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Canadian Council of Ministers of the Environment
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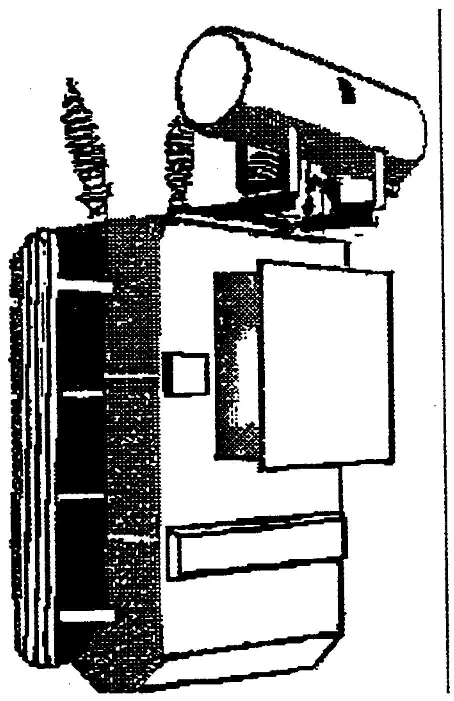
PCB Transformer Decontamination

Standards and Protocols



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PCB TRANSFORMER DECONTAMINATION STANDARDS AND PROTOCOLS

Canadian Council of Ministers of the Environment (CCME)

Based on a study by
Proctor & Redfern Limited
for the
Hazardous Waste Branch
Environment Canada

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The Canadian Council of Ministers of the Environment (CCME) is the major intergovernmental forum in Canada for discussion and joint action on environmental issues of national international and global concern. The thirteen member governments work as partners in developing nationally consistent environmental standards, practices and legislation.

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Ce rapport est aussi disponible en français sous le titre "Décontamination des transformateurs contenant des BPC - Normes et protocoles," à l'adresse ci-dessous.

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Preface

The Canadian Council of Ministers of the Environment (CCME) has worked on developing minimum national approaches for handling, treating and disposing of wastes. As well as producing guidelines for physical, chemical, and biological treatment, incineration and landfilling of hazardous wastes, CCME has also provided guidance with respect to specific wastes such as used oil, biomedical waste and PCBs.

The CCME has committed itself to a policy of phasing out the use of all polychlorinated biphenyls (PCBs) in Canada. This entails the proper management and disposal of transformers to reduce human and environmental exposure to PCBs.

Currently there are no national standards in Canada for the decontamination of PCB transformers. This document provides a national guideline that encourages resource recovery and technological developments in this area. It outlines safe approaches for the reuse, recycling and landfilling of electrical transformers containing PCBs and their components, as well as criteria for evaluating the surface contamination of these components by PCBs.

These guidelines are intended to promote uniform practices and to set minimum national approaches for PCB transformer decontamination in Canada.

Avant-propos

Le Conseil canadien des ministres de l'environnement (CCME) a travaillé à l'élaboration de normes nationales minimales relatives à la manutention, au traitement et à l'élimination des déchets. En plus, de préparer des lignes directrices relatives au traitement physique, chimique et biologique, à l'enfouissement des déchets dangereux, le CCME a également fourni une orientation en ce qui concerne des catégories de déchets précises telles que les huiles usées, les déchets biomédicaux et les BPCs.

Dans le cadre d'une politique d'élimination progressive, le CCME s'est engagé à bannir l'utilisation de tous les biphényles polychlorés (BPC) au Canada, ce qui implique la gestion adéquate et le mode d'élimination approprié des transformateurs afin de réduire l'exposition des être humains, de la faune et de la flore aux BPC.

Il n'existe actuellement, au Canada, aucune norme nationale pour la décontamination des transformateurs contenant des BPC. Ce document présente des lignes directrices nationales qui favorisent la récupération des ressources et encouragent les développements technologiques dans ce domaine. On y trace les grandes lignes d'approches sûres en matière de réutilisation, de recyclage et d'enfouissement des transformateurs électriques contenant des BPC et sous-produits, et on y dresse une liste de critères pour l'évaluation de la contamination de surface de ces sous-produits par les BPC.

Ces lignes directrices ont été conçues pour promouvoir l'adoption de pratiques uniformes et établir des normes nationales minimales en matière de pratiques uniformes et établir des normes nationales minimales en matière de décontamination des transformateurs contenant des BPC au Canada.

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GLOSSARY

PCB	Chlorobiphenyls (polychlorinated biphenyls) are defined in the Canadian Environmental Protection Act as those chlorobiphenyls that have the molecular formula $C_{12}H_{10-n}Cl_n$, where n is greater than 2.
PCB Equipment	Any manufactured item, including any transformer or capacitor, that contains a PCB liquid, PCB solid or PCB substance.
PCB Liquid	Any liquid containing PCBs at a concentration of more than 50 milligrams per kilogram (50 ppm by weight) of the liquid (e.g. PCB-contaminated mineral oil, aqueous suspensions, and askarel).
PCB Solid	A solid that contains more than 50 mg of PCB per kilogram of solid (50 ppm by weight).
PCB Substance	A substance, other than a PCB liquid or a PCB solid, that contains more than 50 mg of PCB per kilogram of the substance.
PCB Waste	Any PCB equipment, liquid, solid, or substance for which there is no longer any use.
Askarel	High PCB concentration transformer fluid, generally containing between 40-80% PCB.
Contaminated Mineral Oil	Low concentration PCB-contaminated transformer mineral oil fluid, generally containing less than 1% PCBs.
Retrofilling	The draining of PCB-contaminated mineral oil transformers followed by refilling with non-PCB mineral oil ($\leq$50 ppm).
Re-Use	Returning transformers to in use service.
Recycling	Collection for subsequent smelting of transformer parts for metal recovery.
Decontamination	The removal of PCBs from a PCB solid, liquid or substance.
Destruction	The destruction of the PCB molecule by thermal means.
Treatment	The destruction of the PCB molecule by chemical means.
Phase Out	The permanent removal from service and placement in storage of PCB equipment.

1.0 INTRODUCTION

The Canadian Council of Ministers of the Environment (CCME) has committed itself to a policy of phasing out the use of all polychlorinated biphenyls (PCBs) in Canada.

In support of this policy, nationally applicable protocols are required to delineate environmentally acceptable methods for decontaminating PCB transformers, which contain about 82% of PCBs currently in use in Canada (Environment Canada, 1994).

In keeping with this requirement, this report reviews methods for the decontamination of PCB transformers and recommends residual PCB contaminant concentrations for their re-use, recycling and disposal.

2.0 NATURE OF THE PROBLEM

2.1 Overview of the Present PCB Situation in Canada

It has been estimated (Canadian Electricity Forum, 1987) that 40,000 tonnes of PCB fluids were imported into Canada, before such imports were banned in 1980. Only about 27,300 tonnes of these imports can be accounted for, which means that the remainder (12,400 tonnes) have probably been released to the environment.

As of December 1992 (Environment Canada, 1992), there were:

12,500 tonnes (t)	Askarel (generally 40 to 80% PCBs) contained in in-service transformers, capacitors, and other electrical and mechanical equipment.
6,080 t	Askarel in storage for disposal.
2,500 t	Askarel contained in in-service lamp ballasts.
5 to 10 t	Low concentration PCBs in PCB-contaminated mineral oil (generally less than 1% PCB).
10 to 20 t	Low concentration PCBs in PCB-contaminated solids.
1,000 t	Askarel exported for destruction overseas.
5,200 t	Askarel destroyed in Canada by incineration.
3 to 4 t	PCBs destroyed through decontamination of PCB-contaminated mineral oil.
27,300 tonnes (approximately)	

Askarels are largely contained in 6,950 in-service askarel transformers, in 3,750 in-storage askarel transformers and in drums from drained or decontaminated askarel transformers. In-service and in-storage capacitors make up the majority of the remainder of the askarel electrical equipment.

CCME has committed itself to a policy for the timely phase-out of all PCBs in Canada. The vast majority of in use PCBs are contained in askarel equipment. Proper management of this equipment is required in order to reduce human and environmental exposure to PCBs. Although the focus of this report is on askarel transformers, low concentration PCB-contaminated mineral oil transformers are also discussed.

The expeditious phase-out of askarel transformers in Canada has been hampered by the lack of commercially available decontamination and disposal options in Canada for this equipment. A major step in encouraging PCB owners to phase-out equipment and encouraging PCB service companies to invest in decontamination, treatment and destruction facilities, is to ensure that consistent, national standards for the decontamination of equipment for re-use, recycling and disposal are clearly documented, disseminated and applied in all provinces.

2.2 Overview of Current PCB Transformer Management Options in Canada

PCB transformers are usually referred to as either PCB-contaminated mineral oil transformers or as askarel transformers. Askarel transformers were designed to contain high concentration PCB dielectric fluids, referred to as askarel. Mineral oil transformers were not designed to contain PCBs but some were inadvertently contaminated at low PCB concentrations either during manufacture or maintenance activities.

The following is a general overview of the main options currently available to PCB transformer owners in Canada for the management of this equipment.

2.2.1 Re-Use of Transformers

- <u>Contaminated Mineral Oil Transformers</u>

  Contaminated mineral oil transformers can be decontaminated using either of two processes; retrofilling or on-line chemical treatment. The success of the treatment is usually assessed by testing the transformer's dielectric fluid a minimum of 90 days of in use service after the completion of the decontamination process. If the fluid contains ≤50 ppm (less than or equal to 50 parts per million) of PCBs, then the process has been successful and the transformer can be re-used as a non-PCB transformer. The decontamination processes and the ≤50 ppm, 90-day test are generally accepted by provincial jurisdictions.

  At the end of their service life, these decontaminated mineral oil transformers are usually scrapped for metal recycling (except in Saskatchewan where the mineral oil must be <5 ppm). The mineral oil can be sent to oil reclaimers, re-used in other mineral oil transformers (often after chemical treatment) or appropriately incinerated (options vary from province to province).

Further information on decontamination processes for mineral oil transformers is given in Appendix A.

- Askarel Transformers

  The decontamination of askarel transformers for re-use is much less frequently carried-out. However there are many circumstances where the process is cost effective compared to scrapping (including eventual transformer disposal costs) and replacement. There are two main types of decontamination processes; series retrofilling and in-situ processing. When either process is used (usually lasting 12 - 24 months), the same 90-day in-service test, as used for testing decontaminated mineral oil transformers, is employed at the end of the processing time. After successfully passing the test, the transformer is considered to be non-PCB equipment in most provinces. At the end of its service life the former askarel transformer could be scrapped with metal components normally available for recycling. Details of the methodologies used for decontaminating askarel transformers are given in Appendix A.

2.2.2 Recycling of PCB Transformers

CCME guidelines (1989) allow the recycling (smelting) of drained waste PCB-contaminated mineral oil transformers of <500 ppm. This has been allowed (under specific permitting) by the Ontario Ministry of Environment and Energy (MOEE) for pole mount transformers <500 ppm. This was considered necessary by MOEE as an interim measure to address rapidly accumulating inventories of scrapped pole-mount transformers.

Incineration (non-slagging) of waste PCB transformers is an acceptable method of decontamination of metal for eventual recycling. The contaminated mineral oil or askarel can also be destroyed in the same process. This option (incineration of transformers and their liquids) is available at the permanent hazardous waste treatment facility at Swan Hills, Alberta and was used at mobile PCB incinerator sites which have operated in Canada (two sites to-date, one at Goose Bay, Labrador 1990 and one at Smithville, Ontario 1991 - 1992).

Waste transformers can also be decontaminated for metal recycling by processes using various solvent cleaning methods. Sanexen Environmental Services Inc. offers mobile transformer decontamination services using an autoclave process ("Decontaksolv") which applies heated solvent vapours to disassembled transformer parts (casings and cores). The drained dielectric fluids, contaminated solvents, and porous transformer materials (wood and paper) must be stored or treated (if >50 ppm) by approved methods. This process is available commercially across Canada. ENSR also has an in-situ processing for in-use askarel transformers that can be used for waste askarel transformers as well.

Further details of waste transformer decontamination for metal recycling are given in Appendix A.

2.2.3 Landfilling of PCB Transformers

Landfilling of PCB transformer carcasses (drained transformers >50 ppm) is not permitted by any jurisdiction in Canada. Landfill owners are hesitant to accept any transformer or piece of electrical equipment in case it may contain PCBs even at low levels (<50 ppm).

3.0 THE NEED FOR NATIONAL TRANSFORMER DECONTAMINATION CRITERIA

3.1 General Needs and Benefits

Currently there are no national standards in Canada for the decontamination of PCB transformers. Establishing such national standards will satisfy the following needs and provide the following benefits:

- provide national criteria for the protection of human health and the environment during activities associated with transformer re-use, recycling and disposal;
- facilitate the phase-out of PCB electrical equipment in a consistent manner in all regions of Canada by providing for the safe re-use, recycling and disposal of PCB transformers;
- reduce PCB owners' current environmental liability by providing alternative options to continued use or storage of PCB transformers;
- reduction of PCB storage space requirements and accompanying cost by removing, from storage, drained PCB transformers which are inherently bulky and heavy;
- permit and encourage resource recovery by recycling metal transformer components;
- encourage the growth of the PCB management service sector in Canada; and,
- encourage Canadian research and development into PCB transformer decontamination technology.

3.2 The Need for Surface Decontamination Criteria

Governments, and society in general, are promoting the recycling of waste products. In the case of transformers, the metal components represent a valuable recyclable commodity. However workers at recycling or smelting facilities must be protected from exposure to PCBs from dermal contact with contaminated transformer metal surfaces. Therefore a maximum permissible PCB surface concentration is required to protect these workers.

A surface concentration criterion is also the most appropriate criterion to develop for the recycling of transformers because many technologies used for decontaminating transformers for recycling operate on drained transformers. Therefore the current standard (≤50 ppm) for the PCB concentration in the transformer fluid is generally not applicable in these situations. In addition, transformers or transformer parts received at smelters will have been previously drained and therefore health and safety, and regulatory compliance will require a surface criterion.

4.0 PCB CONTAMINATION CRITERIA

This section provides a brief review of existing federal and provincial PCB contamination criteria as well as criteria used in the U.S. and Europe. The last sub-section provides a recommended maximum surface contamination criterion for transformers destined for metal recycling.

4.1 Canadian Federal Criteria

The use, re-use, transport, storage, treatment (chemical) and destruction (incineration) of PCBs are regulated by both provincial and federal governments. Provincial regulations vary from province to province but in most provinces, provincial PCB regulations and policies deal with the management of all PCBs except on federal lands, or PCBs owned by federal departments or agencies or federally regulated transportation (rail, air, marine).

The federal government does not have a surface contamination criterion although on a case-by-case basis surface contamination criteria can be designated by Environment Canada. This was the case for the Goose Bay PCB Destruction Project conducted by the Department of National Defence (DND) and regulated by Environment Canada. In this project, a permissible PCB surface contamination criterion of less than or equal to 2.5 micrograms per one hundred square centimetres ($\leq$2.5 ug/100 cm^2) was established and used for metal surfaces (drums and other containers) which had been solvent decontaminated. The end use of the metal was unregulated after successful decontamination. Considerable difficulty was encountered in achieving this criterion, with the result that a large portion of the containers had to be shredded and incinerated.

Also for this project, shredded transformer casings and cores were incinerated in an approved high temperature, non-slagging, mobile PCB incinerator. Since the shredded metal parts were small and surfaces were twisted, it was impractical to subject the incinerated materials to standard surface contamination testing (wet wipe test). In this case the concentration of PCBs by weight on the metal was determined by solvent extraction. The required PCB decontamination standard was <0.5 ppm by weight (which was considered at that time to be roughly equivalent to a $\leq$2.5 ug/100 cm^2 surface concentration).

4.2 Provincial Criteria

In general, most provinces use the >50 ppm PCB standard (except Saskatchewan which uses 5 ppm and Quebec which uses 0.3 mg/l in liquids and 0.01 mg/l in leachate) to define a PCB material (solid or liquid). No province has a regulation dealing with surface contamination; however, most provinces have policies which use, in one form or another, the U.S. EPA 10 ug/100 cm^2 (or 100 ug/100 cm^2 in some special cases) policy for PCB spill clean-up. A few provinces have adopted this standard as policy for waste PCB transformer decontamination for metal recycling. This policy manifests itself in Certificates of Approval or other permits which provinces issue to companies which engage in the decontamination of waste PCB transformers for metal recycling.

Table 4.1 gives the approach each province takes in dealing with transformers for re-use and recycling.

Table 4.1

Provincial Standards for the Re-Use and Recycling of PCB Transformers

Province	Re-use	Recycling
British Columbia	≤50 ppm (unspecified time)	≤50 ppm
Alberta	≤50 ppm after 90 days	≤50 ppm
Saskatchewan	≤50 ppm after 90 days*	<5 ppm
Manitoba	≤50 ppm after 90 days	≤50 ppm
Ontario	≤50 ppm after 90 days	<500 ppm (CCME, 1989) (pole mount transformers only) ≤10 ug/100 cm^2 surface (project specific) <0.5 ppm by weight on metal (project specific)
Quebec	≤50 ppm after 90 days	≤50 ppm ≤10 ug/100 cm^2 surface
New Brunswick	≤50 ppm after 90 days	≤50 ppm
P.E.I.	≤50 ppm after 90 days	≤50 ppm
Nova Scotia	≤50 ppm after 90 days	≤50 ppm
Newfoundland	≤50 ppm after 90 days	≤50 ppm

* In Saskatchewan the management of in-use PCB transformers is governed according to the federal criterion of ≤50 ppm.

Notes:
1) Concentrations refer to PCB concentration in the dielectric fluid unless otherwise stated.
2) 90 days refers to the minimum waiting period, after the decontamination process is completed, before the dielectric fluid is tested.

4.2.1 Decontamination of PCB Transformers for Re-Use

All provinces accept the decontamination criterion of a PCB concentration of ≤50 ppm in the dielectric fluid after a minimum of 90 days for PCB transformers for re-use as non-PCB transformers.

4.2.2 Decontamination of PCB Transformers for Recycling

Currently in all provinces, except Saskatchewan, if a PCB transformer is successfully decontaminated (e.g., ≤50 ppm after 90 days) the transformer can also (in addition to re-use) be scrapped for the recycling of metal components; Saskatchewan uses a criterion of <5 ppm for the scrapping of transformers. However, the full extent to which re-use types of decontamination methods (e.g., retrofilling or flushing with clean mineral oil) are used in Canada to decontaminate PCB transformers for subsequent recycling is unknown, however at least one large utility, Ontario Hydro, makes use of this methodology since they have their own chemical treatment system for the resulting contaminated mineral oil (retrofilling fluids).

Quebec has a surface contamination standard (policy) for the decontamination of PCB waste transformers for metal recycling. This standard (adopted from New York State regulations) was, until recently, a permissible surface contamination of 12.5 ug/100 cm^2 for Arochlor 1250 and 1254 and 25 ug/100 cm^2 for Arochlor 1242 (for both casing and laminations). Recently (1991) the Quebec government replaced the above standard with the U.S. EPA standard of 10 ug/100 cm^2 and uses this standard on Certificates of Approval issued to PCB service companies (Deschenes, 1991).

In Quebec, the 10 ug/100 cm^2 is used to assess the contamination of the transformer casing and the core's laminates. The contamination of the core's windings (tightly wound aluminum and copper wires) is assessed by cutting out a small section of the windings and performing an extraction of the PCBs. The sample would include the paper insulation. The criterion used is $\leq$50 ppm. These methodologies are specific to particular Certificates of Approval and therefore could be subject to change should a company propose a different sampling methodology.

In Ontario, the MOEE has permitted some utilities to send small (pole mount) contaminated mineral oil transformers (<500 ppm) to metal recycling after draining (as per CCME 1989 guidelines). Also, on a project-specific basis (Smithville), MOEE has accepted the U.S. EPA criterion of 10 ug/100 cm^2 for the solvent cleaning of impermeable surfaces, including transformer parts for metal recycling. During the Smithville PCB destruction project, metal surfaces which could not be cleaned by solvent treatment were shredded and incinerated; a <0.5 ppm by weight criterion was used for the metal which was subsequently recycled.

British Columbia has adopted, as policy, the U.S. EPA 10 ug/100 cm^2 surface decontamination requirement for the clean-up of spills on impermeable surfaces. There is no criterion developed or used for waste transformer decontamination in British Columbia other than $\leq$50 ppm in the dielectric fluid.

In Saskatchewan a transformer can be scrapped for recycling if the dielectric fluid contains <5 ppm of PCBs. There is no surface criterion used for waste transformer decontamination. Saskatchewan has adopted, as policy, the U.S. EPA 10 ug/100 cm^2 surface decontamination requirement for the cleanup of spills on impermeable surfaces.

In Manitoba and Nova Scotia, transformers with $\leq$50 ppm of PCBs in the dielectric fluid can be recycled for metal recovery.

P.E.I. has not yet had to deal with the recycling of PCB transformers for metal recovery and a surface contamination criterion has not been established.

New Brunswick uses the U.S. EPA 10 ug/100 cm^2 surface contamination criterion, as policy, for spill clean-up. Less than 50 ppm transformers can be salvaged and recycled, or landfilled. Landfilling is however discouraged. There is also concern in the province about the practices of salvage operators and the province is considering placing some restrictions on these types of operations.

4.2.3 Transformer Disposal Requirements

In general, any transformer going to a landfill would have to have contained ≤50 ppm of PCBs (<5 ppm in Saskatchewan) in the dielectric fluid before draining. All provinces discourage the landfilling of transformers and encourage recycling of the metal where practical.

In addition, landfill owners everywhere are hesitant to accept transformers or transformer components because of the potential liabilities as a result of PCB contamination.

4.3 International Criteria

4.3.1 U.S. Criteria

In North America, the U.S. has been dominant in developing an effective program for the phase-out and destruction of PCBs within its borders. The U.S. 50 ppm PCB standard is based on extensive U.S. EPA cost-benefit studies (U.S. EPA, 1978). The 50 ppm standard has since been adopted by Canada and other countries as a regulation or as a general guideline.

Because PCBs were mainly used in electrical transformers, U.S. regulators developed specific regulations around them. To assist in the development of appropriate management alternatives, they found it desirable to classify transformers in accordance with their in-service PCB concentration as follows:

- "PCB transformers" - dielectric fluid ≥500 ppm PCB.
- "PCB-contaminated transformers" - dielectric fluid 50-499 ppm PCB.
- "Non-PCB transformers" - dielectric fluid <50 ppm PCB.

Classifying transformers in this way permitted regulators to develop specific management guidelines for each class of transformer. The specific U.S. regulations pertaining to the two regulated transformer types are presented in Part 761.60 of 40CFR under the Toxic Substances Control Act (TSCA) and are summarized below.

<u>PCB-Transformer</u>

Following drainage of all free flowing dielectric fluid, the transformer carcass is permitted to be disposed of in either:

a) An approved hazardous waste incinerator; or,

b) In a chemical waste landfill. To qualify for this option, the transformer must first be filled with a solvent, allowed to stand for 18 hours and then thoroughly drained. TSCA permits are required to carry-out this type of decontamination and landfilling.

The drained fluids can be incinerated in an approved hazardous waste incinerator.

PCB-Contaminated Transformers

> These transformers are not regulated following drainage of the free-flowing PCB liquid. A PCB-contaminated transformer carcass is thus permitted to be disposed of directly in a municipal waste landfill or sent for metal recycling.

While carcasses from PCB transformers ($\geq$500 ppm) are permitted for disposal in a chemical waste landfill, this option is no longer popular because of potential liability to the transformer owner if future clean-ups of such landfills are required. As an alternative to landfilling and incineration, the U.S. EPA will allow such PCB transformers to be smelted for metal recovery after they are decontaminated. The decontaminated transformer must pass the EPA surface contamination standard of $\leq$ 10 ug/100 cm^2 on all metal surfaces.

The 10 ug/100 cm^2 criterion is based on U.S. EPA health-risk studies (Federal Register, 1987) which were conducted to assess the risk to human health from spills of PCBs on high-contact restricted access or industrial solid surfaces. The U.S. EPA solid-surface clean-up criteria for PCBs are found in the Federal Regulations 40, Part 761.12, effective May 4, 1987.

The U.S. also have specific regulations (40CFR761.30 (7-1-90 Edition)) regarding the reclassification of transformers. The testing of the retrofilled transformer is to take place after a minimum of 3 months in service. Transformers can be reclassified from PCB transformers ($\geq$500 ppm) to PCB-contaminated transformers (50-499 ppm) or from these two categories to non-PCB status (<50 ppm).

4.3.2 European Criteria

In general, a greater than 50 ppm PCB standard to define PCB materials has been in widespread use in the European Community since 1986. European countries have not yet adopted any surface contamination criteria.

The majority of European countries have agreed to the phase-out and treatment or destruction of all PCB equipment by 1999 (British High Commission, 1991). Various types of incinerators, pyrolyzers and autoclaves are used for decontaminating waste transformers. Incinerators are normally of two different types which affects the end use of the metal components. In Great Britain, slagging incinerators are most popular. The slag is landfilled. If a non-slagging incinerator is used, the metal can be recycled. In Switzerland, a pyrolyzer is available for the decontamination of transformers for metal recycling. In France, solvent cleaning autoclaves are popular and the metal is either recycled or landfilled (see Appendix A for further details). Many countries permit solvent decontamination of transformers for metal recycling. The decontamination criteria are based on PCB concentration on the metal by weight (ppm).

In Germany, transformers containing greater than 2,000 ppm of PCBs cannot be retrofilled (due to increased flushing volumes created at these concentrations). Drained PCB transformers are stored in underground salt mines with some indefinite plans for future metal recycling. PCB liquids are incinerated at several German hazardous waste facilities.

4.4 Recommended Transformer Surface Contamination Limit

4.4.1 Establishing a National Criterion for Canada

As discussed in Section 3.2, a maximum permissible PCB surface concentration limit is required to protect the health of workers at metal recycling (smelting) facilities.

In selecting a maximum permissible surface contamination concentration three approaches can be considered (in order of priority):

1) setting a permissible surface criterion that does not present an unreasonable risk to human health and the environment,

2) the "Best Available Technology" approach, and

3) setting a permissible surface criterion that is generally consistent with current federal/provincial PCB legislation.

The three approaches listed above are not mutually exclusive.

4.4.1.1 Criteria Based on Risk to Human Health and the Environment

Exposure estimates used to evaluate the risk associated with various clean-up standards for solid surfaces were developed for the U.S. EPA's Office of Toxic Substances. In indoor industrial settings human exposure would be potentially from dermal contact and inhalation but the principal exposure route would be expected to be through dermal contact. EPA has estimated that inhalation exposures to residual indoor PCB levels of 10 ug/100 cm^2 are associated with a 1 x 10^{-6} (1 case in a 1,000,000 population) level of oncogenic risk (risk of causing cancer) while dermal exposures to the same level of PCBs on low contact surface areas are associated with a 1 x 10^{-5} level of oncogenic risk (Federal Register, 1987).

Other calculations by the EPA's Exposure Assessment Branch indicate an oncogenic risk of 1.6 x 10^{-5} (dermal exposure) for high contact indoor occupational surfaces contaminated at 10 ug/100 cm^2 (U.S. EPA, 1986).

As a final note, the U.S. National Institute of Occupational Safety and Health has reported 0.5 ug/100 cm^2 as the background level of PCBs on indoor hard surfaces and that this level on high-contact indoor hard surfaces would be associated with a level of oncogenic risk between 1 x 10^{-5} and 1 x 10^{-6} (Federal Register, 1987).

Health risk assessments tend to be very conservative, using worst-case exposure scenarios. Depending on the details of the exposure scenario the resulting health risk levels will vary as demonstrated above.

Based on the above levels of risk, the U.S. EPA believes that a surface concentration of ≤ 10 ug/100 cm^2 for high contact surfaces in a restricted-access industrial facility would not present unreasonable risks to workers or to the general population. (Federal Register, 1987).

The U.S. EPA has not specified what exactly is an unreasonable risk, but it can be inferred from the above discussion and other U.S. EPA documents that an unreasonable risk is generally viewed as a risk greater than 1×10^{-5}.

The U.S. EPA has established a contamination criterion of $\leq$10 ug/100 cm^2 for PCB transformers ($\geq$500 ppm) destined for metal recovery (smelting), based on its 1987 PCB Spill Clean-up Policy (40 CFR 761.12).

4.4.1.2 Criteria Based on Best Available Technology

A second approach could be considered whereby the lowest surface concentration achievable by available proven technology is the basis for establishing a maximum permissible surface contamination criterion.

This approach may not be practical in this case because the various proprietary techniques used to decontaminate transformers have not been assessed in terms of the lowest residual surface level achievable. However, a review of U.S. experience with the decontamination of waste transformers demonstrates that the methodology to decontaminate PCB transformers to less than 10 ug/100 cm^2 has only been developed over the last few years and that there was considerable trial and error and failed attempts to commercialize these methods.

Recent experience at the Smithville project in Ontario has also demonstrated that 10 ug/100 cm^2 can be a difficult criterion to achieve when dealing with drained PCB transformers which have been in storage for many years (due to deterioration of metal surfaces). Solvent washing failed to achieve the criterion but repeated sandblasting did eventually achieve the required results. In the end, sandblasting proved to be more expensive than incineration. The condition of the Smithville transformers (which were stored outside before the MOEE took charge of the site) is probably not typical of the waste transformers stored inside properly designed PCB storage shelters, nor does the solvent washing method used by the Smithville project contractor necessarily reflect the state-of-the-art of this methodology.

It would appear that although a lower surface contamination criterion may be achievable on transformers recently removed from service, it would result in considerably more cost unless more efficient decontamination methods are developed.

4.4.1.3 Criteria Based on Current PCB Legislation

Current federal/provincial legislation, except Saskatchewan, defines an electrical transformer as a PCB waste if that transformer is no longer in use and contains PCBs in the dielectric fluid at a concentration >50 ppm by weight. Electrical transformers containing fluid with a PCB concentration of $\leq$50 ppm by weight are unregulated. Therefore to ensure that the surface criterion is compatible with the existing regulations, the relationship between the PCB concentration in dielectric fluid and PCB surface contamination should be known.

Industry data (S.D. Myers, Ontario Hydro and Hydro Quebec) concerning the distribution of PCBs in contaminated mineral oil transformers demonstrate that there is a direct relationship between the transformer fluid PCB concentration and the PCB surface concentration on internal metal components. As one would expect, PCB surface concentrations increase as fluid concentrations increase. Unfortunately data concerning the distribution of PCBs in ≤50 ppm transformers were not available. However, all the industry data indicated that a ≤50 ppm transformer would have PCB surface concentrations considerably less than 10 ug/100 cm^2. Ontario Hydro has reported that an analysis of its data and Hydro Quebec's data (Ecosomme, 1990 and 1994) indicate that a surface contamination of 10 ug/100 cm^2 corresponds to a dielectric fluid PCB concentration of approximately 200 ppm. However there is significant scatter in the data.

4.4.2 Recommended Permissible Surface Contamination Criterion

A permissible surface contamination criterion of 10 ug/100 cm^2 PCB is recommended for the following reasons (in order of priority):

1) it represents a reasonable risk to human health and safety and the environment;

2) it can be achieved (under most circumstances) by commercially available decontamination methods; and

3) it is consistent with the intent of current federal/provincial regulations which use the 50 ppm standard .

This criterion is recommended on the basis that its application is limited to transformer metal components destined for recycling by smelting.

It also assumes that public access to these transformers is restricted during the decontamination and subsequent metal recycling processes. No restrictions are placed on the initial PCB concentration of the dielectric fluid in the transformer, provided that a final PCB residual surface contamination limit of 10 ug/100 cm^2 can be achieved after decontamination.

There is some variation in the level of risk calculated by various U.S. EPA and other agencies however, this is not unexpected given that different exposure scenarios will produce different risk levels. Risk assessments tend to be very conservative (risks are over-valued or over-stated) and since the highest risk level reported is 1×10^{-5} (risk of cancer) and this is in general considered by U.S. EPA as a reasonable risk, this report accepts the 10 ug/100 cm^2 as an acceptable limit for the protection of human health.

5.0 RECOMMENDED DECONTAMINATION STANDARDS AND PROTOCOLS

The previous chapters in this report have reviewed PCB transformer management practices in Canada and elsewhere. It was concluded that a 50 ppm PCB concentration in the dielectric fluid is almost the universal standard for distinguishing a PCB transformer from a non-PCB transformer and that ≤10 ug/100 cm^2 of PCB appears to be a technologically achievable, health-risk-based permissible surface contamination limit for metal materials destined for recycling.

Since there are tens of thousands of PCB transformers to be managed in Canada, it is important to develop management protocols for their re-use, recycling and disposal which allow for the efficient and cost effective decontamination of transformers and which recognize the different potential health and environmental risks posed by the main two types of PCB transformers, i.e., the relatively low concentration PCB-contaminated mineral oil transformers and the high concentration PCB askarel transformers.

5.1 Protocols for the Decontamination of PCB Contaminated Mineral Oil Transformers for Re-use, Recycling and Disposal

Small pole-mount mineral oil transformers account for the majority of PCB transformers. Ontario Hydro estimates (P. Guimond, 1994) that it has 38,000 of these mineral oil transformers in the 50-500 ppm PCB range still in use. Although the number of transformers of this type is high, they represent only a small fraction of the total PCB inventory (on the basis of weight percent of pure PCBs, as discussed in Section 2.1) and the environmental and health risks due to their low PCB contamination level. Cost effective methods for managing this type of transformer are essential if there is to be a realistic cost/benefit to the public (assuming that PCB management costs are reflected in electricity costs).

Figure 5.1 illustrates the recommended protocols for the re-use, recycling and disposal of PCB-contaminated mineral oil transformers.

5.1.1 Re-use Protocols for Contaminated Mineral Oil Transformers

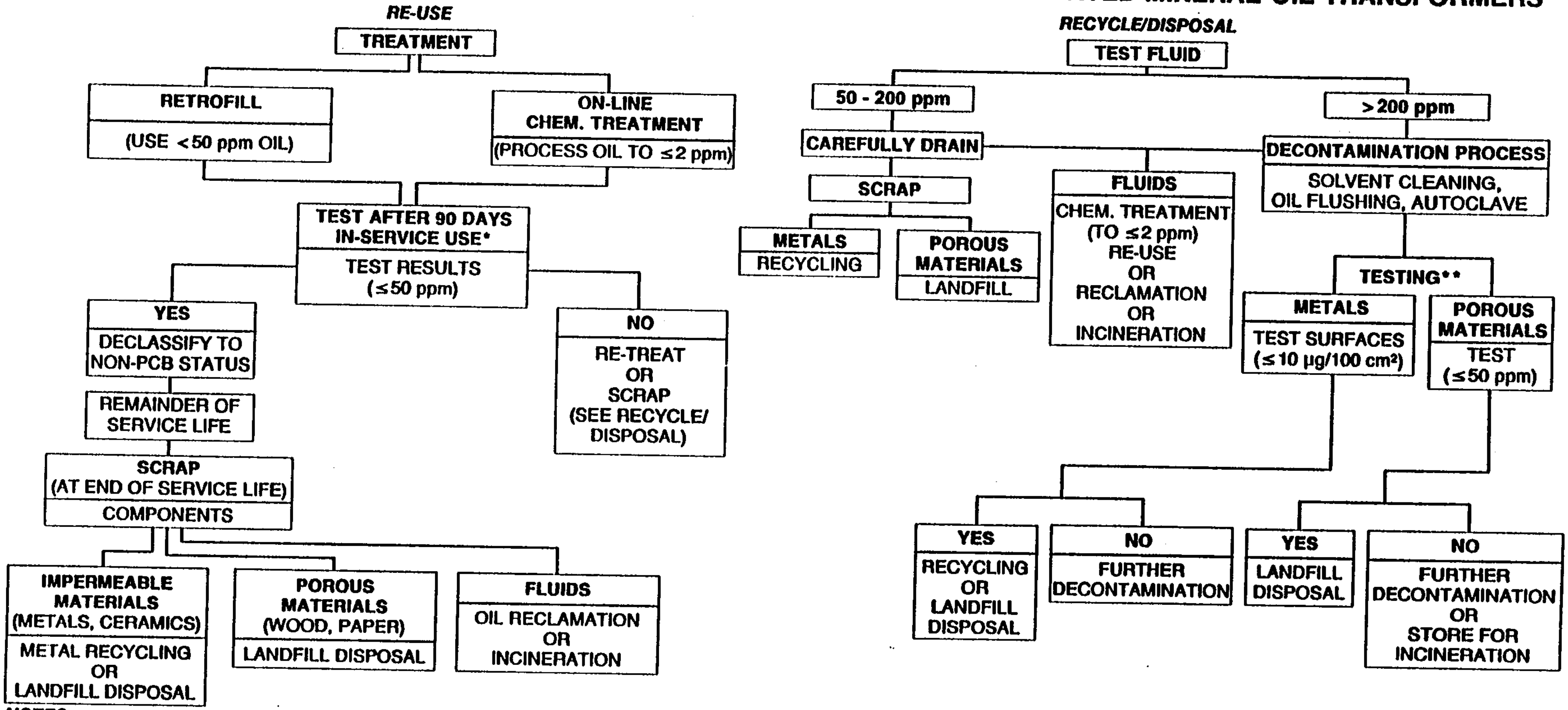
As discussed in Section 2.0 and Appendix A, technologies for the decontamination of PCB-contaminated mineral oil transformers in Canada for re-use are in widespread use. Industry experience has shown that if the transformer's mineral oil has remained (during service) at a PCB concentration of less than 50 ppm, 90 days after the decontamination process, it is unlikely to exceed 50 ppm during the remainder of its service life. However, the higher the PCB concentration in the original fluid the more likely the failure unless additional or repeated measures are taken.

Industry studies (EPRI, 1989) have demonstrated that by careful draining 90% to 95% of the PCBs in a transformer can be removed. Therefore, for transformers containing ≤500 ppm of PCBs careful draining should result in a retrofilled concentration of not more than 50 ppm (e.g., representing 90% removal by draining and assuming retrofilling with clean mineral oil). This conclusion is reinforced by the observed "leach back" effect (as described in Appendix A) whereby simple retrofilling decontamination methods result in a 10% recontamination of the transformer fluid.

Since retesting of the transformers after retrofilling (90-day test) amounts to a considerable cost for owners with large inventories of these transformers, the 90-day test should be waived for ≤500 ppm (original concentration) mineral oil transformers if the owner has demonstrated through controlled studies the effectiveness of the retrofilling technique. The approved retrofilling process should be the subject of a certificate of approval or permit provided by a regulatory authority and be subject to both internal and external auditing.

This report does not recommend the development of a standard retrofilling procedure by regulatory agencies because of the limitations this would place on utilities and service contractors, rather, it is believed that performance criteria and demonstrated ability are preferable approaches.

FIGURE 5.1
PROTOCOLS FOR THE RE-USE, RECYCLING AND DISPOSAL OF PCB-CONTAMINATED MINERAL OIL TRANSFORMERS



NOTES

* PCB TRANSFORMER OWNERS WHO HAVE DEMONSTRATED TO REGULATORY AUTHORITIES THAT THEIR TRANSFORMER RETROFILLING METHODOLOGY PROVIDES FOR:
i) THE REMOVAL OF AT LEAST 90% OF THE ORIGINAL FLUID THROUGH CAREFUL DRAINING; AND
ii) THE PCB CONCENTRATION OF THE REPLACEMENT FLUID TO BE INCLUDED IN THE CALCULATION OF THE END POINT PCB CONCENTRATION OF THE TRANSFORMER'S FLUID,
BE ALLOWED TO PROCEED (THROUGH SPECIAL PERMITTING) DIRECTLY TO DECLASSIFICATION WITHOUT THE 90 DAY TESTS FOR TRANSFORMERS WITH INITIAL PCB CONCENTRATIONS ≤500 ppm.

** PCB TRANSFORMER OWNERS WHO HAVE DEMONSTRATED TO REGULATORY AUTHORITIES THAT THEIR DECONTAMINATION METHODS RELIABLY RESULT IN ≤50 ppm IN THE POROUS MATERIALS AND ≤10 µg/100 cm² ON THE METAL SURFACES SHOULD BE ALLOWED (THROUGH SPECIAL PERMITTING) TO PROCEED DIRECTLY TO SCAPPING WITHOUT FURTHER TESTING FOR TRANSFORMERS WITH INITIAL PCB CONCENTRATIONS OF 200-500 ppm.

It is worth noting that with or without the 90-day test some mineral oil transformers will not be ≤50 ppm some time after the retrofilling process. This is due to the wide variety of transformer sizes, designs, quantities of porous materials and less than adequate retrofilling methods. Studies have indicated that during the 90-day period both electrical loading (EPRI, 1989) and elevated temperature (Husain et al, 1991) accelerate the desorption of PCBs from the transformer core and therefore aid in transformers reaching a PCB equilibrium within the 90 day period. These assisting measures are particularly important for mineral oil transformers >500 ppm in order to identify decontamination failures within the 90 day test period.

For those owners wanting to decontaminate ≤500 ppm transformers without the 90 day test it is critically important that their retrofilling methods and quality assurance program be adequate to ensure relatively few failures. In particular, if owners are using mineral oil for retrofilling which is contaminated with PCBs (but ≤50 ppm) then the PCB concentration of this retrofilling fluid must be included in the calculation of the end point PCB concentration of the fluid.

Eventually all decontaminated transformers will reach the end of their service life and will be scrapped. The question then arises as to whether we can assume that mineral oil transformers which have been decontaminated (to less than 50 ppm) for re-use could meet a criterion of 10 ug/100 cm^2 for surface contamination and less than 50 ppm for porous (wood and paper) materials. Industry data (EPRI, 1989) indicate that the equilibrium (between the transformer fluid and other internal materials) process for the metal surfaces proceeds very quickly (within days). The process is slower for paper and wood, but within 90 days for mineral oil transformers (Husain et al, 1991).

Since the metal components of the decontaminated mineral oil transformer will meet the ≤10 ug/100 cm^2 recommended surface contamination criterion and the wood and paper materials will meet the ≤50 ppm criterion for non-PCB solid materials these transformers should be accepted for metal recycling or landfill. Recycling is preferred since this makes use of a recoverable resource and the high temperatures of the smelting process will completely decontaminate the metal.

5.1.2 Recycling and Disposal Protocols for Contaminated Mineral Oil Transformers

Waste transformer decontamination methods are described in Appendix A and are suitable for decontaminating mineral oil transformers provided that results indicate surface contamination is ≤10 ug/100 cm^2 for impermeable materials and that the PCB concentration is ≤50 ppm for porous materials.

As in the re-use protocol, it is important to consider where measures can be taken to reduce the cost of managing these transformers.

Ontario Hydro data (Husain, 1992) indicates that in general the 10 ug/100 cm^2 surface contamination level corresponds roughly to a dielectric fluid PCB concentration of 400 ppm (although there is considerable scatter in the data) and a 50 ppm concentration in the porous materials corresponds roughly to a dielectric fluid PCB concentration of 200 ppm.

Therefore, it may be reasonable for regulatory purposes to consider allowing ≤200 ppm mineral oil transformers to be drained and then scrapped without any further testing of metal surfaces or porous material. This consideration is recommended by Proctor & Redfern and appears on Figure 5.1.

For transformers containing more than 200 ppm PCBs some form of decontamination process is required to reduce the porous material to ≤50 ppm and to ensure that the metal surface PCB concentrations are ≤10 ug/100 cm^2 (See wipe testing protocol, Appendix B). Again, it would seem practical and cost effective to allow large-inventory transformer owners to waive the surface and porous materials testing requirements (for transformers containing 200-500 ppm PCBs) if they can demonstrate a decontamination method which reliably results in ≤50 ppm in the porous materials and ≤10 ug/100 cm^2 on metal surfaces. The approved decontamination method and quality control aspects would be the subject of a certificate of approval or permit. Again, as in Section 5.1.1, this report does not recommend the development of a standard regulated procedure for decontamination but instead believes performance criteria and demonstrated ability provide the flexibility that owners and contractors will want.

5.2 Protocols for the Decontamination of Askarel Transformers for Re-use, Recycling and Disposal

Figure 5-2 illustrates the protocols recommended for the decontamination of askarel transformers for re-use, recycling and disposal.

5.2.1 Re-use Protocols for Askarel Transformers

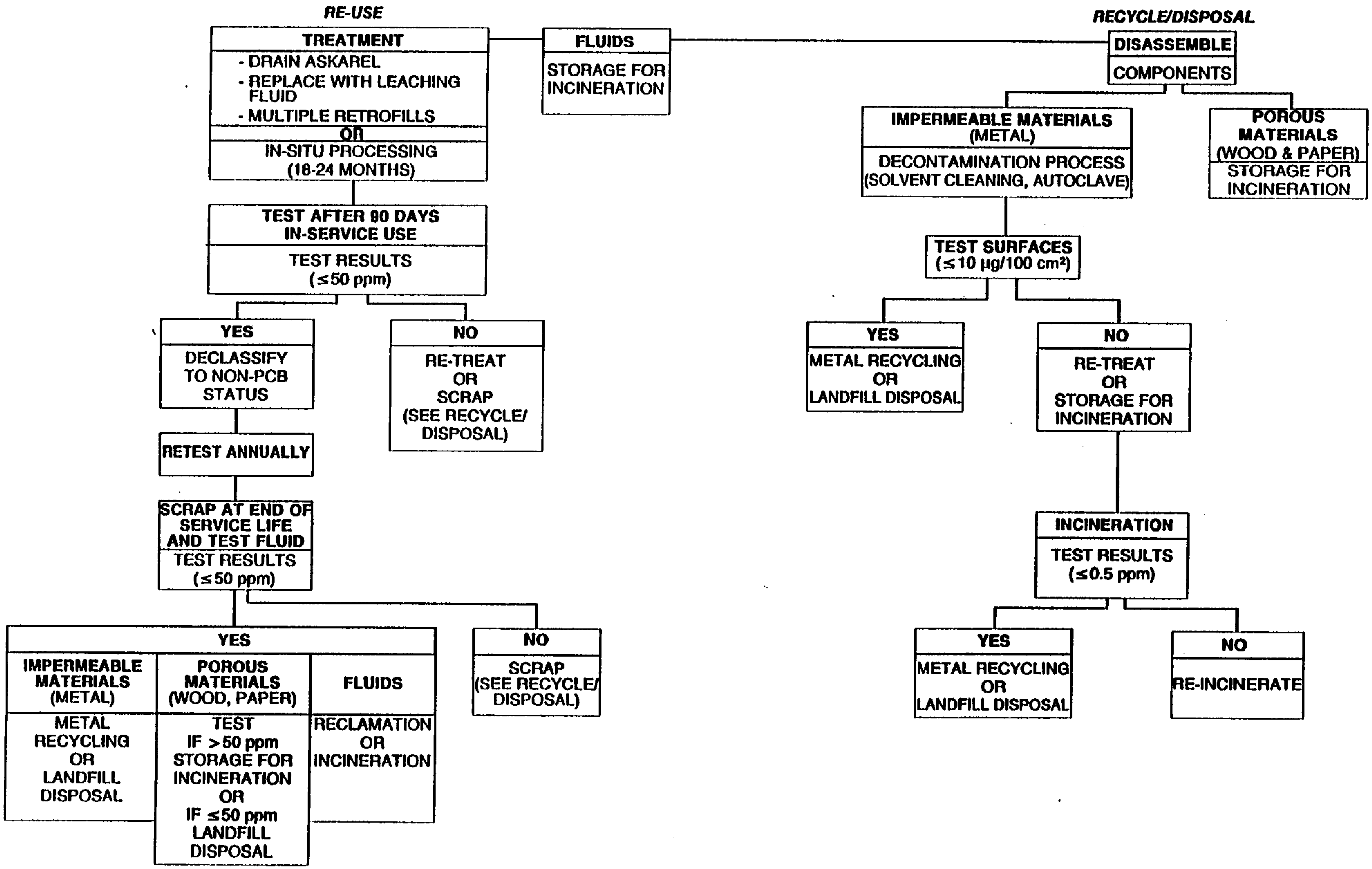
As described previously in Section 2.0 and Appendix A, in-service askarel transformers can be decontaminated (over a processing period of 12 - 24 months) to yield a dielectric fluid containing less than 50 ppm PCBs at 90 days after processing is completed. However, studies (Myers et al, 1991) of early attempts to decontaminate these transformers have demonstrated that the dielectric fluid may not remain at this 90-day PCB concentration for the remainder of the transformers' service. These early failures appear to be the result of the termination of the decontamination process before equilibrium between the fluid and porous materials had been reached.

This increase in the PCB concentration in the dielectric fluid after 90 days is due to the slow leach-back of PCBs into the dielectric fluid from the transformer's porous materials. For some decontaminated former askarel transformers, PCB concentrations in the dielectric fluid were as high as 500 ppm and wood materials as high as 26,000 ppm at the time of scrapping (Myers et al, 1991).In light of these data, this report recommends a modification to the 90-day in-service test for askarel transformers which would stipulate additional in-service testing of the transformer on an

annual basis for three years after the completion of the decontamination process. If for some reason the transformer is not in-service (energized) during the 90 day test period it should be stored at comparable internal temperatures during the 90 day test period. Unlike the situation with contaminated mineral oil transformers (see Section 5.1), the testing requirements for askarel transformers (specified above) are not expected to be financially onerous for owners due to the relatively small population of askarel transformers (compared to contaminated mineral oil transformers) and relative to the considerable cost of decontaminating in-service askarel transformers.

In addition, if silicone is used as the final dielectric fluid after the decontamination process (rather than the leaving in the leaching fluid) then testing of the silicone fluid should be conducted for ten years at five year intervals. The transformer's non-PCB status would revert to PCB status if tests

FIGURE 5.2
PROTOCOLS FOR THE RE-USE, RECYCLING AND DISPOSAL OF ASKAREL TRANSFORMERS



at any time showed that the PCB concentration in the dielectric fluid was greater than 50 ppm.

At the end of their service life, former askarel transformers, which have been decontaminated (e.g., passed the three- or ten-year tests recommended above) while in use, will be removed from service and could be scrapped. In view of the problem discussed above, this report recommends that the dielectric fluid of these transformers be tested to verify the transformers' PCB status. If it is ≤ 50 ppm, they should be allowed to go to metal recycling since industry experience has shown that the metal surface contamination will be less than 10 ug/100 cm^2. However, there is a lack of empirical data on the porous materials. Unless shown otherwise, these materials should be considered a PCB waste (i.e., >50 ppm) and be properly separated and stored, or destroyed by approved methods.

5.2.2 Recycling Protocols for Askarel Transformers

Decontamination methods suitable for preparing waste askarel transformers for recycling are described in Appendix A. Due to the high concentration of PCBs in the askarel fluid and the resulting more difficult decontamination of impermeable surfaces and porous materials, verification testing of surfaces and porous materials is required.

Metal surfaces are required to be wipe sampled as per the sampling methodology in Appendix B. Porous materials (wood and paper) are to be considered PCB wastes (i.e., >50 ppm) unless proven otherwise.

5.3 Landfilling of Mineral Oil Transformers

Recycling of transformers for metal recovery should always be encouraged as the environmentally appropriate solution. If this cannot be achieved, the final management alternative is the disposal of transformer carcasses by landfilling. Although the U.S. EPA allows disposal of transformers containing less than 500 ppm of PCBs by simply draining the fluids first and then landfilling of the intact carcass, a more conservative approach has been taken in this report. It is recommended that PCB transformers containing >200 ppm of PCBs destined for landfilling be subjected to the same cleaning methodologies as used for recycling PCB transformers and the same contamination limits, i.e., ≤10 ug/100 cm^2 for impermeable parts and ≤50 ppm for porous materials. Those PCB transformers with ≤200 ppm should be allowed for landfilling after careful draining of dielectric fluids.

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APPENDIX A

Decontamination Technologies

APPENDIX A

A.0 DECONTAMINATION TECHNOLOGIES

A.1 Decontamination Methods for In-Use Mineral Oil Transformers

Decontamination methods for mineral oil transformers involve either retrofilling or on-line chemical treatment. Alternatively, the unit could be replaced but if it is in good operating condition and system loads are expected to remain unchanged the replacement option is usually excluded in favour of one of the decontamination methods.

The choice of retrofilling as a method usually depends on:

- the initial PCB concentration in the oil;
- the requirements, if any, to keep the system energized (i.e., no shutdown allowed);
- the number and size of transformers to be dealt with; and,
- whether re-use of the oil is desired.

Reclassification of a transformer to non-PCB status (in accordance with most provincial standards and U.S. regulations, 40 CFR 761.30 (7-1-90 Edition)) requires that the PCB concentration in the transformer dielectric fluid be $\leq$50 ppm, a minimum of 90 days after decontamination has been performed. The reason for the minimum 90-day waiting period is to account for the "leach-back" of PCBs from the transformer core into the transformer dielectric fluid. Residual PCBs are found absorbed in the wood, paper and interior spaces of a transformer core laminates and windings. Over time, these residues leach out and mix with the clean or treated mineral oil. The leaching process is continuous but is mainly complete after 90 days in an operational transformer. Approximate leach-back percentages (of original, pre-decontamination PCB concentration) associated with various decontamination methods for mineral oil transformers with initial PCB concentrations under 500 ppm are as follows:

- On-line to a mobile chemical treatment unit in either an energized or non-energized mode yields an expected leach-back of approximately 3-5%.
- Hot retrofill (flush) with 1.5 volumes of clean, hot mineral oil has an expected leach-back of approximately 5%.
- Cold retrofill (flush) with one volume of clean mineral oil performed 3 times has an expected leach-back of approximately 10%.
- Cold retrofill with one volume of clean mineral oil has an expected leach-back of approximately 15%.

After these technical considerations, the treatment method employed is largely influenced by economics. For example, it is preferable to use clean ($\leq$2 ppm) mineral oil in the retrofilling process since it is the differential PCB concentration between the retrofilling fluid and the transformer's internal components which, in large part, governs the speed of the decontamination process, however, for economic reasons some utilities prefer the option of using mineral oil $\leq$50 ppm for retrofilling. The PCB concentration of this mineral oil must be included in the calculation of the transformer fluid's end point concentration.

Transformers with an initial mineral oil PCB content greater than 1,000 ppm can require multiple treatments (spaced several months apart) before decontamination below 50 ppm is achieved.

Retrofilling of transformers must be done under controlled conditions to prevent damage to the transformer and to maximize the efficient removal of PCBs.

A.2.1 Decontaminating In-Use Askarel Transformers

The decontamination of askarel transformers, with PCB concentrations between 40-80%, is normally carried out by either series retrofill or in-situ processor methodologies. Due to the leach-back problem, mineral-oil-type retrofilling is uneconomical (and generates large quantities of contaminated leaching fluid) for the decontamination of askarel transformers.

In recent years, new innovative approaches to the retrofilling have been introduced based on replacement of the original askarel fluid with a special PCB leaching fluid that also serves as a dielectric fluid. Details of these various methods and their advantages and disadvantages follow.

<u>Series Retrofill:</u> With the series retrofill option, the process takes place as follows:

- The transformer is de-energized and taken out of service.
- The askarel fluid is then drained, placed in storage or sent for destruction (incineration where available).
- The transformer is re-gasketted.
- The unit is flushed with a solvent.
- The unit is refilled with an interim fluid that serves as a PCB solvent and dielectric fluid.
- The unit is re-energized and put back in service. Over time, PCBs leach from the internal components into the fluid.
- After a period of time (usually a few months), the unit is de-energized, the interim fluid drained and the unit is refilled.
- The process is repeated three to seven times as needed to achieve a final PCB level in the fluid of less than 50 ppm (usually considerably less, e.g. less than 10 ppm).

- The unit is reclassified as non-PCB if after a minimum of 90 days the dielectric fluid is still less than 50 ppm.

- The final fluid (either silicone, or often the leaching fluid) is placed in the transformer.

This process can take between 12-24 months or longer to complete. The resultant PCB-contaminated fluid has to be either stored or incinerated. In Canada, incineration of the contaminated fluid is only only available in Alberta.

Industry experience has demonstrated that some transformers decontaminated by this method may not continue to stay below 50 ppm after the 90 day test. (See Section 5.2.1.)

In-Situ Processing: This option employs a processor to remove the PCBs from the dielectric fluid by distillation. The initial procedure is similar to the Series Retrofill method where the transformer is taken out of service for approximately 24 hrs, drained of its askarel fluid and re-gasketted. It is then refilled with the special PCB leaching fluid, connected to the processor, and put back into service. The processor has two functions. It circulates the fluid through the transformer promoting leaching of PCBs from the internal components while, at the same time, distilling the re-circulating fluid and separating the PCBs. The continuous distillation process maintains the leaching fluid at low PCB concentration levels. It is the differential PCB concentration between the fluid and internals of the transformer which drives the leaching process. This process continues until the residual PCB concentration in the leaching fluid remains well below 50 ppm. A remote monitor can be employed to track the progress of PCB removal. At the conclusion of the processing period, usually 18-24 months, the processor is disconnected and the transformer begins a 90-day in-service period. If, upon testing at the end of 90 days, the PCB concentration is below 50 ppm, the transformer is re-classified to non-PCB status. However, some industry experience has demonstrated that some transformers may not continue to stay below 50 ppm after the 90-day test due to premature termination of the process (See Section 5.2.1).

Depending on the initial choice of leaching fluid, a second outage to replace it with a permanent dielectric fluid may or may not be necessary. If a Factory Mutual approved nonflammable fluid having similar cooling properties as askarel is used for the processing operation, this fluid can be permanently left in the transformer. In this case, the only outage required would be for the initial refilling. If such a fluid was not chosen, a brief outage is required to replace it with a dielectric fluid such as silicone.

At the moment in Canada, only Rondar Inc. (ENSR licencee) and Westinghouse offer in-use askarel transformer decontamination.

A.3 Decontamination of Waste PCB Transformers

A.3.1 General

For the purpose of this report, a PCB waste transformer is defined as any transformer which has been permanently removed from service and either contains, or contained before it was drained for storage, PCB liquids >50 ppm. This definition, therefore, includes transformer carcasses that contained either askarel or contaminated mineral oil. In Canada, it has been estimated that there are approximately 3,750 askarel and 3,100 contaminated mineral oil transformers in storage (Environment Canada, 1992).

Decontaminating in-use PCB-contaminated mineral oil transformers is expected to result in significantly lower numbers of these units requiring treatment as a PCB waste.

There are two practical options for the disposal of a transformer (or its components) once it has been decontaminated; the metal parts can be recycled by smelting or the transformer can be landfilled. Regulations regarding the decontaminated transformer's end use or disposal vary from country to country and from province to province.

A.3.2 Decontamination Methods for Waste PCB Transformers

Basically these decontamination methods consist of either some form of solvent cleaning of the disassembled transformer or some form of heating/incineration process used to vapourize and then destroy the PCBs. These technologies and methods are further described in the following subsections.

A.3.2.1 Solvent Decontamination of Waste Transformers

There are various solvent decontamination methods, some of which rely heavily on relatively unsophisticated or manual methods such as dipping and flushing of disassembled parts, and others which involve more sophisticated facilities such as autoclaves. Currently in the U.S. there is a trend towards reliance on the more manual methods which usually involve the following steps:

i) The PCB transformer is usually first drained of its dielectric fluid at its installation location. The dielectric fluid is either stored or sent to an approved incinerator for destruction.

ii) The transformer carcass is then transported to the solvent decontamination facility.

iii) Upon arrival the unit is appropriately tagged for tracking purposes and then given a primary de-greasing or solvent flush to remove residual PCB liquids and to minimize worker exposure.

iv) The top of the unit is then removed by cold cutting, and the core is lifted out of the casing and separated into its various components, such as lamination core, coil windings, wires, bushings, wood, plastic and insulators.

v) The metal components destined for smelting are given a series of vigorous solvent flushes to meet the surface decontamination criteria set by the regulatory agency. The solvent is normally regenerated through distillation.

vi) Recovered PCB liquids and combustible components (mainly wood, paper and plastic) are shipped to an approved hazardous waste incinerator for disposal.

vii) Wipe tests are then performed on the cleaned metal components. In some cases, the PCB concentration is assessed on a weight basis.

viii) Metal components which meet regulatory criteria for PCB surface contamination are then shipped to metal recycling facilities for smelting.

The number of solvent rinses required for decontamination of transformer component parts is largely dependent on the PCB content of the original dielectric fluid. For example, transformers with askarel-type fluids require more extensive flushing than those which contained PCB-contaminated mineral oil.

A schematic representing the solvent decontamination process employed by U.S. firms is illustrated in Figure A-1. There are three firms in the U.S. with EPA permits to operate solvent decontamination facilities for ≥500 ppm transformers destined for metal recycling. All plants are stationary. The firms are:

- Unison Transformer Services Inc. Ashtabula, Ohio; Yarington, Nevada; Kansas City, Kansas;
- Aptus Inc., Coffeyville, Kansas; and,
- Transformer Consultant Ltd. (S.D. Myers) Akron, Ohio.

For PCB owners who are concerned about future liabilities of 50-499 ppm transformers, the above companies also offer decontamination of these transformers to meet the same recycling requirements as for ≥500 ppm transformers (i.e., ≤10 ug/100 cm^2).

In Canada, Chem-Security (Alberta) Ltd. conducted pilot studies of solvent decontamination at the Alberta Special Waste Treatment Centre in Swan Hills but have not commercialized the process due to the difficulty of controlling fugative emissions. A solvent decontamination process is used by Sanexen Environmental Services Inc. of Montreal. Sanexen's process ("Decontaksolv") for PCB transformers is illustrated in Figure A-2. Aside from the fact that the Sanexen system is mobile, the main difference from the U.S. stationary technology is the use of a vapour/liquid autoclave unit that is employed for secondary degreasing. Sanexen has found that combined heating, circulation and vaporization of the solvent is an effective means for removing the PCBs from a transformer's intricate and tightly wound metal core.

The ENSR Operations in-situ processor for decontaminating in-use askarel transformers can also be used to decontaminate waste askarel transformers.

Ontario Hydro decontaminates waste mineral transformers using standard in-use mineral oil retrofilling techniques. Since Ontario Hydro has its own mineral oil decontamination unit this method is practical for them. Where this method is used it is preferable to use clean mineral oil (≤2 ppm) since it is the differential between the retrofill fluid PCB concentration and the transformer's internal components' concentrations which governs, in large part, the speed of the decontamination process. However, if for economic reasons mineral oil >2 ppm but ≤50 ppm PCB is used then the PCB concentration of the retrofilling fluid must be included in the calculation of the fluid's end point PCB concentration.

FIGURE A.1 Transformer Decontamination by SOLVENT DEGREASING PROCESSES In United States - Stationary Facilities

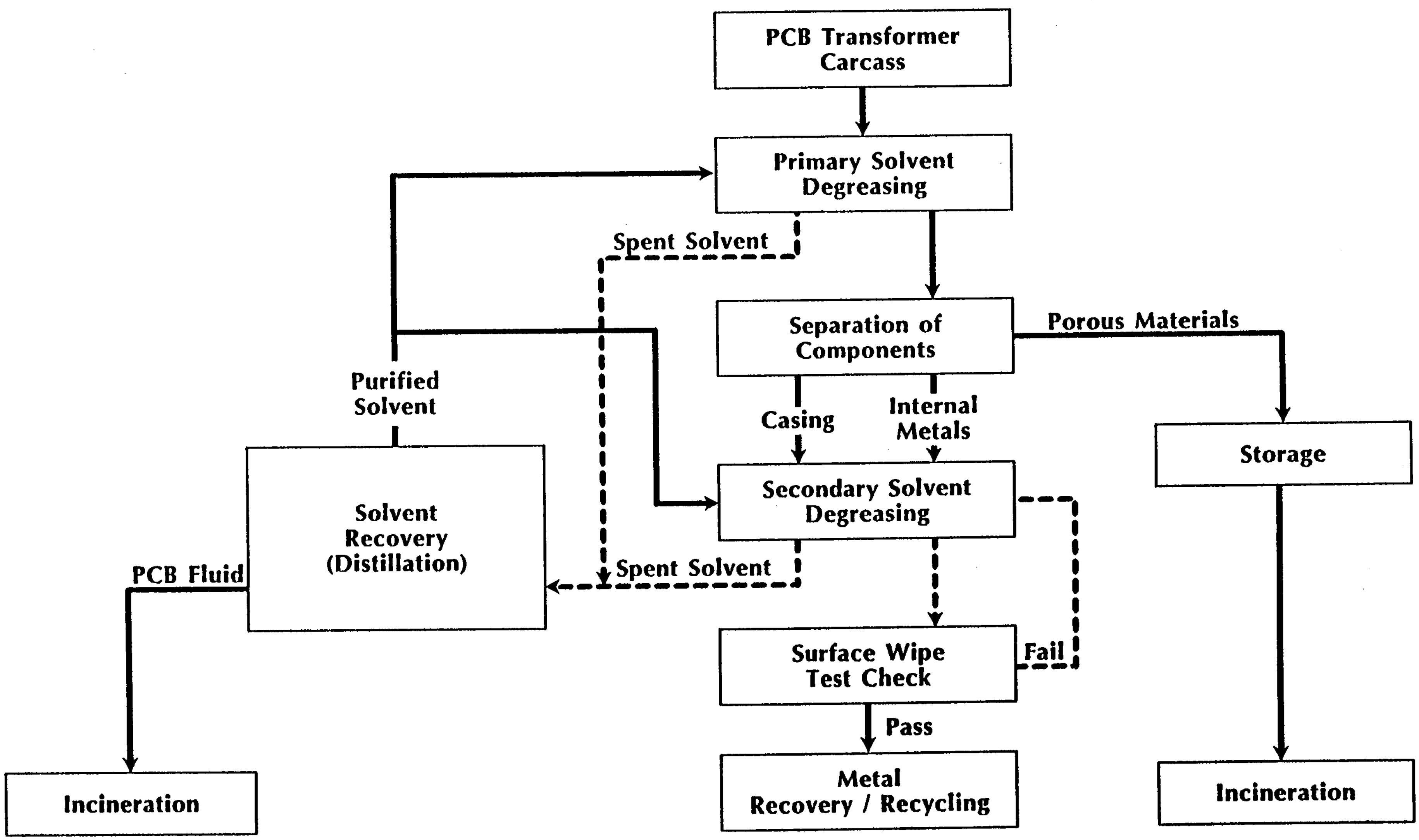
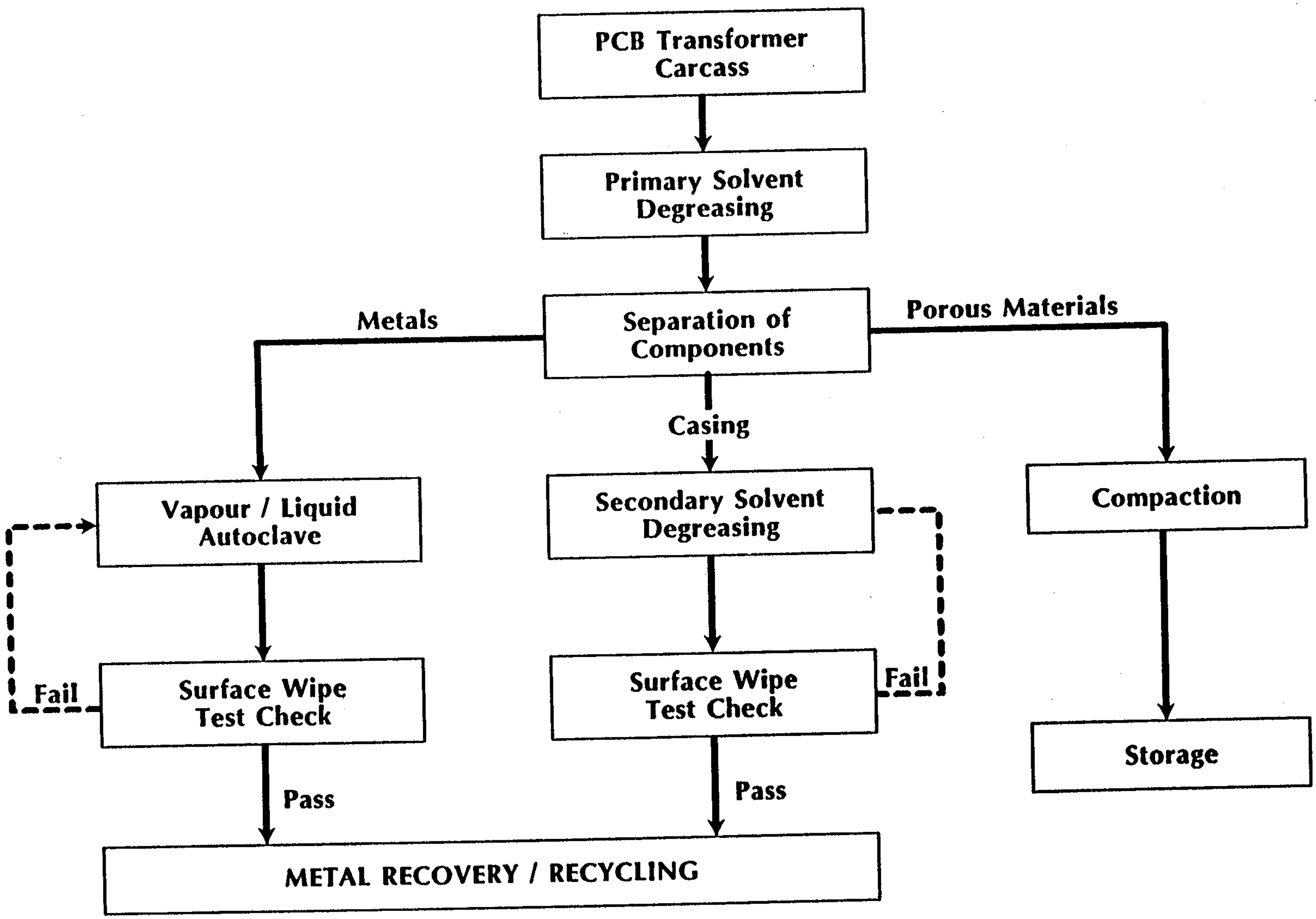


FIGURE A.2 SANEXEN'S SOLVENT DECONTAMINATION PROCESS - Mobile Facility



A.3.2.3 Incineration and Other Heating Processes for the Decontamination of Waste Transformers

Non-Slagging Incinerators

Incineration processes normally involve the direct burning at high temperatures of the PCB waste in the presence of oxygen. Transformers are normally shredded before incineration. In non-slagging kilns or furnaces, the shredded transformer parts are subjected to temperatures in the range of 800-900°C. On exposure, the residual PCBs and any combustible components (paper, wood) are vapourized. The combustion gases normally pass through a secondary combustion chamber (operating at approximately 1,200°C) to ensure complete combustion of PCBs (usually requiring 99.9999% destruction and removal efficiency). The incinerated metal can be either recycled or landfilled.

In Canada, at the Alberta Special Waste Treatment Centre, Swan Hills Alberta, Chem-Security (Alberta) Ltd. operates a rotary kiln for the destruction of hazardous wastes including PCB solids and liquids. Chem-Security also uses a transformer furnace which decontaminates whole transformers. Gases from the furnace are sent to the secondary combustion chamber of an existing incinerator. Over 1600 transformers have been treated by this system. No other incinerators in Canada are permitted to burn PCBs except for two mobile PCB incinerators; one an infrared furnace (owned and operated by O.H. Materials of Canada) which was licensed by the Newfoundland Department of Environment and Lands and Environment Canada to operate at Goose Bay, Labrador during 1990 and the other a rotary kiln (owned and operated by Ensco Inc.) licensed by the Ontario Ministry of the Environment to operate at Smithville, Ontario during the period 1991-1992. Both mobile incinerators decontaminated quantities of shredded transformers and capacitors.

Vesta Technologies of Fort Lauderdale Florida conducted a successful demonstration burn of PCB materials using their Vesta 200 model rotary kiln at a Hydro Quebec site in 1992.

In the U.S. four companies (Pyrochem, Rollins Environmental Services, General Electric and Aptus) operate commercial rotary kiln, stationary PCB destruction facilities approved under TSCA.

Slagging Incinerators

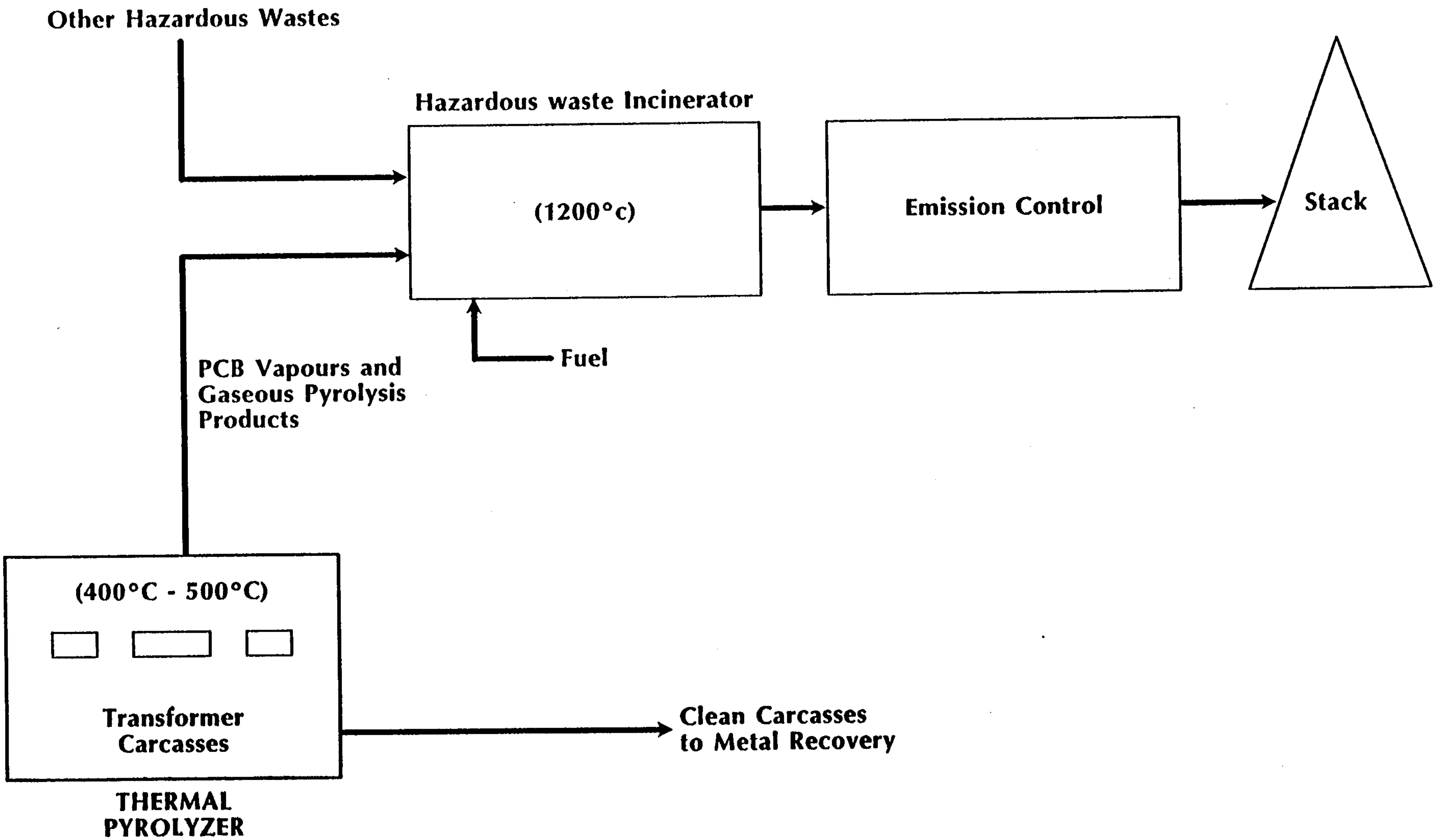
Slagging incinerators operate at higher temperatures than non-slagging incinerators and the metal components of the transformer melt and form a slag; the metal cannot be recovered for recycling. The slag is usually landfilled. PCBs and all combustible materials are destroyed at this temperature. Rechem operates a fixed-hearth slagging incinerator at Pontypool, South Wales. The incinerator is capable of destroying whole transformers. The slag is landfilled.

Pyrolyzers

The other type of heating device commonly used (in Europe) for the decontamination of waste PCB transformers is the low temperature thermal pyrolyzer which heats wastes at lower temperatures (400-500°C) than incineration in the absence of oxygen (Figure A-3). At these temperatures residual PCBs on the transformer surfaces are volatilized and are withdrawn into a high temperature (1,200 °C) secondary combustion chamber or through a chemical reaction chamber (molten soldium hydroxide bath) for final destruction of the PCBs. Non-metal transformer parts (wood, paper) are also decontaminated in the pyrolyzing chamber. The pyrolyzer chamber will normally accept whole or dismantled transformers depending on the size of the chamber and size of transformer.

W+E Umwelttechnik AG of Zurich, Switzerland has recently commissioned a 3-metre diameter low-temperature recycling (LTR) reactor that will accept waste PCB transformers up to 630 KVA in size. In this pyrolysis process, the transformer cores and/or carcasses are placed in a chamber which is purged with nitrogen and placed under a slight vacuum. The chamber is then heated to about 400 °C. The gases generated will either be passed through an NaOH-reactor for dechlorination, or passed directly into a hazardous waste incinerator.

FIGURE A.3 Thermal Decontamination of PCB Transformers with Metal Recovery



APPENDIX B

Recommended Wipe Test Sampling Methodology
for Transformer Metal Surfaces

Recommended Wipe Test Sampling Methodology

For Transformer Metal Surfaces

Purpose

This wet wipe sampling protocol is recommended for the verification of PCB surface concentrations on metals which are to be sent to metal recyclers for subsequent smelting. In particular, it deals with the sampling of electrical transformers, including the location of samples and the number of samples per location.

Pre-Sampling Preparation

1. In pre-cleaned 250-ml glass jars, place in each a 10 cm by 10 cm, 12 ply, sterilized gauze pad. The jars are then sealed with lids lined with hexane-cleaned aluminum foil or teflon.

2. Disposable templates are prepared such that the inner edges represent a minimum of 100 cm^2 surface area. The template can be of any shape appropriate for the surface being tested (e.g., square or rectangular) but should be at least 100 cm^2. Smaller surface areas can be sampled if circumstances dictate; however, such an approach presents a risk of not detecting PCBs due to the small sample size and the limitations of the analytical equipment. Templates are normally made of heavy paper or cardboard.

Required Sampling Equipment

1. Prepared sampling jars each containing a gauze pad.
2. Disposable templates.
3. Latex gloves.
4. Markers and labels.
5. Container for disposing of used templates and gloves.
6. Chain of custody sheets.
7. Metal forceps.
8. Solvent - bottle of pesticide-grade hexane.

Sampling Methodology

1. Using a disposable template and wearing latex gloves, mark with a piece of chalk a 100 cm^2 area on the metal surface to be tested. Dispose of the template and gloves. Alternatively, the template may be taped to the surface.

2. Open one sample jar. Wearing a clean pair of latex gloves, remove the gauze pad from the jar. Add 4 or 5 mL of hexane to the gauze pad quantitatively from a pump buret on the solvent bottle.

3. Starting in one corner, wipe the pre-marked area with the gauze pad in rows ensuring the entire area is covered. Use a uniform and steady pressure.

4. Open the gauze pad and refold to expose fresh surfaces.

5. Wipe the marked area in rows which are perpendicular to the previous ones. Ensure the entire area is swabbed equally. Use a uniform, steady pressure.

6. Place the gauze pad back into the jar. Close lid and label sample appropriately.

7. Dispose of gloves.

8. Complete a chain of custody form prior to removing the samples for analysis.

Variations on Sampling Methodology

In the case of composite samples, the gauze pads which comprise the composite may be placed (after wiping the appropriate areas), in the same sampling jar, which is then labelled as a composite sample. For example, if four areas are to be composited, gauze pads from four prepared sampling jars would be used, one for each area. Rather than returning each gauze pad to the jar it originated from, the gauze pads would all be placed into one jar after the wipes are performed.

To sample wires, a length representing a 100 cm^2 area is marked and wiped by drawing the wire back and forth a total of eight times through a gauze pad which completely surrounds the wire. The gauze pad is opened to expose a fresh surface and the wiping is repeated until the entire marked length of wire is sampled.

Sampling Locations

1. The sampling locations for each transformer tank will be as follows:

   Composite 1 consists of:
   - flat surface adjacent to or below a fin port,
   - side wall,
   - weld joint/seam, and
   - bottom tank surface (if accessible).

   Composite 2 consists of:
   - interior of fin,
   - side wall or bottom surface,
   - weld joint/seam, and
   - side wall corner.

2. For the wires, two composite samples will be submitted for each transformer decontaminated. Each composite will consist of two randomly selected lengths of wire each of which represents a 100 cm^2 area.

3. For the laminations, two composite samples will be submitted for each transformer decontaminated. Each composite will consist of two randomly selected areas, each of 100 cm^2.

4. For the bushings, one composite sample will be submitted for each transformer decontaminated. The composite will consist of two randomly selected areas, each of 100 cm^2.

For each set of 10 or fewer samples, one gauze blank and one hexane blank should be submitted.

Analysis

Analysis will normally be by capillary GC-ECD using Aroclor standards for quantitation. Alternative analytical methods include GC-ELCD or GC-MS.

Large Inventory Considerations

For utilities and contractors using proven transformer decontamination methods on large inventories of transformers the number of samples taken and analyzed can be reduced by developing a reduced sampling scheme which would provide 95% confidence level.

Shredded Material

If the transformer has undergone a decontamination process which involves shredding of all or parts of the transformer then surface sampling may be impractical. In this case, an extraction of the PCBs from the shredded material may be performed and the resulting analysis expressed in ppm by weight.