution to a National Problem

J. J. Garland, PECO

In the Fall of 1980, Franklin Institute Research Laboratories (FIRL) of Philadelphia and Philadelphia Electric Company (PECO) signed an agreement to pool their resources on a PCB destruction process. As part of the agreement, PECO erected a PCB destruction facility at their Oregon maintenance facility, where transformers have been repaired and transformer oils reprocessed for many years.

The destruction facility was specifically designed to implement a reagent developed at FIRL. The reagent, NaPEG™, was undergoing tests in FIRL's laboratories, and looked most promising. Subsequently, FIRL erected a pilot plant to produce NaPEG™ in Elverson, PA some 25 miles from central Philadelphia.

FIRL and PECO filed a joint application with Region 3 of the Environmental Protection Agency (EPA) in May of 1981, seeking permission to demonstrate the NaPEG™ process on transformer oils, with increasing levels of PCB contamination. The application was approved in the Fall of 1981.

To date, EPA demonstrations have been conducted at two levels of contamination, 225ppm PCB's and 590ppm PCB's, and reduced the level of contamination to zero detectable. In addition, the process created no environmental hazards either while being conducted, or in the final residue. Finally, the processed oil has better insulating characteristics than it exhibited prior to processing, and shows no evidence of new elements which would make its re-use questionable.

A third run with 6800ppm PCB's was invalidated by a valving error at completion, which contaminated the clean oil. Interim readings indicate that the process was again successful, but the run will be repeated.

While the demonstration program calls for two more runs, at levels up to 50,000ppm PCB's, EPA has indicated that PECO may apply for a batch processing permit after the third run, so that processing of contaminated oils can be implemented. FIRL is continuing with laboratory work to optimize the NaPEG™ process.

The advantages of the NaPEG™ process, in addition to destroying PCB's while retaining good oil, are the comparative simplicity of the process, the absence of any free sodium, and the compactness of the processing facility, which could be made portable if conditions warranted.

Discussion

Q. What Permits do you have?

A. This permit was for a test demonstration only.

Q. Can the process be used for spill clean-up?

A. Contaminated Axpole was painted three weeks ago. Test Readings are scheduled for December 10, 1981.

Q. Do you expect to reuse the treated oil?

A. Yes. In low voltage equipment.

RAPID CLEANSING OF PCBs FROM TRANSFORMER WINDINGS

G. Tappa
J. Olmsted
Positive Technologies Inc.

Rapid Cleansing of PCBs from Transformer Windings

G. Tappa
J. Olmsted

PCB REMOVAL FROM TRANSFORMERS - PAST HISTORY

Until now, removal of PCB fluids from transformers was hindered due to the physical limitations of cleansing techniques. Just emptying the PCB fluid (askarel) from a transformer and refilling with another fluid would not come close to satisfying the United States Environmental Protection Agency's requirements for transformer reclassification. (These requirements call for PCB levels to fall below 500 PPM for a transformer to be classified rebuildable ["PCB Contaminated Transformer"] or below 50 PPM to be considered clean ["Non-PCB Transformer"].) Such simple refilling (or retrofilling) of a PCB transformer would bring it down only to a level of about 5 to 7% PCB contamination (50,000 to 70,000 PPM), 100 to 1,000 times more contaminated than acceptable to the EPA.

Proper rinsing or flushing techniques occasionally were able to reduce PCB concentrations to from 2 to 4% (20,000 to 40,000 PPM), still far above EPA requirements.

(Unfortunately, high volumes of solvent are required to properly flush a transformer. These volumes become PCB contaminated, and must be disposed of as PCB liquid waste.)

Finally, some companies have attached an active filter to the transformer after it had been retrofilled to further reduce concentrations of PCB. These filters have reportedly been able reduce PCB concentrations down slightly below 1%, and may over a period of <u>years</u> be able to bring levels below 500 PPM.

(These filters become PCB solid wastes, requiring disposal.)

WHY DON'T AVAILABLE METHODS CLEAN TRANSFORMERS COMPLETELY? AND WHY DON'T THEY STAY CLEAN?

First, askarel sticks to the surface of just about everything.

(Good rinsing procedure with the right solvents will probably dislodge the great majority of fluid sticking to steel, etc.)

Second, liquid filled transformers were designed to operate full of fluid, not to be drained bone dry. The bottom of a transformer is basically flat, rather than tapered towards a drain. The cooling fins or radiators often have small reservoirs at their bases where liquid will collect. The base of the core of the transformer is welded onto angle iron which may form additional reservoirs.

(Good rinsing will not do quite as well here.)

Third, there are <u>thousands</u> of nooks and crannies within the core and coil assembly of <u>any</u> liquid filled transformer. Hundreds of these openings are specifically designed in to provide cooling, while most others are there as an incidental side effect of the manufacture of the unit.

(Because these openings are usually small and hidden within the center of the transformer, flushing often cannot reach them well enough to promote effective cleaning.)

Fourth, and most important, transformers are full of porous cellulose materials (wood, linen, and paper), which over a period of time have absorbed liquid PCB <u>into their pores</u>. These millions of pores will retain approximately two percent of the liquid volume of the transformer.

(No amount of flushing can cleanse these pores properly. Only months and <u>years</u> of continuous contact with new, clean fill liquid and continuous physical and thermal agitation would cause the small, but significant amounts of PCB to "leach" out of the cellulose. Once out, this PCB increases the contamination of the new fluid, and causes it to be unacceptable.)

THE Zero/PC/Forty REVOLUTION

Basically, it is impossible to use conventional techniques to clean transformers to a satisfactory level because liquids cannot penetrate into the minute openings where PCBs hide. Zero/PC/Forty (patent pending) can, because it transforms its cleansing material into a gas to penetrate into those locations within the transformer where fluids cannot reach.

A precise combination of liquid sprays, rinses, and soaks interspersed with gas bombardment of transformer interiors now allows transformers to be reduced to 500 PPM and below with treatments lasting only five days.

The Zero/PC/Forty uses much greater volumes of cleaning solution than other cleaning methods to achieve more thorough cleaning. It generates far less liquid PCB waste, however, because Zero/PC/Forty removes PCBs from its solutions as it operates. The "TPF Solvent" used by Zero/PC/Forty is in a continuous regeneration mode removing PCBs from our TPF solvent to less than one part per million.

THE Zero/PC/Forty HARDWARE

The Zero/PC/Forty processor is actually two portable units that are connected once they have been positioned near the transformer to be cleaned. Both the "Storage" and "Activator" sections are approximately six and one half feet tall, six feet long, and three feet wide. Each of the units weighs about 900 lbs. empty and 3,000 lbs. full of cleansing material. Each unit is on wheels and has lifting eyes so that it may be easily moved into position.

The Storage unit actually contains most of the controls, valves, actuators, timers, alarms, sensors, etc., that make the process operational. It requires a power supply of 240 volt, single phase, 100 amperes. It is connected to its sister unit, the Activator, by a series of hoses, wire cables, thermocouple leads, and pressure tubing. The Activator is in turn connected to the transformer by a 4" hose and other similar sensors, etc. The transformer itself is fitted with a network of valves, spray nozzles, pressure and temperature probes, and insulation.

Each Zero/PC/Forty processor package is designed to clean and retrofill a transformer of up to 300 gallon capacity. Larger transformers can be accommodated by either "piggy-backing" two or more sets of processors or by adding expansion units.

Expansion units are identical in size to the original units, but weigh about 650 lbs. each, and do not contain instrumentation or control. Each additional set of expansion or piggy-back units will require an additional 80 amperes.

Zero/PC/Forty RETROFILLING OF A PCB TRANSFORMER

Proper cleaning of a PCB filled transformer will require that the transformer first be drained of its liquid, then be processed for four days, be filled slowly at a high temperature, and be allowed to settle for a period of at least four hours before energizing. In addition to the original volume of PCB liquid, approximately 30 gallons of high PCB concentration fluid will have to be removed from the processor and disposed of.

All of the above steps will be done by the Zero/PC/Forty processor, except the original draining of the transformer.

Zero/PC/Forty RETROFILLING OF A HIGHLY PCB-CONTAMINATED OIL TRANSFORMER

Essentially, this will be done as above, except that the processing time could be reduced, depending on the contamination level.

Zero/PC/Forty PREPARATION OF A PCB TRANSFORMER FOR SCRAPPING

Preparation for scrapout would be done in the conventional manner, first emptying the transformer of askarel and packaging it for disposal, then filling it with TPF solvent. A minimum of eighteen hours later, the TPF would be removed from the transformer and be routed through the Activator unit to have the TPF solvent extracted from the solution (at a rate of 30-40 gallons per hour). The remaining PCBs would be packaged for disposal, a small fraction of the original volume of the transformer.

TRAINING

Customers acquiring Zero/PC/Forty processors will be required to provide for the training of sufficient personnel to assure that the processor will be properly operated and maintained at all times. For the first unit, two employees must be certified. For each additional processor, one additional employee must be certified.

Training will consist of a three day program to be presented in locations throughout the U.S. Each program will be held at a major hotel in the area, with lodging and all meals provided by Positive Technologies, Inc.

The first day of the training will include a thorough coverage of PCB rules and regulations, and their application in the real world. Each student will receive a copy of "PCB Regulations Made Understandable," a complete text of all Federal PCB regulations fully documented, cross-referenced, and indexed, and with a publisher's list price of $175.

Speakers will address such subjects as:
1) What are the current Federal regulations?
2) How are they being enforced?
3) How may PCB owners comply reasonably with the regulations?
4) What will future regulations probably require?
5) How may PCB owners best prepare for these changes?
6) How do individual state regulations differ from the federal?

The second day will include full information on the retrofill of transformers.

The third day will include full instruction on the use and maintenance of the Zero/PC/Forty system.

At the end of each day, a test will be given to those persons attending for certification. A complete knowledge of the material will be expected. If the employee does not have a grasp of the material, an additional fourth day of training and testing will be provided. If he/she still is not in command of the material, no certification will be given.

Cost of the seminars is $1,800 per employee. If the employee satisfactorily completes the course in the initial three day period, a $300 rebate will be refunded to his employer.

Certified operators will be expected to take a one day refresher course each year at a cost of $600.

For those wishing only to take the extensive first day of the course and receive the book, "PCB Regulations made Understandable", the cost will be $400. Certification of completion of this course will be provided.

Discussion

Q. Do you have published data on your results?

A. No. Results of tests are not completed.

EXPERIENCES IN HIGH EFFICIENCY UTILITY BOILER INCINERATION OF PCBs

W. C. Renfro
Northeast Utilities

For presentation at EPRI PCB Seminar December 1-3, 1981, Dallas, Texas

Experiences in High Efficiency Utility Boiler Incineration of PCBs

William C. Renfro
Northeast Utilities

Introduction

This paper describes our experiences in meeting regulatory requirements, surmounting local opposition, and, finally, burning PCB-contaminated waste mineral oil in our Middletown Unit 3 boiler in Connecticut. Northeast Utilities, consisting of several operating companies in Connecticut and Massachusetts, accumulates unsalvagable mineral oil from distribution and substation transformers in large quantities each year.

When the second set of PCB regulations became effective in July 1979, utilities were presented with three alternative means to dispose of waste transformer oil having 50-500 parts per million PCB concentrations. Because our Transformer Maintenance Department estimated some 30,000 gallons of this "PCB-contaminated oil" would be generated in the system each year, we began to seriously consider the benefits and costs of each of three alternatives:

1. Incineration in an EPA-approved PCB incinerator;

2. Burial in EPA-approved chemical waste landfills; or

3. Qualifying a high efficiency power plant boiler.

We chose the last option for a number of economic, logistic, and environmental reasons, including the following:

1. No incinerators were approved for disposal of PCBs by EPA.

2. Transport to then available chemical waste landfills would:

   a. be expensive;

   b. involve greater risk of spills;

   c. waste the energy content of the oil;

   d. not destroy the PCBs; and

   e. involve at least a slight risk of eventual groundwater contamination.

3. Most plants in the NU system could meet the EPA criteria.

Choosing a High Efficiency Boiler

By late 1979 we had concluded that burning PCB-contaminated oil at one of Northeast Utilities' 18 oil-fired boilers was the most reasonable and cost-effective choice. After engineering evaluations of all our plants, Middletown Unit 3, a 233 MW Babcock and Wilcox, five-cyclone boiler was chosen because of its:

1. Central location in our service area;

2. High operating temperatures (greater than 3000°F in the cyclones decreasing to greater than 2000°F at the top of the furnace before entry into the superheaters);

3. Long residence times (calculated to be longer than 1.6 seconds);

4. Elevation above the 100 year flood level (permitting storage of PCBs on site); and

5. High capacity factor (insuring availability for use in burning PCB-contaminated oil).

Qualifying the Boiler

In early 1980, we began to engineer oil storage and feed systems at the plant. An 8,700 gallon tank to handle PCB-contaminated oil was placed inside an impervious concrete retention basin with sufficient volume to contain the volume of the tank plus rain from a 100 year storm. A positive displacement gear pump was installed inside the retention basin to transfer oil from the tank to an independent injection nozzle in one of the cyclones. Appropriate control room instrumentation, sensors, alarms, and pump trips were incorporated into the system to ensure that the mineral oil feed rate remained below 10% of the fuel oil feed rate and that mineral oil injection tripped off when the boiler operating level fell below 75% of full power.

In April 1980 the unit was operated at loads of 100%, 88%, and 77% for two hours each to measure excess oxygen and carbon monoxide in the exhaust gases in the breechway to the stack. These tests confirmed that the boiler conditions met EPA criteria because the stack gas oxygen concentration remained above 3% and carbon monoxide was below 50 parts per million (actually always zero).

To guarantee smooth operation of the project, detailed written procedures and checklists were prepared. These supplemented other, corporate-wide procedures for handling PCBs, spill cleanup, storage, reporting, Spill Prevention Control and Countermeasure Plans, and recordskeeping.

Finally, a 30 page Environmental Evaluation of the entire project was prepared. This report provided a detailed description of why and how the PCB-contaminated oil would be burned. A Northeast Utilities atmospheric dispersion model was applied to four years of actual meteorological tower data from the site, together with an assumed 99.995% PCB destruction efficiency (gleaned from the literature), to project worst-case ambient air concentrations of PCBs and hydrochloric acid. The results showed that under worst-case assumptions the highest ground level concentration in any of the 440 square kilometers in a 20 x 20 kilometer grid around the plant would amount to 3.9×10^{-5} micrograms per cubic meter for PCBs and 0.4 micrograms per cubic meter for hydrochloric acid. Thus, the highest possible ambient PCB concentration amounted to about one twenty-five thousandth of the occupational standard recommended by the National Institute of Occupational Safety and Health. We did not predict any ambient levels of partial decomposition products of PCBs (such as furans),

because the combustion conditions were adequate for total breakdown of these molecules.

Communicating with EPA and Other Officials

By early May 1980, all of the written procedures, stack gas test results, and environmental evaluations were ready to be submitted to the EPA as the required notification of intent to burn PCB-contaminated oil. Although we had some previous discussions about the project with EPA and Connecticut Department of Environmental Protection (DEP) officials, there had been no communication with local communities. When the issue of possible early discussions with officials of the communities in the plant's vicinity was raised within the company, two points of view were expressed. The first was that no state or federal regulations required such prior notification and to publicize the project plans would precipitate opposition. The second viewpoint held that, although an early open discussion with the local communities might produce some controversy, taking the initiatives in a forthright fashion would prevent a later media "expose" and would place the company in a better position to deal with opposition as it developed. The latter viewpoint prevailed and on June 13, 1980 a company representative visited the mayor and health director of Middletown, to inform them of our intent to submit notification to the EPA, and to offer to describe the PCB-contaminated oil burning plan to any other community officials they deemed appropriate. Four days later, on 17 June 1980, our notification of intent to burn was mailed to the EPA and identical documents were hand carried for discussion to the DEP and city officials of Middletown.

Subsequent Controversy

As must be evident from the preceding account of our preparations for this project, we planned and implemented it to the best of our technical abilities and with reasonable foresight for public concern, given the innocuous nature of the project. However, the next 10 months brought much more controversy, delay, expense, and litigation than we anticipated. For the benefit of others, who may be anticipating disposal of PCBs, other toxic substances, or hazardous wastes, a chronology of our experiences is attached as an appendix. In brief, opposition to the project, led by the same city officials and local politicians we had voluntarily attempted to work with, built up rapidly and was sustained by constant news media attention. We were fortunate to gain early approval and support from the state DEP. After a number of meetings with the EPA and agreeing to several of their requirements, we also got their approval for the project. Still, it was necessary to go through months of debate and to prevail in two lawsuits before burning any PCBs. (See appendix for details).

Experience in Burning

We burned approximately 17,000 gallons of oil averaging 80 parts per million in PCBs in late February 1981, without incident. Thus, we joined Potomac Electric and Power, Duke Power, Union Electric, and Baltimore Gas and Electric Companies in this activity. (The state of Maryland had taken the position that the PCB-contaminated oil is boiler fuel, not toxic substance). In early July 1981, we burned an additional 15,000 gallons of 75 parts per million PCBs, again, without incident.

However, we were soon faced with another form of opposition. Toward the end of the Connecticut state legislative session in May 1981, several special bills were proposed to ban burning of PCBs in the state except in special approved incinerators. Although these bills were all narrowly defeated, it became necessary to agree to a special program of sampling and analyses for PCBs, polychlorinated dibenzofurans (PCDFs) and polychlorinated dibenzo-para-dioxins (PCDDs) during a PCB-contaminated oil burn.

We had previously argued against suggestions that the effectiveness of the burning operations would be enhanced by monitoring the stack effluents for PCBs, PCDFs, and PCDDs. We pointed out that the definitive tests had already been performed at Bay City, Michigan and further tests would be duplicative and expensive. Further, all previous experimental data and actual stack analyses showed that if any unburned PCBs escaped destruction their concentrations would be below detectable levels. Nevertheless, we were forced into performing a state-of-the-art program of stack gas sampling and analysis. A Scope of Work was prepared that built on the Bay City experience and proposals were elicited from experienced, highly competent vendors.

The sampling protocol involved simultaneous use of both modified Method 5 and Source Assessment Sampling System (SASS) trains during an 8-hour preliminary test without transformer oil and three 8-hour burns of PCB-contaminated mineral oil. These stock samples were taken in early September 1981 during three days of PCB-contaminated oil burning in which about 8,000 gallons were burned each day (PCB content: 380, 220, and 220 parts per million on respective days).

The gas chromatographic/mass spectrometric analytical results were completely encouraging. No PCBs, PCDFs, or PCDDs were detected in any sample. Based on the minimum detectable limit of the sampling and analytical methods the destruction of PCBs in this high efficiency boiler was greater than 99.997 percent.

Lessons Learned

As we stated from the start of this project, Northeast Utilities believed that destruction of PCBs in waste transformer oil in an appropriate utility boiler is a safe, economic, and environmentally compatible process when carried out according to EPA regulations. Our experience during this extended and sometimes bitter controversy has led us to a few conclusions, including the following:

1. Careful planning and effective communication about the project are essential. Personnel within the company should agree on all parts of the project, including position papers and public communications.
2. Open, forthright public discussion is imperative as each issue arises (where possible, issues should be anticipated).
3. Concerns expressed by private citizens and politicians should be addressed promptly and adequately.
4. Above all, such a project should not be attempted without clean and unwavering support from the company's upper management.

Discussion

Q. Will you accept oil from others?

A. No. Our committment to the local community is to burn only our own oil, as required.

Appendix 1

A chronology of significant events in Northeast Utilities' project to burn PCB-contaminated transformer oil at Middletown Unit 3.

Day 0 ... submittal of Notice of Intent to burn, 17 June 1980.

Day 3 ... local newspaper carries story of the project using data from the notification document.

Day 8 ... local officials are reported by newspaper article to be inquiring of state and federal regulators about the project and some town councilmen express concern about air quality effects.

Day 9 ... state air pollution engineer, uninformed about PCBs, expresses concern to a newspaper reporter that "in the right place at the right time the incineration could be lethal." On the following day high level state agency officials repudiate this concern.

Day 11... state Department of Environmental Protection Commissioner announces his agency's approval of the project.

Day 16... Middletown Mayor in a press conference calls for delay and threatens injunction - various state and U.S. politicians join him in opposition. A Wesleyan University chemistry professor references a Dow Chemical Corporation report to suggest dioxins might be released during PCB burning.

Day 17... from this day onward each new day brought more media coverage of the burgeoning controversy, such as: newspaper articles, T.V. news coverage, editorials, letters to the editor, news conferences with candidates for political office, citizens' petitions, student rallies, and responses from the company and regulatory officials.

Day 20... city officials state that zoning regulations require a permit to store or dispose of PCBs and other wastes.

Day 28... company officials meet with city officials and university advisors for a detailed discussion of all aspects of the project. We answered all questions but the next edition of the local paper quoted them as havng new as well as previous questions about safety of the project.

Day 29... EPA acknowledges NU's notification and requests a 30 day delay in responding in order to study the documents and await results of EPA-sponsored stack tests at Bay City, Michigan. NU agrees.

Day 37... Area Director of OSHA states to reporters that he is concerned about occupational safety of plant workers during PCB burning. When contacted, he had no questions.

... NU meets with EPA Region I staff for a detailed discussion of all issues in the Middletown PCB burning project. EPA agreed to send a letter confirming the sufficiency of the NU project following receipt of some additions to the project procedures, none of which were particularly difficult.

Day 43... mayor and city officials are given a briefing and tour of the plant to observe the PCB-contaminated oil plumbing system.

Day 44... a public workshop was convened in which NU, EPA, DEP, and officials from interested communities discussed all aspects of the problem. At the end of this meeting there appeared to be no unanswered technical questions about safety or environmental compatibility, yet the following day newspapers quoted some of the city officials as having continued concerns.

Day 47... NU is served with subpeonas and a city suit to enjoin it from burning PCB-contaminated oil.

Day 63... an extended public meeting was held in Middletown with a panel representing the city, EPA Region I, EPA-Headquarters, DEP, university advisors to the city, and NU. Many citizens made statements in opposition and presented petitions to stop the project.

Day 65... Goodyear Tire and Rubber Company announces development of a chemical method to destroy PCBs in oil, prompting opponents of the NU project to call for its abandonment. After a detailed evaluation, NU provides a report on Day 73 with reasons the Goodyear method is inappropriate for disposal of its PCB-contaminated mineral oil.

Day 79... Middletown Superior Court trial of a suit to enjoin the NU project begins and requires all or parts of 10 days of testimony of 15 witnesses.

Day 139.. Middletown Common Council passes a surprise ordinance banning transport of hazardous wastes on designated city streets. The ordinance is clearly aimed at blocking PCB-contaminated oil transported to our plant. Later NU successfully brought suit to enjoin enforcement of this ordinance.

Day 200.. Middletown Superior Court Judge dismisses all the complaints brought by the city in the preceding court trial.

Day 260.. as part of an agreement outside regulatory requirements between EPA and the company, a large scale PCB spill and cleanup demonstration was carried out at the plant for the EPA, DEP, city officials, politicians, and news media. A complete trial burn was also performed using non-PCB oil to demonstrate efficacy of the system.

Days 278, 280, 284..approximately 17,000 gallons of PCB-contaminated oil was burned at the plant without incident.

Day 294.. Northeast Utilities publishes a half page advertisement in two major newspapers to provide all concerned citizens with an overview of this long, controversial affair.

FIELD OPERATION OF PPM, INC.
MOBILE UNIT FOR DECONTAMINATION OF PCB CONTAMINATED SOILS

L. Centofanti
Southeastern Technologies, Inc.

FIELD OPERATION OF PPM, INC.
MOBILE UNIT FOR DECONTAMINATION OF PCB CONTAMINATED OILS

Dr. Louis Centofanti
Southeastern Technologies, Inc.
Suite 220
1955 Cliff Valley Way, N.E.
Atlanta, GA 30029-1401

A variety of laboratory processes have been proposed for the decontamination of PCB oils. Most of these processes require high temperatures, flammable solvents, toxic and hazardous materials or mixing incompatible material (sodium and oxygen) and would suffer from operational problems on a commercial scale. To overcome these problems, Southeastern Technologies, Inc. of Atlanta, Georgia has developed a new process which overcomes most of these problems. PPM, Inc. was formed as a joint venture between Southeastern Technologies, Inc. and Development Resources, Inc. of Kansas City to build mobile units and market the process.

The mobile unit takes contaminated oils (up to 2000 ppm) and chemically destroys the PCB's producing a reusable oil, an aqueous solution and small amounts of solids. Small volumes of oil produced by the process have passed all the standard transformer tests to which it has been subjected. Because of the uncertainties of long-term effects, at this time we recommend the use of the oil only as a fuel.

For our first commercial run and as our EPA demonstration, Kansas City Power & Light agreed to allow us to clean over 17,000 gallons of contaminated oil they were storing. The oil contained about 230 ppm of Aroclor 1260 and 1242, and was a mixture of transformer oil, fuel oil, and various flushing oils. KCP & L had approached another firm with an approved chemical process about decontaminating the oil, but the firm would not treat the oil. Because of the presence of fuel oil, the KCP & L oil is very difficult for other processes to treat. The Southeastern Technologies process is designed to handle problem oils.

Field tests of the PPM, Inc. mobile unit at KCP & L lasted one and a half weeks. The unit operated successfully, and PCB levels were reduced to undetectable levels. EPA has taken samples and is presently evaluating the process for approval. Initial economic analysis of the field test indicates that the mobile unit will be easily competitive with other chemical processes and other methods of disposal.