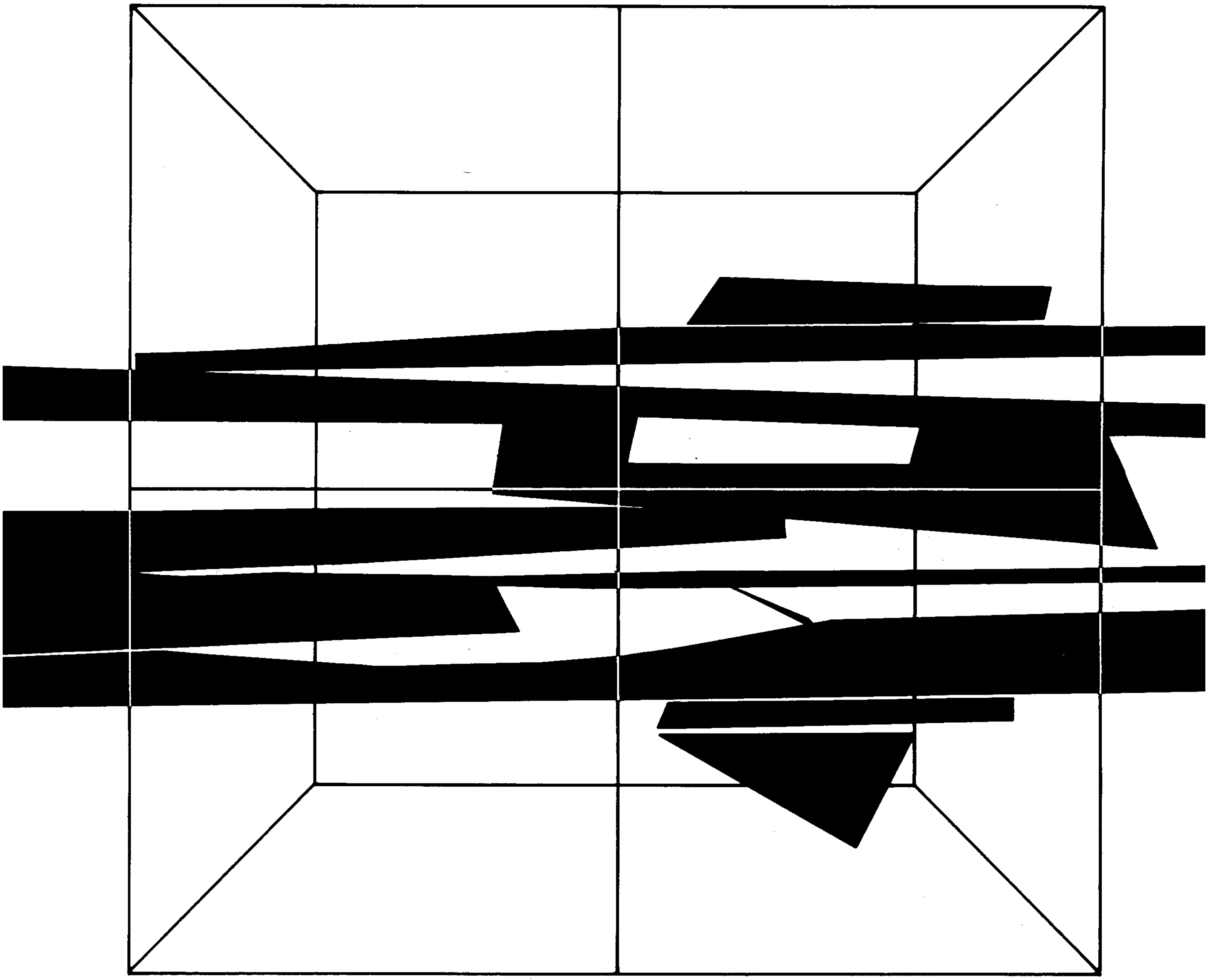
The Evaluation of Mobile and Stationary Facilities for the Destruction of PCBs

Report EPS 3/HA/5
May 1989



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THE EVALUATION OF MOBILE AND STATIONARY FACILITIES FOR THE DESTRUCTION OF PCBs

by

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for

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ABSTRACT

This report provides an up-to-date appraisal of polychlorinated biphenyl (PCB) destruction technologies. Over 60 companies and organizations were surveyed to obtain information on processes that destroy PCBs contained in both liquid and solid wastes. The information was reviewed, the technologies evaluated and the status of each technology identified as commercial, near-commercial or promising.

Stationary rotary kiln incineration with flue gas treatment has been proven commercially at several U.S. and European facilities. Three stationary industrial hazardous waste facilities which will incinerate PCB wastes are under development in Canada. Eight North American companies were identified that offer near-commercial mobile/transportable destruction technologies. Mobile, sodium-based and PEG/KOH (poly(ethylene glycols)/potassium hydroxide) processes for the decontamination of PCB-contaminated oil are considered proven commercial PCB destruction technologies. Four companies operate mobile facilities using PCB-contaminated oil dechlorination technologies in Canada. Promising technologies for the treatment of PCB solid wastes are low-temperature oxidation, chlorine removal, vitrification, biodegradation and thermal extraction.

RÉSUMÉ

Le présent rapport porte sur les techniques actuelles de destruction des biphényles polychlorés (BPC) contenus dans des déchets liquides et solides. L'information de base sur ces techniques a été obtenue auprès de plus de 60 entreprises et organismes. Un examen de l'information a permis d'évaluer les techniques existantes et de faire le point sur leur développement: elles existent au stade commercial, au stade pré-commercial et au stade de la mise au point (à fort potentiel).

L'incinération en installation fixe dans un four rotatif avec traitement des gaz de carneau a fait ses preuves dans plusieurs entreprises américaines et européennes. C'est pourquoi trois usines de traitement des déchets industriels dangereux pour l'incinération des BPC sont en voie de réalisation au Canada. Il existe en Amérique du Nord huit entreprises qui possèdent des installations de destruction mobiles ou transportables au stade pré-commercial. La décontamination des huiles contenant des BPC à l'aide des procédés au sodium et au PEG/KOH (glycols de polyéthylène/potasse) est considérée comme une Technique éprouvée dans les installations mobiles commerciales. Quatre entreprises exploitent des installations mobiles de déchloruration des huiles contaminées par des BPC au Canada. Les techniques les plus prometteuses pour le traitement des déchets solides de BPC incluent l'oxydation à faible température, la déchloruration, la vitrification, la biodégradation et l'extraction thermique.

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NOTICE

This report on the evaluation of PCB destruction technologies is an update of a previous report on this subject, which was prepared jointly under contract with Environment Canada by ORTECH Corporation, Envirochem Services and Monenco Consultants Limited.

The report has been reviewed by the Technology Development and Technical Services Branch, Environment Canada, and approved for publication. Approval does not necessarily signify that the contents reflect the views and policies of Environment Canada. Mention of trade names or commercial products does not constitute recommendation or endorsement for use.

READERS' COMMENTS

Readers who wish to comment on the content of this report should address their comments to:

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SUMMARY

This report identifies and evaluates existing polychlorinated biphenyl (PCB) destruction technologies suitable for immediate application in Canada. Operating requirements, performance, economics, and other pertinent characteristics of the various technologies are given, with emphasis on mobile technologies to destroy wastes containing relatively high concentrations of PCBs.

Three categories of destruction technologies are defined. A commercial technology is defined as one that has successfully destroyed PCB-containing wastes under sustained routine field conditions for at least one year in Canada or elsewhere. A near-commercial technology is defined as one for which a permit application for commercial operation has been submitted in a North American jurisdiction. A third technology category, promising, is also identified. The availability of information for all technology categories depended on the development status of the technology, the status of the regulatory permit process, and the willingness of companies to release technical and economic data.

Technologies for the destruction of PCB wastes are classified as thermal destruction, which is either stationary, mobile/transportable, or incineration-at-sea; chemical oil treatment; and alternative PCB solid waste treatment.

Tables S.1, S.2 and S.3 list the PCB destruction technologies evaluated by category and classification.

The status of the PCB destruction technologies can be summarized as follows:

Stationary Destruction Technologies

- Stationary rotary kiln incineration with flue gas treatment has been proven for PCB destruction at several American and European facilities. These facilities have operated in the U.S. since 1981 and in Europe since 1975 and have undergone extensive regulatory monitoring and assessment during the successful destruction of all types of PCB wastes.

- Three stationary industrial hazardous waste facilities are under development in Canada: the Alberta Special Waste Management Corporation, the Ontario Waste Management Corporation (OWMC), and the Selenco/Sanivan Group (Quebec). It is anticipated that the Alberta facility will commence commercial treatment of Alberta PCB wastes in 1988. The Selenco/Sanivan Group are planning to receive Canadian PCB wastes in 1988 and to commence commercial destruction in 1990.

TABLE S.1 SUMMARY OF THERMAL PCB DESTRUCTION TECHNOLOGIES

PCB Destruction Technologies	Commercial	Near-Commercial	Promising/ Developing
Stationary	- Ensco Environmental Services - Hessian Industrial Waste Inc. (HIM) - Kommunekemi - Pyrochem - ReChem International (IEM Corp.) - Rollins Environmental Services - SAKAB - SCA Chemical Services	- Alberta Special Waste Management Corp.* - Arc Technologies Co. - Selenco/Sanivan Group*	- Ontario Waste Management Corp.*
Mobile/ Transportable		- Ensco Environmental Services MWP2000 - Haztech, Inc.* - IT Corp. - Ogden Environmental Services, Inc. - O.H. Materials, Inc.* - Riedel Environmental Services* - Selenco/Sanivan Group* - Shirco Infrared Systems, Inc.	- Vesta Technology Ltd. - Westinghouse Electric Corp.
Incineration at Sea		- Chemical Waste Management, Inc.	

* Organizations that propose to operate PCB destruction technologies designed and constructed by others. These organizations are not proponents or developers of specific technologies.

TABLE S.2 SUMMARY OF CHEMICAL PCB DESTRUCTION TECHNOLOGIES

PCB Destruction Technologies	Commercial	Near-Commercial	Promising/Developing
Stationary Oil Treatment	- PCB Eliminators - PPM Canada, Inc. - Trinity Chemical Co.		
Mobile Oil Treatment	- Chemical Decontamination Corp. - Chemical Waste Management, Inc. - Excel Tech Inc. - PPM Canada, Inc. - Rondar, Inc. - Selenco/Sanivan Group - Sun Environmental Ltd. - Transformer Consultants	- General Electric Co. - IT Corp. - Ozonics Technologies Inc.	

TABLE S.3 SUMMARY OF ALTERNATIVE PCB SOLID WASTE TREATMENT TECHNOLOGIES

PCB Treatment Technologies	Commercial	Near-Commercial	Promising/Developing
Biodegradation	- Detox Industries, Inc.		- Bioclear Corp.
Chlorine Removal			- Galson Research Corp.
Low Temperature Oxidation			- Modar, Inc.
Solvent Extraction			- Acurex - O.H. Materials, Inc.
Thermal Extraction			- SRH Associates, Inc.
Vitrification			- Battelle Pacific Northwest Laboratory

The commercial treatment of Ontario PCB wastes is scheduled to commence in 1991 at the OWMC facility.

Mobile/Transportable Destruction Technologies

- Eight North American companies have near-commercial mobile/transportable destruction technologies. Rotary kilns and circulating bed combustors are capable of handling liquid and solid PCB wastes. The infrared system can currently treat only PCB-contaminated soils and sludges. The plasma pyrolysis system can handle only liquid PCB wastes.

Incineration at Sea

- Ocean Combustion Service, a subsidiary of Chemical Waste Management, Inc., offers commercial PCB destruction to the European market. This company does not have a permit to operate in Canada or the U.S. Chemical Waste Management, Inc. have been negotiating with the U.S. Environmental Protection Agency for a permit and the Vulcanus I and II vessels are considered near-commercial in North America.

PCB-Contaminated Oil Treatment

- Mobile, sodium-based and PEG/KOH-based processes for the decontamination of PCB-contaminated oil are considered to be proven PCB destruction technologies. Treatment of oils with PCB concentrations exceeding 10 000 ppm is generally not economical. Four companies operate chemical treatment technologies in Canada.

Alternative PCB Solid Waste Treatment Technologies

- Alternative technologies to thermal destruction are being developed for the treatment of solid PCB wastes. Those considered promising are low temperature oxidation, chlorine removal, vitrification, biodegradation and thermal extraction.

1 INTRODUCTION

The development of hazardous waste management programs by government and industry has emerged in recent years as a national priority. Although a number of technologies have proven effective in destroying PCB wastes, and others have been proposed, the need for an up-to-date review and critical assessment of available PCB destruction technologies was identified. This report was prepared in response to that need and was undertaken as a project under the Canadian Council of Resource and Environment Ministers (CCREM) Action Plan.

PCBs have been, and continue to be, used primarily as dielectric fluids and coolants for electrical equipment and in a variety of lesser applications(1). Regulatory restrictions on the use of PCBs in Canada were initiated in 1977 with the Chlorobiphenyl Regulations No. 1, enacted under the Environmental Contaminants Act(2). These regulations restricted the use of PCBs to in-service and new electrical capacitors, electrical transformers, and associated switchgear. They also restricted use to in-service heat transfer equipment, hydraulic equipment, electromagnets and vapour diffusion pumps. In 1980, an amendment to the Chlorobiphenyl Regulation No. 1(3) prohibited the use of PCBs in new equipment and further restricted the use of PCBs in existing equipment. Effective August 1, 1985, the Chlorobiphenyl Regulation No. 2 (Product)(4) limited the maximum concentrations of PCBs (50 ppm) in specified electrical equipment when imported, manufactured or sold.

These regulations have prevented the introduction of new equipment containing PCBs and the upgrading of old equipment with new PCB fluids. The concentration of greater than 50 ppm by weight of PCBs is used to define a PCB waste that requires treatment. The primary source of PCB wastes is PCB equipment which is taken out of service. To date, the phasing-out of PCB equipment has not been regulated.

The present Canadian PCB inventory(1) indicates that significant quantities of PCB wastes require destruction and that one or more technologies are needed to handle PCB wastes such as:

- transformer and capacitor fluids containing high concentrations of PCBs,
- contaminated mineral oils containing low concentrations of PCBs,
- capacitor and other electrical equipment casings, cores and windings,
- containers used to hold PCB wastes,
- sludges, aqueous suspensions, rinsings and solvents, and
- contaminated soils, rags and other solid materials.

2 PROGRAM SCOPE AND SOURCES OF INFORMATION

This report provides a comprehensive review of available PCB destruction technologies, including current information on processes that destroy PCBs contained in both liquid and solid wastes (e.g., oils, aqueous suspensions, sludges, soils, and capacitors). Highest priority was assigned to mobile facilities for the destruction of high concentration PCB wastes, and to the identification of commercial and near-commercial facilities that can be applied immediately and are most promising for use in Canada. Less emphasis was given to other technologies (e.g., non-dedicated waste destruction facilities and incineration at-sea) for which only general information was obtained.

Selection criteria were established to identify and efficiently gather information on commercial and near-commercial PCB destruction technologies. For the purposes of this report, a commercial technology is defined as one that has successfully operated commercially for at least one year on PCB waste. Near-commercial technology is one for which a permit application to destroy PCB wastes has been submitted. For the United States, identification of these technologies was undertaken by obtaining U.S. Environmental Protection Agency (EPA) lists of permitted PCB destruction facilities and those technologies for which permit applications have been submitted. A third category of PCB destruction technologies was also defined for data gathering purposes. This category, defined as promising or developing technologies, encompasses those technologies that do not satisfy the definitions for commercial and near-commercial technologies, but nevertheless should be referenced since some of them may enter the near-commercial category in the near future.

Data gathering was undertaken for all three technology categories, but with an overall priority given to mobile facilities capable of destroying high concentration PCB wastes. In addition to U.S. EPA permit lists, Canadian provincial environment agencies and American and European technology proponents were contacted, and reports and publications on PCB destruction technologies[5-12] were reviewed to supplement the initial technology list.

Where appropriate and feasible, information was requested from the technology proponents on the following topics:

i) a description of the process, including process design specifications such as waste types accepted, feed rate, and destruction efficiency;

ii) monitoring aspects, including both process control and emission monitoring;

iii) emergency shutdown procedures and other safety features;

iv) description of operating data, including process stream emissions, potential fugitive emissions, operational requirements, economic factors, minimum and maximum throughput quantities, manpower requirements, run duration, and susceptibility to climatic conditions;

v) demonstration test results;

vi) development stage (commercial, near-commercial);

vii) destruction efficiency and overall performance characteristics;

viii) mobility features;

ix) names of contact personnel for each technology;

x) approvals received for commercial units and conditions for operation; and

xi) costs for PCB waste destruction.

Contacts were made with individuals by telephone or by personal meetings. To facilitate discussions with technology proponents, a list of key parameters was assembled. If a company requested further clarification of the type of information required, this list was then forwarded to that company.

The amount of information available was found to depend on such factors as the development status of the technology, the status of regulatory permitting, and the willingness of the companies to release technical and economic data.

3 AVAILABLE TECHNOLOGIES

3.1 Evaluation Criteria

In order to identify PCB destruction technologies most suitable for immediate application in Canada, several technology evaluation criteria were established. These criteria were used to select commercial, near-commercial and promising PCB destruction technologies from a long list of candidate technologies that were surveyed.

- **Operational status**

  To be categorized as "commercial", the technology must have operated successfully under sustained routine field conditions at a commercial scale for at least one year. Appropriate process control and shut-down systems must have been in place and demonstrated for effectiveness and reliability during the time of commercial operation.

  To be categorized as "near-commercial", an application for commercial operation (full-scale or pilot scale) must have been under review by government agencies in North America, or trial burns must have been under way.

  To be considered as "promising", the technology should have reached the stage of development such that it was considered that it could be applied to the commercial destruction of PCB wastes in less than two years.

- **Regulatory approval**

  Regulatory agency approval must have been obtained for the destruction of PCB wastes. These regulations usually stipulate process performance requirements. For example, the U.S. EPA requirement for the incineration of PCB solid wastes, is that PCB mass air emissions must be no greater than 1.0 milligram PCB per kilogram of PCB introduced to the incinerator. Similarly, for chemical treatment technologies, the PCB content of the decontaminated mineral oil must be less than 2 ppm.

- **Waste types accepted**

  The technology must have operated on PCB wastes representative of one or more of the actual PCB waste types and forms which require destruction in Canada, for example, PCB-contaminated oils, sludges, soils and solids and/or capacitors.

- **Canadian availability**

  The technology must be available for immediate application in Canada, within the constraints of the permit procedure in the jurisdiction of interest. Foreign technology must have been demonstrated to be accessible through a Canadian corporate office or agent.

- **Performance documentation**

  The operation of the technology must have been clearly demonstrated and documented. For incinerators, this demonstration would have included appropriate monitoring and assessment to verify that emissions of PCBs, polychlorinated dibenzofuran (PCDFs), polychlorinated dibenzo-p-dioxin (PCDDs) and other pollutants are within acceptable limits. The process must have been tested at the maximum specified feed rates and associated PCB concentrations with satisfactory performance.

  Appropriately documented and complete information and data had to be readily obtainable to confirm compliance with the afore-mentioned criteria.

All technologies identified were assessed from available information using the above criteria. Technologies with regulatory approval that had operated for one or more years were automatically classified as commercial. The first four criteria were used to evaluate and select commercial, near-commercial and promising technologies from the complete listing of technologies surveyed for potential application in Canada. Performance documentation, mobility features and economic factors were used in conjunction with the first four criteria to evaluate further the development, approval and potential for the immediate application of a technology in Canada.

3.2 Technology Evaluation

PCB waste treatment and destruction technologies may be classified into the following types:

- thermal destruction,
- chemical dechlorination, and
- solvent extraction.

Thermal technology has been used for the destruction of many hazardous organic compounds including PCB wastes. The various types of incineration systems include rotary kilns, liquid injection, and alternative thermal systems such as infrared energy, plasma arc, molten bed reactors and circulating bed combustion. These thermal technologies can be stationary, transportable or mobile.

Chemical dechlorination is widely used for the destruction of low-level PCB liquid wastes. This technology is usually used in the mobile mode to conduct on-site decontamination of PCB-contaminated mineral oil in bulk or in electrical equipment. Treatment of oils with PCB concentrations exceeding 10 000 ppm is usually technically possible but not economical.

Recently, solvent extraction technologies have been developed which can be used to remove PCBs from solid wastes such as contaminated soils, or to flush electrical equipment to remove high level PCBs. Solvent extraction is not a destruction technology but rather a treatment procedure which will remove the PCBs from the material or equipment of concern. The solvent wash solution which contains PCBs requires further treatment by thermal incineration or chemical dechlorination to finally destroy the PCBs.

In addition to these established technologies, research is being conducted to develop alternative processes for the treatment of PCB solid wastes such as soils, sludges and sediments.

A list of all technologies surveyed, by process type, is presented in Table 1. The technology types in Table 1 are stationary incineration, in-house incineration, mobile/transportable, incineration-at-sea, stationary and mobile oil treatment, and alternative PCB solid waste treatment. The in-house incineration was identified as separate from stationary commercial because technologies of this type accept only specific in-house PCB wastes, not the range of PCB wastes anticipated at a commercial facility.

3.2.1 Stationary PCB Destruction. All the commercial, stationary PCB destruction processes utilize rotary kiln incinerators. Rotary kiln incinerators are preferred over other incinerator types such as liquid injection, multiple hearth and molten salt incinerators because of their ability to handle both liquids and solid wastes either alone or in combination. The PCB rotary kiln incinerators have secondary combustion chambers after primary combustion in the rotary kilns. Primary and secondary combustion chamber operating temperatures are typically between 1100°C and 1300°C. Gas-phase residence time in the combustion chamber varies from less than one to several seconds. Flue gases contain hydrochloric acid (from the combustion of chlorinated organic wastes),

TABLE 1 PCB DESTRUCTION TECHNOLOGIES SURVEYED

PCB Destruction Technology	Companies/Organizations
Stationary Incineration: Rotary Kiln	Ensco Environmental Services Hessian Industrial Waste Inc. (HIM) Kommunekemi Ontario Waste Management Corp. Pyrochem Rollins Environmental Services SAKAB SCA Chemical Services Selenco/Sanivan Group
Stationary Incineration: Other Thermal	Alberta Special Waste Management Corp. Arc Technologies Co. Chem Security Ltd. International Environmental Materials Corp. Los Almos National Laboratory ReChem International Ltd. Rockwell International Energy Systems
In-house Incineration: Liquid Injection	Dow Chemical Co. General Electric Co. LaPorte Chemical Corp. Vulcan Materials Co.
In-house Incineration: Other Thermal	Aluminum Co. of America Tennesse Eastman
Mobile/Transportable: Rotary Kiln	Ensco Environmental Services EPA - Office of Research and Development IT Corp. M&S Engineering Sitex Vesta Technology Ltd. Weston
Mobile/Transportable Incineration: Liquid Injection	Ensco Environmental Services
Mobile/Transportable Incineration: Other Thermal	Drycor Industries GA Technologies Haztech, Inc. J.M. Huber Corp. Ogden Environmental Services O.H. Materials, Inc. Riedel Environmental Services Rockwell International Systems Shirco Infrared Systems, Inc. Selenco/Sanivan Group Westinghouse Electric Corp.

TABLE 1 PCB DESTRUCTION TECHNOLOGIES SURVEYED (Cont'd)

PCB Destruction Technology	Companies/Organizations
Incineration-at-Sea: Liquid Injection	Chemical Waste Management, Inc. Environmental Oceanic Services Seaburn, Inc.
Stationary Oil Treatment: Sodium Process	PCB Eliminators PPM Canada, Inc. Trinity Chemical
Mobile Oil Treatment: Sodium Process	Chemical Decontamination Corp. Chemical Waste Management, Inc. Excel Tech, Inc. PPM Canada, Inc. Rondar, Inc. Selenco/Sanivan Group Sun Environmental Transformer Consultants
Mobile Oil Treatment: Other Processes	General Electric Co. IT Corp. Niagara Mohawk Power Corp. Ozonics Technology, Inc.
Alternative PCB Solid Waste Treatment	Acurex Battelle Pacific Northwest Laboratory Bioclear Corp. Detox Industries, Inc. Galson Research Corp. O.H. Materials, Inc. Modar, Inc. SRH Associates, Inc.

particulates, and metals from inorganic contaminants in the kiln waste feed. Flue-gas treatment systems are employed to remove these contaminants.

Four U.S. companies (Ensco Environmental Services, Pyrochem, Rollins Environmental Services and SCA Chemical Services), operate commercial rotary kiln, stationary PCB destruction facilities. Although these companies accept all forms of PCB waste from any U.S. location, they do not accept Canadian wastes because of the border closure to PCB waste transport by U.S. law.

The trial burns for U.S. EPA certification of these rotary kilns for commercial PCB destruction included monitoring and risk assessment of emissions of toxic combustion by-products (dioxins and furans). The air emissions from these facilities were considered acceptable by the U.S. EPA.

In addition to the four United States companies, three European hazardous waste treatment operations destroy PCB wastes by rotary kiln incineration. These are Hessian Industrial Waste Inc. (HIM) in West Germany, Kommunekemi in Denmark, and SAKAB in Sweden.

These European commercial facilities are large national hazardous waste treatment facilities which handle both organic and inorganic hazardous industrial wastes. Organic wastes, including PCBs, are destroyed in large rotary kiln incinerators whose capacities are of the order of 6 to 12 tonnes per hour. PCB wastes are only a small portion of the total organic wastes destroyed. These facilities accept only wastes from within the country in which they are located, and operate under their respective national environmental regulations. Emission monitoring was conducted at the HIM facility at Biebeshiem during the destruction of PCB and non-PCB chlorinated wastes. Emissions of dioxins and furans were 0.57 ng/m^3 and 16.2 ng/m^3, respectively. There was also no difference in dioxin and furan emissions between the firing of PCB wastes and non-PCB chlorinated wastes.(13)

A significant amount of experience has been obtained in the incineration of PCB-containing wastes at stationary rotary kiln incineration facilities in the United States and Europe. Destruction and removal efficiencies for PCBs at these facilities have been measured at greater than 99.9999 percent. The concentrations of dioxins and furans in the flue gas (less than 1 ng/m^3 to 50 ng/m^3) during the destruction of PCBs have been considered acceptable by the U.S. EPA and European authorities. These facilities operate under government approval, have operated commercially for more than one year and have handled PCB wastes in the form of liquids, sludges, and drums containing PCB wastes and capacitors.

The support systems and residue disposal capabilities for these stationary facilities include extensive receiving, storage and waste material transfer systems plus treatment systems for liquid effluents and solid residues.

In Canada, construction of the ASWMC facility (Swan Hills, Alta.) is complete. Two other facilities are under development, one by the Ontario Waste Management Corporation and the other by Selenco/Sanivan. These facilities are designed for treatment of both organic and inorganic hazardous wastes by incineration and physical/chemical treatment.

The ASWMC facility employs two Von Roll rocking kilns to incinerate organic wastes including PCBs (Table A-7). Each kiln can handle wastes in 200-litre drums and the combined total destruction capacity will be 1400 kilograms per hour. The two kilns discharge to a common air pollution control system comprising a quench tower followed by a series of wet scrubbers. The ASWMC facility has been built and will be operated by Chem-Security Ltd. The facility has been issued a permit to conduct trial burns by the Alberta Department of the Environment.

The OWMC facility will use one Von Roll rotary kiln, with future provision for a second if required (Table A-12). The design capacity of each kiln is 4280 kilograms per hour. Preliminary engineering is complete and OWMC is presently preparing an environmental assessment.

The Selenco/Sanivan Group have proposed a facility in Senneterre, Quebec, for the storage and destruction of organic hazardous wastes including PCBs (Table A-17). The site has approval from the Quebec government for the storage of hazardous wastes. The facility was scheduled to receive waste shipments starting in the first quarter of 1988 and to begin destruction of wastes including PCBs in 1990. High concentration PCB wastes and solids will be incinerated in a rotary kiln and PCB-contaminated mineral oil (less than 3300 ppm) will be destroyed with a chemical dechlorination process.

Arc Technologies are developing a pyrolytic system for the destruction of PCB-filled capacitors (Table A-8). Unopened capacitors are fed into a sealed DC arc furnace where organic materials pyrolyze and inorganic materials melt to form a molten pool in the furnace. This technology was developed in association with the Electric Power Research Institute to handle PCB capacitors from U.S. utilities. The system is designed to handle up to 11 000 kg/h of PCB-filled capacitors. Applications have been submitted for a U.S. Toxic Substances Control Act permit and trial burns were scheduled for October 1987. Although this technology is considered near-commercial, the facility in Model City, New York, is not accessible to Canadian PCB wastes.

In addition to the three Canadian stationary destruction facilities, a Canadian company, International Environmental Materials Corporation (IEM Corp.) offers a PCB disposal service (Table A-15). IEM Corporation ships Canadian PCB wastes to the ReChem International Limited hazardous waste incinerator in Pontypool, Wales, for destruction. These shipments are conducted under the Transportation of Dangerous Goods Act and the International Maritimes Goods Code. The import of wastes into Great Britain and the incineration of these wastes are permitted under U.K. legislation, Control of Pollution (Special Waste) Regulations 1980. IEM Corporation has been offering this service since 1986.

A summary of the evaluation of stationary PCB destruction technologies is presented in Table 2.

Cofiring of hazardous wastes in cement kilns is an attractive alternative to incineration because it makes use of the heat content of the waste. Cement kilns provide temperatures and residence times similar to those required for incinerators dedicated to hazardous wastes. Cement kilns operate at temperatures greater than 1100°C, have gas residence times exceeding 1.5 seconds, and have a highly turbulent combustion zone. In addition to the savings derived from the heat value, using existing equipment saves the capital costs required to build a separate incinerator. A limitation of using cement kilns for waste incineration is that the waste must not have an adverse affect on the cement product.

In 1975/76, an experimental program was conducted at the St. Lawrence Cement Co., Mississauga, Ontario to evaluate the use of a rotary cement kiln to destroy chlorinated liquid wastes. The technology was successful in destroying wastes with up to 50 percent PCBs. However, in spite of this success, further development was cancelled because of a strong negative public reaction.

3.2.2 In-house PCB Destruction. Six U.S. companies (Aluminum Co. of America, Dow Chemical Co., General Electric Co., La Porte Chemical Corp., Tennessee Eastman, and Vulcan Materials Co.) operate, or have operated, eight stationary PCB destruction systems for on-site disposal of in-house PCB liquid wastes. In all cases, these systems are part of the companies' in-house waste disposal systems, and EPA approval has been granted for destruction of in-house PCB wastes as an alternative to off-site disposal. The EPA permits apply only to the destruction of in-house wastes and the companies cannot accept wastes from other sources; therefore the incinerators cannot be considered commercial.

TABLE 2 SUMMARY EVALUATION: THERMAL PCB DESTRUCTION TECHNOLOGIES

PCB Destruction Technologies	Commercial	Near-Commercial	Promising/ Developing
Stationary	- Ensco Environmental Services - Hessian Industrial Waste Inc. (HIM) - Kommunekemi - Pyrochem - ReChem International (IEM Corp.) - Rollins Environmental Services - SAKAB - SCA Chemical Services	- Alberta Special Waste Management Corp.* - Arc Technologies Co. - Selenco/Sanivan Group*	- Ontario Waste Management Corp.*
Mobile/ Transportable		- Ensco Environmental Services MWP2000 - Haztech, Inc.* - IT Corp. - Ogden Environmental Services, Inc. - O.H. Materials, Inc.* - Riedel Environmental Services* - Selenco/Sanivan Group* - Shirco Infrared Systems, Inc.	- Vesta Technology Ltd. - Westinghouse Electric Corp.
Incineration at Sea		- Chemical Waste Management, Inc.	

* Organizations that propose to operate PCB destruction technologies designed and constructed by others. These organizations are not proponents or developers of specific technologies.

Seven of the destruction systems utilize liquid injection incinerators and one system uses a standard aluminum melting furnace. None of the liquid injection units was originally designed for PCB destruction and all have been modified as required. Generally, companies would not divulge operating details or information about waste quantities treated, although the quantity of in-house PCB-contaminated oil (350 ppm average PCB concentration) at one location was 6.06 million litres. At least two of the companies reported that they now ship all in-house PCB wastes off-site for disposal at Rollins Environmental Services or Ensco, in lieu of treatment in their in-house facilities.

In the U.S., eighteen high-efficiency boilers are permitted to destroy PCB wastes in conjunction with the firing of coal or oil/gas fuels. Since these boilers are for in-house use only and do not operate commercially, they were not included in the technologies surveyed.

3.2.3 Mobile/Transportable PCB Destruction. A number of companies have developed mobile/ transportable PCB thermal destruction systems. These mobile/transportable systems have the advantage that destruction can be performed on-site, which eliminates the costs and risks of transporting wastes from a waste site to a stationary destruction facility. Few systems are truly mobile in that the system or system modules can travel by road to the site and be operative with no additional site assembling or fabrication. In general, the size and complexity of thermal destruction systems requires site preparation, system module assembly, and a commissioning trial burn period prior to hazardous waste operation.

Companies with rotary kiln systems are Ensco Environmental Services, IT Corporation, Vesta Technology Ltd. and Roy F. Weston, Inc. Companies with alternative thermal destruction systems are Riedel Environmental Services, O.H. Materials, Inc., Haztech, Inc., Shirco Infrared Systems, Inc., Ogden Environmental Services, and Westinghouse Electric Corp.

Ensco Environmental Services has three transportable, commercial organic waste destruction units which were designed to accept PCBs. The MWP2000 system is a transportable, rotary kiln system which can accept liquid and solid wastes including soils and shredded electrical capacitors (Table A-19). The rotary kiln unit comprises six trailer modules and requires four to six weeks for site set-up and shakedown. A destruction and removal efficiency of greater than 99.9999% has been demonstrated with trichlorobenzene and PCB wastes. Expected destruction costs are in the range of $350 to $1000 U.S./tonne. A minimum job size for MWP2000 unit of 2300 cubic metres is suggested. The MWP2000 system has been used since 1984 to destroy chlorinated organics in wastewater, sludges and soils at a contaminated waste lagoon site in Florida. EPA trial burns with the MWP2000 system were conducted with PCB wastes and dioxin-contaminated solid wastes in 1986 and 1987 under the Toxic Substances Control Act (TSCA). This mobile rotary kiln system is considered near-commercial because it is currently in the regulatory permit stage of development; final approval was anticipated by late 1987. The Selenco/Sanivan Group are proposing to use the MWP2000 system in Canada.

Ensco Environmental Services has also two liquid injection systems. The MWP75 system has EPA permits for commercial liquid PCB destruction in six EPA regions. This system is transportable, but has been operated only at Ensco's stationary facility (Eldorado, Arkansas) because economics have favoured transport of liquid wastes to the site, rather than transporting the unit to the wastes. The MWP100 system is a second generation liquid injection unit based on the design and experience with the MWP75. The MWP100 system demonstrated the required PCB destruction efficiency in 1984 EPA trial burns. However, EPA certification requires additional test burns to monitor dioxin and furan emission levels, and these tests are not planned. Ensco Environmental Services do not intend to develop these liquid injection units further, since they are developing the MWP2000 rotary kiln system. Based on their development and regulatory status, the MWP75 and MWP100 could be evaluated as commercial and near-commercial technologies; however, they were not evaluated further because Ensco Environmental Services does not offer these technologies commercially for transportable PCB destruction.

IT Corporation of Knoxville, Tennessee, is developing a transportable rotary kiln system for PCB waste destruction (Table A-21). A permit application has been submitted for TSCA approval and trial burns were scheduled for October 1987. This rotary kiln unit is capable of handling 20000 kilograms/hour of contaminated soil. This technology is considered near-commercial.

Roy F. Weston, Inc., of West Chester, Pennsylvania, is developing a rotary kiln system for remediation of an Illinois waste site containing PCB-contaminated soil. This destruction system is specific to the Illinois site remediation program and Roy F. Weston, Inc., will not offer the system in Canada.

Vesta Technology Ltd. of Florida has developed a mobile rotary kiln system (Table A-27) which is on one flat bed trailer and requires only minimal time to set up on-site (24 hours). To date this system has operated only on non-PCB wastes. This system was designed to also handle PCB wastes. Vesta was planning to conduct trial burns on PCB wastes for Quebec Hydro during the summer of 1988. This technology is considered promising.

Riedel Environmental Services, O.H. Materials Inc. and Haztech, Inc. all intend to employ the Shirco technology. Shirco Infrared Systems Inc. has pilot-scale and full-scale transportable infrared energy systems to thermally destroy PCB-contaminated soils (Table A-25). Both the pilot-scale and the full-scale units have operated at Superfund sites for the destruction of hazardous organic wastes. As part of a TSCA permit submission by Shirco, trial burns were conducted in 1986. Trial burns with the pilot-scale unit achieved greater than 99.9999% destruction and removal efficiency on PCB-contaminated soil. Riedel Environmental Services (Table A-24), O.H. Materials (Table A-23) and Haztech, Inc. (Table A-20) have submitted TSCA permit applications. The Shirco System is considered near-commercial. O.H. Materials have a Canadian office in Oakville, Ontario and have proposed to use the Shirco system for the remediation of a PCB waste site in Ontario.

Ogden Environmental Services Inc. has developed a circulating bed technology for the destruction of organic hazardous wastes including PCBs (Table A-22). Ogden acquired the circulating bed combustion technology of GA Technologies Inc. and offer both stationary and transportable systems of various capacities. The technology received a TSCA permit in early 1987, to handle soil containing up to 10 000 ppm PCBs. Although the technology has regulatory approval it was still considered near-commercial because it had not operated commercially for one year. In Canada, Ogden Environmental Services is marketing this technology through their associate Toronto company, Ogden Allied Canada.

The mobile plasma arc technology of Westinghouse Electric Corp. has been tested at pilot and full-scale with PCB liquid wastes (Table A-28). This technology is considered promising.

The EPA Office of Research and Development (ORD) operates a full-scale, transportable rotary kiln system which is used to demonstrate the capability of this technology to destroy a variety of hazardous wastes. The unit is capable of handling PCB liquids, sludges and solids including soils and capacitors, but has only been tested on PCB liquid wastes. The transportable unit comprises four trailer modules. A trial burn on 40% by weight feed of askarel demonstrated a destruction and removal efficiency of 99.99991%. Estimated commercial destruction costs are in the range of $250-1100 U.S. per tonne. Since the system is operated by private companies under contract to the EPA and will not be accepting commercial waste for destruction, it was not evaluated further.

The J.M. Huber Corporation advanced electric reactor has been proven at the pilot scale, and is permitted in various EPA regions and states, but the company has decided not to pursue application to hazardous wastes in the future. The Rockwell International Energy Systems molten salt combustor has also been tested at pilot-scale and has a research permit for PCB burns. Rockwell does not intend to provide waste treatment services.

A summary of the evaluation of mobile/transportable thermal PCB destruction technologies is presented in Table 2.

In addition to these mobile/transportable destruction technologies, others were surveyed but not evaluated. The development status and company backgrounds of these technologies varied considerably. The companies range from relatively new, small companies to well-established international corporations. In some cases, the application of new or existing thermal technologies to PCB destruction has been proposed in concept only and operating systems have not been constructed. In other cases, operating pilot-scale systems are well-developed and have been demonstrated on a limited scale for PCB destruction. Although many of the systems show promise technically as future commercial means of PCB destruction, it is not known what the future development status is and whether it could be applied to commercial PCB destruction of Canadian wastes within less than two years.

3.2.4 At-Sea Incineration. In addition to land-based facilities for the destruction of PCBs, one U.S. company (Chemical Waste Management Inc.) has incineration-at-sea vessels.

In addition to Chemical Waste Management, Inc. of the United States two additional incinerator ships, the Vesta owned by Lehnkering Montan Transport A.G. of West Germany and the Matthias II owned by Incimer, Inc., undertake commercial hazardous waste destruction in Europe.

At-Sea-Incineration, Inc., of Elizabeth, N.J., built two vessels for the incineration of liquid hazardous wastes, including PCBs, but neither of the ships underwent EPA performance testing. These ships were not evaluated further because At-Sea-Incineration, Inc. recently filed for bankruptcy.

Chemical Waste Management, Inc. owns and operates the Vulcanus I and II which use vertical liquid injection incinerators (Table A-29). The Vulcanus I has operated commercially in Europe and has undergone a series of hazardous waste incineration tests that date back to 1974. The Vulcanus I PCB test burns sanctioned by the U.S. EPA were undertaken in late 1981 and August 1982. The Vulcanus II, launched in 1982, has three incinerators at the stern. It has not undergone a U.S. EPA PCB test burn program to date, but has operated commercially in Europe. The Vulcanus I and II vessels are considered near-commercial.

Environmental Oceanic Services of Seattle, Washington, proposed leasing a ship and mounting an incinerator in association with 16 containers on deck. Seaburn Inc. of Greenwich, Connecticut, proposed to utilize an ocean-going barge equipped with an incinerator and bulk containers to dispose of liquid hazardous waste. Further development by these two companies has not proceeded as a final decision by the EPA on the permitting of hazardous waste incineration at sea is pending.

United States regulations governing the destruction of hazardous wastes using incineration-at-sea vessels are under review. Initial evaluation of the test burn data from the Vulcanus I indicated that the destruction efficiencies required for incinerating chlorinated organics, including PCBs, were achieved. However, the testing protocols used and validity of results have since been questioned by a number of organizations and this has caused the EPA to re-evaluate its policy regarding incineration-at-sea.

In Canada, the incineration of hazardous wastes at sea is governed by the Canadian Environmental Protection Act. Canada is also a signatory to the 1972 London Dumping Convention. Under this agreement, member countries have adopted uniform regulations for the incineration of hazardous wastes at sea.

3.2.5 Mobile Oil Treatment Processes. Chemical processes for the decontamination of PCB-contaminated oil are regarded as proven technologies. The most common chemical destruction method is based on the use of sodium which reacts selectively with the chlorine in the PCB molecule to produce sodium chloride and non-halogenated polyphenyl. In most commercial systems, the products of this reaction are readily separated to permit the base oil to be recycled or re-used. The principal commercial application of the process is the removal of PCBs from PCB-contaminated mineral oil. Other chemical destruction methodologies have been developed, and three companies have proceeded to the near-commercial stage in developing non-sodium chemical destruction processes.

A review of information from companies using chemical PCB-destruction technologies indicates several general conclusions:

- Full-scale, sodium-based processes have been successfully used commercially since 1979 in the United States. The sodium-based processes can be classed as proven technology.
- Chemical methods have been successfully applied to treat oils in energized transformers.

The following companies offer commercial mobile services:

Chemical Decontamination Corp.,
Chemical Waste Management, Inc.,
Excel Tech Inc.,
PPM Canada Inc.,
Rondar, Inc.,
Selenco/Sanivan Group,
Sun Environmental Ltd., and
Transformer Consultants.

All of the above companies offer full-scale commercial operations. Two additional companies, PCB Eliminators and Trinity Chemical, operate stationary PCB dechlorination units. In Canada, PPM Canada Inc. (Table A-36) has performed commercial PCB dechlorination in Nova Scotia, New Brunswick, Quebec, Ontario, Saskatchewan and British Columbia. PPM Canada Inc. is also operating one of its mobile units in the stationary mode in Saskatchewan. Sun Environmental, formerly Sunohio (Table A-39), has provided commercial services in Manitoba, Ontario, Quebec and Prince Edward Island.

Rondar Inc. is a Canadian company which operates commercially Ontario Hydro's mobile oil treatment process (Table A-37). Rondar has provided commercial services in Nova Scotia, Quebec and Ontario.

The Selenco/Sanivan Group of Burlington, Ontario has two mobile dechlorination units. These units, which utilize the Transformer Consultants Inc. process, have operated commercially in Quebec (Table A-38). A permit application to operate in Ontario has been submitted to the Ontario Ministry of the Environment for approval.

Mobile PCB decontamination technologies can be used to treat contaminated oils with maximum PCB concentrations from 7000 to 20 000 ppm. Contaminated oil feed rates vary by process type and concentration of PCBs in the contaminated oil. Typical feed rates range from 700 to 3000 litres per hour. These mobile technologies consist of one or two trailer modules and require less than three days of set-up time. Treatment costs depend upon the volume of oil to be processed, the concentration of PCBs in the oil, and the site location. General costs range from \$0.50 to \$5.50 per litre of oil treated. Construction costs, excluding development costs, are reported to range from \$400 000 to \$700 000 U.S. Wastes generated are reaction by-product sludges, cartridge filters, and rags and cloths. The treatment and disposal of liquid and solid residues generated by these dechlorination processes is the responsibility of the operator of the process.

Concentrations of PCBs and other contaminants are monitored and the solid residues disposed of in accordance with local regulations.

Three companies are developing non-sodium based processes. General Electric is developing a mobile oil treatment system based on a PEG/KOH (poly(ethylene glycols)/potassium hydroxide) process (Table A-33). General Electric has an EPA research and development permit to test the unit and have submitted an application for commercial operation. In addition to offering the service in the United States, they will also offer it in Canada through Canadian General Electric, Burlington. This technology is considered near-commercial.

IT Corporation of Torrance, California, has purchased the Niagara Mohawk Power PEG/KOH technology and has applied for a commercial TSCA permit. They also intend to offer this service in Canada. This technology is considered near-commercial.

Ozonics Technology Inc. of Closter, N.J., is developing a mobile oil treatment process that uses a combination of ozone, ultra-violet light and ultrasonics to decontaminate PCB-contaminated oils (Table A-35). An application has been submitted for commerical operation; therefore the technology is considered near-commercial.

A summary of the evaluation of chemical oil treatment processes is presented in Table 3.

TABLE 3 SUMMARY EVALUATION: CHEMICAL PCB DESTRUCTION TECHNOLOGIES

PCB Destruction Technologies	Commercial	Near-Commercial	Promising/ Developing
Stationary Oil Treatment	- PCB Eliminators - PPM Canada, Inc. - Trinity Chemical Co.		
Mobile Oil Treatment	- Chemical Decontamination Corp. - Chemical Waste Management Inc. - Excel Tech Inc. - PPM Canada, Inc. - Rondar, Inc. - Selenco/Sanivan Group - Sun Environmental Ltd. - Transformer Consultants	- General Electric Co. - IT Corp. - Ozonics Technologies, Inc.	

3.2.6 Alternative PCB Solid Waste Treatment. Currently various technologies are available to treat and destroy the range of PCB wastes. These have been identified and evaluated in previous sections. In addition to the thermal technologies available to handle PCB-contaminated solids, research and development is underway on alternative methods of managing and destroying PCB solid wastes. The U.S. EPA has evaluated six potentially applicable technologies for the treatment of PCB-contaminated sediments(14): low-temperature oxidation; chlorine removal; pyrolysis; extraction and concentrating; vitrification; and biodegradation. The solvent extraction processes of Acurex, O.H. Materials Inc. and Oak Ridge Laboratory, and the pyrolysis process of of J.M. Huber Corp. were considered potential candidates by the U.S. EPA.

The low-temperature (supercritical water) oxidation process of Modar Inc. (Table A-46) was considered a candidate for potential application by the EPA and can be considered a promising technology.

The chlorine removal process of Galson Research Corporation (Terraclean-Cl) (Table A-45) was also considered a candidate by the EPA and is considered promising technology.

An in-situ vitrification process developed by Battelle Pacific Northwest Laboratory (Table A-42) for the U.S. Department of Energy has demonstrated the capability of treating PCB-contaminated soils in a pilot test.(15) The U.S. Environmental Protection Agency is considering the use of this technology to vitrify sludge contaminated with PCBs.(15) Vitrification process technology can be considered promising.

Two companies are actively developing biodegradation processes for the treatment of soils contaminated with hazardous wastes including PCBs. Detox Industries Inc. of Stafford, Texas, have been granted a commercial permit (Table A-44). Bioclear Corporation of Houston, Texas, have applied for a research and development TSCA permit. They intend to develop a commercial transportable PCB destruction technology (Table A-43). The Detox process is considered commercial and the Bioclear process is considered promising.

In addition, SRH Associates Inc. are developing a thermal system to extract PCBs from contaminated sludges and soils (Table A-49). A fluidized bed is used to vapourize organic material including PCBs. The vapours are then condensed and collected. This process is at the developmental stage and is considered promising.

A summary of the evaluation of these alternative PCB solid waste treatment technologies is presented in Table 4.

TABLE 4 SUMMARY EVALUATION: ALTERNATIVE PCB SOLID WASTE TREATMENT TECHNOLOGIES

PCB Treatment Technologies	Commercial	Near-Commercial	Promising/Developing
Biodegradation	- Detox Industries, Inc.		- Bioclear Corp.
Chlorine Removal			- Galson Research Corp.
Low Temperature Oxidation			- Modar, Inc.
Solvent Extraction			- Acurex - O.H. Materials, Inc.
Thermal Extraction			- SRH Associates, Inc.
Vitrification			- Battelle Pacific Northwest Laboratory

4 CONCLUSIONS

Based on this evaluation of PCB destruction technologies, rotary kiln incineration with flue-gas treatment is preferred for commercial stationary PCB destruction. This technology is capable of handling not only PCB wastes but other industrial organic hazardous wastes. Companies in Europe and United States that utilize rotary kilns successfully operate regional or national hazardous waste treatment facilities. The Alberta Special Waste Management Corporation, the Ontario Waste Management Corporation, and Selenco/Sanivan Group are developing hazardous waste treatment facilities. The Alberta facility opened in Swan Hills in 1988, while facilities are expected to be commercially operational in Quebec in 1990 and in Ontario in 1991. IEM Corp. of Edmonton provides a service that ships PCB wastes to Great Britain for destruction.

Eight North American companies have near-commercial mobile/transportable destruction technologies. Three companies, Ogden Environmental Services, O.H. Materials Inc. and the Selenco/Sanivan Group have Canadian representation.

Of the eight commercial, mobile oil treatment technologies, four are operating in Canada; these are Sun Environmental, PPM Canada, Inc., Rondar Inc. and the Selenco/Sanivan Group. In addition, two companies, IT Corp. and General Electric Co., have near-commercial technologies which they intend to offer in Canada. These oil treatment technologies are proven; four are immediately available in Canada and are capable of destroying PCBs in PCB-contaminated oil. It may be noted that PCB-contaminated oil represents a large portion by volume of PCB wastes in Canada.

Solvent extraction technology is being developed by six American companies for application to PCB-contaminated soils and is considered a promising technology. The alternative technologies of low-temperature oxidation, chlorine removal, vitrification, thermal extraction and biodegradation are also being developed for the treatment of PCB solid wastes and are considered promising technologies.

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